

# **NOTICE**

**All drawings located at the end of the document.**

**Removal of Dissolved Uranium and Nitrate from  
Groundwater Using Reactive Materials:**

**Laboratory Column Treatability Tests**

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## Executive Summary

The treatment of elevated concentrations of dissolved uranium and nitrate in groundwater was evaluated using reactive media in dynamic flow-through column tests at the University of Waterloo. The project was undertaken under contract with Rocky Mountain Remediation Services, L. L. C. between February and July 1999. The tests used site water from the vicinity of the Solar Ponds Plume at the Rocky Flats Environmental Technology Site. The columns were designed to replicate potential configurations of *in situ* permeable reactive barriers at the field scale.

Two different approaches to treatment were evaluated. In the first, two columns in series were used. The reactive medium in the initial column (H<sub>1</sub>) was hardwood sawdust to promote microbially mediated removal of nitrate by denitrification. In the second column (H<sub>2</sub>), the reactive medium was elemental iron to promote the removal of uranium by reductive precipitation reactions. In the second approach, one column containing a mixture of sawdust and elemental iron (90:10 by weight) was used to promote a combination of denitrification and uranium removal.

Flow of water through the columns was maintained at a rate of approximately 186 ml day<sup>-1</sup>. The residence time of water in each column was approximately 3.3 days in the sawdust column, 2.2 days in the iron column and 3.05 days in mixed iron/sawdust column. The test was maintained for more than 100 days. The initial uranium (total) concentration in the influent water was as much as 3 µg/L, and this was increased to approximately 200 µg/L on Day 41. The initial influent concentration of nitrate was less than 3 mg/L (as NO<sub>3</sub>), but this was increased to approximately 200 mg/L on Day 41 and to approximately 300mg/L on Day 76.

On average the nitrate concentrations in the effluent from Column I were of the order of 200 mg/L less the influent concentrations. The nitrate removal attributed to denitrification, discounting the conversion of nitrate to ammonia, within the mixed iron/sawdust media was 12.4 to 14 mg NO<sub>3</sub>-N L<sup>-1</sup> day<sup>-1</sup> (55 to 60 mg NO<sub>3</sub> L<sup>-1</sup> day<sup>-1</sup>). In Column H<sub>1</sub> the nitrate removal attributable to denitrification within the sawdust was approximately 4 to 6 mg NO<sub>3</sub>-N L<sup>-1</sup> day<sup>-1</sup>, but there was little evidence of denitrification within the 100% iron medium in Column H<sub>2</sub>. Nitrate losses within Column H<sub>2</sub> could be attributed to nitrate reduction to ammonia. The advance of the uranium front, as defined by the input concentration, was delayed significantly relative to the velocity of water in Columns H<sub>1</sub> (sawdust) and I (iron-sawdust). With the very modest decrease in Column H<sub>1</sub> it was assumed that sorption was responsible for the delayed advance of uranium. In Column I, where the uranium removal exceeded that in Column H<sub>1</sub>, the presence of iron caused significant reduction in Eh conditions, and uranium removal by reduction and precipitation or co-precipitation of solid mineral phases may have been achieved. The removal efficiency for uranium by iron in Column I was estimated to be 1.35 mg U removed per gram of iron. It is anticipated that the removal efficiency for uranium by a reactive medium of 100% iron would be as high or exceed that of the iron-sawdust mixture. This could not be confirmed in Column H<sub>2</sub> because the effluent from Column H<sub>1</sub>

attained a peak concentration of uranium of 4  $\mu\text{g/L}$  by the end of the testing period. The results of the laboratory-testing program suggest that favorable *in situ* treatment of groundwater containing dissolved nitrate and uranium could be achieved using sequential cells of permeable reactive media consisting of a mixture of elemental iron and sawdust followed by 100% elemental iron.

## 1.0 Introduction

The University of Waterloo, under contract with Rocky Mountain Remediation Services, L.L.C., undertook laboratory column treatability tests to evaluate the removal of dissolved uranium and nitrate in groundwater from the Solar Ponds Plume at the Rocky Flats Environmental Technology Site. The treatability tests involved the use of flow-through columns packed with permeable reactive media. The reactive media included sawdust and zero-valent iron. The sawdust has been used as a source of organic carbon to promote microbially-mediated denitrification in nitrate removal barriers (Robertson et al. 1997,1999). The zero-valent iron has been used effectively in laboratory and field applications to remove chromium and other electroactive metals from water through the creation of strong reducing conditions and the precipitation of low-solubility metal species (Blowes et al. 1997).

Groundwater and surface water collected in an interceptor trench in the vicinity of the proposed treatment cell for the Solar Pond Plume contain as much as 200 µg/L of total uranium ( $U_{TOT}$ ) and 300 mg/L of nitrate. Trace metal constituents also include cadmium and selenium at concentrations of several mg/L or less.

## 2.0 Experimental Procedures

The column experiments were undertaken in the Radioisotope Laboratory, Department of Earth Sciences, UW. The columns were acrylic and were fabricated at UW. The barrels of the columns were 40 cm in length and 5 cm in diameter, with an internal volume of approximately 810 mL. There were two ports on both the top and basal plates of each column. Each port consists of a threaded nylon fitting, to which a length of teflon® tubing was attached. In addition, there were 15 sample ports spaced equally along the length of the column barrel. These ports consist of small threaded nylon connectors. Syringe needles, which had been partially filled with glass wool, were inserted through these ports to the column interior. The base of each needle was sealed by a plug, which could be removed for sampling.

The columns were filled in the vertical position, from the base to the top with the basal plate attached. The basal filter layer consisted of washed Ottawa sand (20-30 Standard U.S. mesh). The central portion of the column was then filled with reactive material, approximately 125 g at a time. The material was introduced from the top of the column, and was lightly tapped into place. A top sand filter layer was also added in a manner similar to that at the base prior to attaching the top plate. The mass of sand and reactive media added to each column was recorded.

Two treatment schemes were employed. In the first system, the reactive media was a mixture of zero-valent iron and sawdust in a single column (Column I). The sawdust was obtained from Kitchener Forest Products (Kitchener, Ontario), and was referred to as hardwood sawdust. The iron was obtained from Connelly-GPM (Chicago, IL). It is referred to as Iron Aggregate (ETI-CC-1004). The second treatment system consisted of two columns in series. The first column (Column H<sub>1</sub>) contained only sawdust and the second column contained only zero-valent iron (Column H<sub>2</sub>).

Prior to the introduction of site water, the columns were flushed with CO<sub>2</sub> gas and then were saturated with deionized water. Approximately 1 L of water was pumped through each column over a several hour period. The porosity of the reactive media was estimated by comparing the dry and saturated mass of each column.

Water was pumped from an input container to the columns by a multi-channel, high-precision peristaltic pump. Separate supply lines were used for Column I and Columns H<sub>1</sub> and H<sub>2</sub>. Flow occurred upward through each column. The flow rate was maintained at approximately 200 mL, or less than one-half pore volumes, per day. Through the use of control valves, it was possible to collect samples of water prior to its introduction to Column I and Column H<sub>1</sub>, and effluent water from H<sub>1</sub> prior to its introduction to H<sub>2</sub>. Sample cells in the effluent lines from both Column I and Column H<sub>2</sub> facilitated the collection of effluent water prior to its discharge to waste containers. Samples could have been collected from any of the 15 sample ports on each column. All discharge water was collected and delivered to the UW waste facility for disposal. A schematic diagram of the column configuration is shown in Figure 1.

Water samples were collected using 30mL glass syringes to minimize exposure of the water to the atmosphere. For the collection of samples of the input, water was

pumped through the input valves directly to the syringe. For the collection of water from the valve between Columns H<sub>1</sub> and H<sub>2</sub>, and from each sampling port, the syringe was filled with the effluent valves closed and with the pump operating at normal rates. Pumping was temporarily stopped to facilitate water collection from the output sample cells associated with Columns I and H<sub>1</sub>. The water in the sample cell was displaced using pressurized argon, and was collected directly in the syringe.

For each sample several mL of unfiltered water was introduced to two modified plastic syringes for the measurement of Eh and pH. The remaining water was filtered through a 0.45 µm filter. Two to three mL of water were retained in a small glass vial for the measurement of alkalinity in the laboratory. The remaining sample was split into several portions. Approximately 15 mL of water was introduced to a plastic vial and acidified to pH <2 with hydrochloric acid for the analysis of metals and major cations. A similar volume of water was preserved with nitric acid (pH <2) for the analysis of total uranium. Ten to 15 mL of sample was acidified (pH <2) with sulfuric acid and retained for the analysis of ammonia and nitrate. The 8 mL sample for the analysis of major anions was not acidified.

Alkalinity was measured in the laboratory using a Hach digital titrator (Titration Method 2320 B; American Public Health Association (APHA), 1992). Eh (Oxidation-Reduction Potential Method 2580 B; APHA, 1992) and pH (Electrometric Method 4500-H<sup>+</sup> B; APHA, 1992) measurements were initiated in the laboratory using Orion and Orion Ross electrodes, respectively, immediately after the sample had been collected in the syringe. The major cations and metals were analyzed by Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES; EPA Method 200.7, U. S. EPA, 1991) in the Water Quality Laboratory at UW. The major anions, including nitrate, were analyzed by Ion Chromatography (IC: EPA Method 300.0, U. S. EPA, 1993) in the Water Quality Laboratory, UW and at Philip Analytical Services, Burlington, Ontario. Ammonia nitrogen was analyzed by colorimetry using the phenate method (4500-H NH<sub>3</sub>; APHA, 1992) at UW. Preliminary analyses of nitrate and ammonia were also performed using a Hach DR/2000 Spectrophotometer; nitrate was measured using the high range, cadmium reduction method (Hach Method 8039) and ammonia was measured using the salicylate method (Hach Method 8155). Total Uranium analyses were performed at the General

Engineering Laboratories (Charleston, SC) using phosphorescence analysis (KPA-ASTM D5174).

### 3.0 Column Characteristics

In Column I the reactive material consisted of a mixture of elemental iron (Connelly GPM) and hardwood sawdust (Kitchener Forest Products). The column contained 255.04g sand, 44.185g iron, and 400.727g sawdust. The moisture content of the sawdust was approximately 62.5% or 250.45g, and it was not dried prior to use to minimize potential impacts on the microbial populations. The sawdust and iron mixture occupied approximately 33.2 cm of the column between the two sand filter layers, and had a pre-saturated, packed bulk density of approximately  $0.661 \text{ g/cm}^3$ . The saturated mass of the column and its contents exceeded the dry mass by 346g. The interior volume of the endplates and tubing attached to the column was assumed to be 25 mL, so the total water content, or water-filled pore volume, of the column was estimated to be 571.45 mL. This yielded a total porosity of 0.705 for the contents of the column, and incorporated the primary porosity of the sawdust, iron and sand, and potentially some secondary porosity associated with the sawdust.

In the H-series of columns, flow of water occurred through an initial column of sawdust and a second column of zero-valent iron. Column H<sub>1</sub> contained 247.61g of silica sand and 416.755g of sawdust. The sawdust contained 260.47g of water. The sawdust occupied 33.2 cm of the column barrel between the sand filter layers. The pre-saturated, packed bulk density of the sawdust in the column was  $0.619 \text{ g/cm}^3$ . The water-saturated mass of the column, excluding an allowance for water in the end plates and tubing, exceeded the dry mass by approximately 355.19g. Incorporating the moisture within the sawdust, the column contained approximately 615.65 mL of water. Thus, the porosity of the sand and sawdust within the column was 0.76.

Column H<sub>2</sub> contained 250.27g of silica sand and 1,624.05g of zero-valent iron. The iron occupied 33.5 cm (678.99mL) of the column barrel, so the dry bulk density of the iron was  $2.39 \text{ g/cm}^3$ . The water-saturated mass of the column, excluding the estimated

volume of water in the end plates and tubes, was 411.12 mL more than the dry mass. Thus, the porosity of the sand and iron was approximately 0.51.

#### 4.0 Column Flow and Influent Characteristics

Site water was first introduced to the columns on February 18, 1999. With the exception of a break in flow for several days in late June, flow was maintained continuously until July 10, 1999. In Column I, the average flow rate was 186.2 mL per day and corresponded to approximately 0.326 pore volumes per day. The average residence time of water in Column I was 3.06 days. The average flow rate was 186.8 mL per day through the two H-series columns. This flow corresponded to 0.303 pore volumes per day in Column H<sub>1</sub> and 0.452 pore volumes per day in Column H<sub>2</sub>. The average residence time of water in Columns H<sub>1</sub> and H<sub>2</sub> was 3.30 and 2.20 days, respectively.

The initial input water had neutral pH (7 to 8.5), alkalinity of 100 to 200mg/L as CaCO<sub>3</sub>, Eh of 100 to 400mV, and concentrations of chloride and sulfate of approximately 90 and 50 mg/L, respectively. The concentration of uranium (total) was less than 3 µg/L and nitrate was less than 3 mg/L (expressed as NO<sub>3</sub>). Although the input reservoirs were not isolated from the atmosphere, Eh conditions within the input water became more reducing with time. The input water was modified on two occasions as the tests progressed. On April 1, 1999 (Day 41), the concentration of uranium was increased to approximately 200 µg/l and the nitrate concentration was increased to approximately 200 mg/L. The uranium concentration was increased by adding 4 mL of an atomic-absorption analytical standard (1000 mg/L in dilute nitric acid: Solutions Plus, Inc.) to approximately 20 L of site water in its original container. The nitrate concentration was increased by the addition of approximately 5.4g of sodium nitrate (NaNO<sub>3</sub>) to the same container. The second modification occurred on May 5, 1999 (Day 76), when the nitrate concentration of the input water was increased to approximately 300 mg/L. The concentration of ammonia in the input solution was generally less than 1 mg/L throughout the test.

## 5.0 Column Treatment

As the influent water passed through Column I, the pH remained at near-neutral levels, the alkalinity increased by tens of mg/L and the Eh generally decreased. In the early period of the test, nitrate concentrations in the effluent from Column I were low and similar to those in the input solution. After the influent concentrations had been increased on Days 41 and 76, nitrate concentrations decreased significantly within Column I. Nitrate concentrations in the effluent ranged from less than 20 mg/L (as  $\text{NO}_3$ ) when the input concentration was approximately 200 mg/L, to between 100 and 130 mg/L when the input concentration was approximately 300 mg/L. Ammonia concentrations typically ranged between 5 and 7 mg/L in the effluent. Nitrite concentrations were generally less than 0.05 mg/L, but it was present at approximately 3 mg/L for several days after the input nitrate concentration was first increased.

On average the concentration of nitrate in the effluent from Column I was 200 mg/L (as  $\text{NO}_3$ ; approximately 45 mg/L  $\text{NO}_3\text{-N}$ ) less than in the influent, but ammonia concentrations increased from non-detectable levels to 5 to 7 mg/L (as  $\text{NH}_4$ ; 4 to 5.5 mg/L as  $\text{NH}_4\text{-N}$ ). The residence time of the water in Column I was approximately 3 days. Thus, the removal efficiency for nitrate in the iron/sawdust mixture in Column I, discounting the nitrate that was transformed to ammonia, was approximately 12.4 to 14 mg  $\text{NO}_3\text{-N L}^{-1} \text{ day}^{-1}$ , or approximately 55 to 60 mg  $\text{NO}_3 \text{ L}^{-1} \text{ day}^{-1}$ . The concentration of total uranium in the effluent from Column I was less than 0.2  $\mu\text{g/L}$  throughout the test. The concentration of uranium at the first port above the interface of the sand and iron/sawdust mixture (I-P2), a travel distance of 1.5 cm, was 87  $\mu\text{g/L}$  after 15.1 L of influent containing 200  $\mu\text{g/L}$  uranium had been introduced to the column over an 81 day period. The concentration of uranium at the second, third and fourth ports (I-P3, I-P4, and I-P5), each 2.5 cm further along the column, was 16.6, 3.14 and 1.19  $\mu\text{g/L}$ , respectively. The concentrations of chloride and sulfate were similar in the input and output, indicating that sulfate-reducing conditions were not established within the column.

In Column H<sub>1</sub>, there was a slight decrease in Eh conditions as water flowed through the column. The concentration of nitrate was approximately 72 mg/L (as  $\text{NO}_3$ ; 16.25

mg/L as  $\text{NO}_3\text{-N}$ ) lower in the effluent relative to the influent. The production of ammonia was modest in Column  $\text{H}_1$ , and concentrations were typically less than 1 mg/L (as  $\text{NH}_4$ ). The removal efficiency for the sawdust media in Column  $\text{H}_1$  ranged from approximately 4 to 6 mg  $\text{NO}_3\text{-N L}^{-1} \text{ day}^{-1}$ , or approximately 18 to 27 mg  $\text{NO}_3 \text{ L}^{-1} \text{ day}^{-1}$ . The highest measured concentration of uranium in the effluent from Column  $\text{H}_1$  was 4.41  $\mu\text{g/L}$  prior to the termination of flow, but concentrations were generally less than 1  $\mu\text{g/L}$ . A profile of samples collected at the conclusion of testing indicated that the uranium concentration in the pore water had attained the input concentration of approximately 200  $\mu\text{g/L}$  at or beyond the seventh sampling port, a transport distance of approximately 14.2cm through the sawdust. The appearance of increasing concentrations in the effluent, and the advance of uranium at the input concentration through the column, suggest that the capacity of sawdust alone to remove uranium from solution is low. Similar to Column I, the chloride and sulfate concentrations did not change appreciably as water passed through Column  $\text{H}_1$ .

The effluent from Column  $\text{H}_1$  was used as the influent for Column  $\text{H}_2$ . Nitrate was introduced to Column  $\text{H}_2$  at concentrations ranging from 5 to 50 mg/L. Input uranium concentrations were initially low, increasing to a maximum concentration of approximately 4  $\mu\text{g/L}$  at the end of the test. Uranium was not detected ( $<0.1 \mu\text{g/L}$ ) in the output from Column  $\text{H}_2$  throughout the test. Nitrate concentrations in the effluent were of the order of 120 mg/L (as  $\text{NO}_3$ ) lower than those in the input, but ammonia was also present at concentrations of as much as 45 mg/L (as  $\text{NH}_4$ ) in the output. Measured Eh in the effluent from Column  $\text{H}_2$  indicated that reducing conditions had been established within the reactive iron. The appearance of ammonia in conjunction with the disappearance of nitrate, however, suggested that denitrification was negligible.

## 6.0 Implications and Discussion of Results

The column-testing program indicated that the iron/sawdust mixture in Column I was the most effective of the two treatment options investigated for nitrate removal. The concentration of nitrate in the effluent was of the order of 200 mg/L less than that in the influent, and approximately 5 to 7 mg/L of ammonia was generated within the column.

The concentration of nitrate in the effluent while the input concentration was 200 mg/L was typically less than 20 mg/L, but the effluent concentration increased to 100 to 130 mg/L when the input concentration was approximately 300 mg/L. This implies a constant rate of nitrate removal. Discounting the nitrate that was converted to ammonia and the nitrate in the effluent, the nitrate removal rate was of the order of 12.5 to 14 mg/L NO<sub>3</sub>-N L<sup>-1</sup> day<sup>-1</sup>.

The nitrate removal achieved in by the sawdust mixture in Column H<sub>1</sub> ranged from 4 to 6 mg NO<sub>3</sub>-N L<sup>-1</sup> day<sup>-1</sup>, which resulted in decrease of approximately 75 mg/L of nitrate (as NO<sub>3</sub>) between the influent and effluent. There was negligible conversion of nitrate to ammonia within the column. In Column H<sub>2</sub>, the decrease of nitrate concentrations between influent and effluent was similar to that achieved in Column H<sub>1</sub>, but there was strong evidence to suggest that most of the loss of nitrate could be accounted for by the generation of ammonia. The conversion of ammonia to nitrate subsequent to its release in the effluent could be expected to occur in many groundwater and surface water environments.

After the introduction of 15.1 and 16.2 L of uranium-amended influent, respectively, the uranium front, as defined by the input concentration, had advanced less than 1.5 cm in Column I and more than 14.2 cm in Column H<sub>1</sub>. During this period, approximately 3.0 mg of uranium had been introduced to Column I while 3.2 mg of uranium had been introduced to Column H<sub>1</sub>. The average linear flow velocities in Columns I and H<sub>1</sub>, based on calculations using estimates for porosity, a column length of 40 cm and the records of flow, were approximately 13.1 and 12.1 cm/day, respectively. Over the 81 days of flow in Column I, and the 87 days of flow in Column H<sub>1</sub>, it could be assumed that water would have traveled 10.6 and 10.5 m, respectively. Thus, there was significant retardation in the advance of the uranium front relative to that of water flow in both columns, but the retardation was at least a factor of 10 greater in Column I than in Column H<sub>1</sub>. For Column H<sub>1</sub> (sawdust), influence on Eh conditions was minor and it is likely that this retardation was largely a function of sorption. For Column I (sawdust and iron), however, Eh conditions were significantly reduced, and the retardation likely included attenuation by precipitation or co-precipitation of reduced solid-phase mineral phases. Based on average mixture characteristics throughout the column, it can be

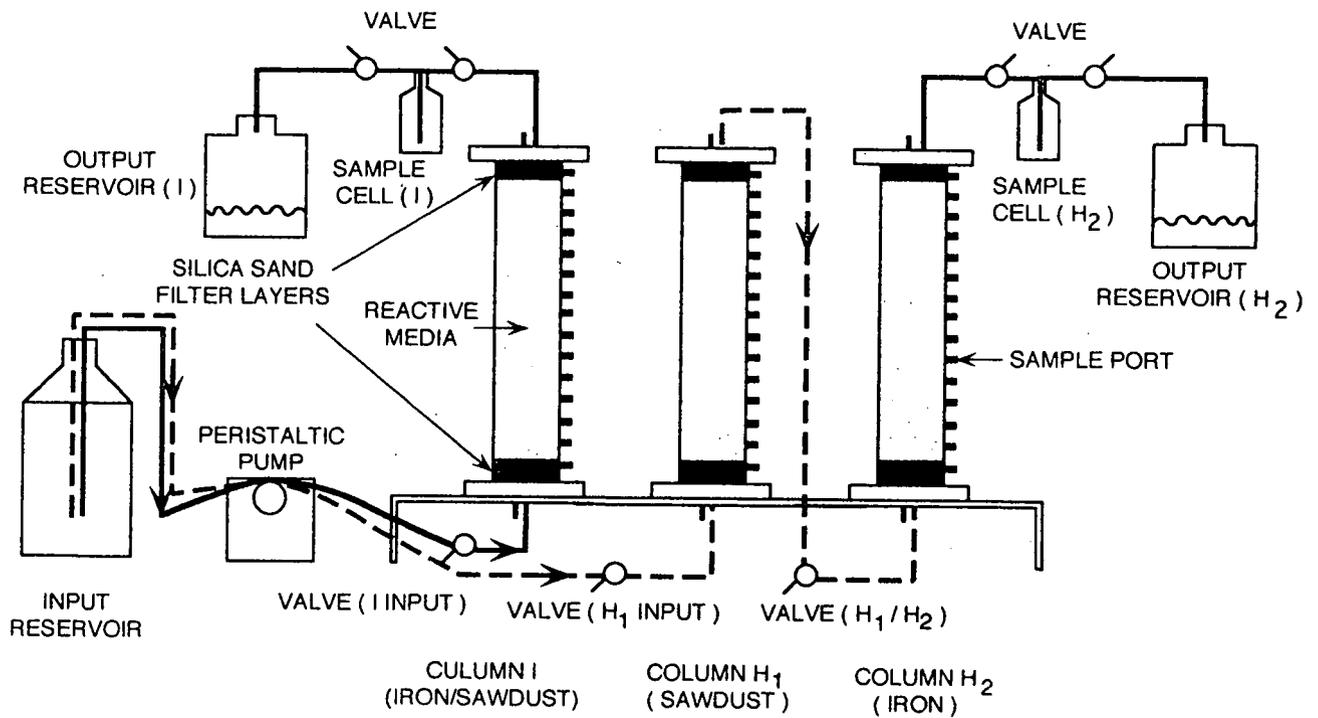
estimated that there was about 2.0g of zero-valent iron in the first 1.5 cm of reactive media, and that this iron was responsible for the removal of 90 % of the uranium contaminant mass. The treatment efficiency of the iron was of the order 1.4 mg uranium removed for each gram of iron (1.35 mg U/ g Fe).

There were insufficient data to estimate the removal of uranium by zero-valent iron in Column H<sub>2</sub>. The final concentration of uranium in the effluent from Column H<sub>1</sub> was 4µg/L, so it can be assumed that less than 50 µg of uranium was introduced to Column H<sub>2</sub> during the test. There was about 50g of zero-valent iron in each centimeter along Column H<sub>2</sub>, so there was approximately 75g of iron between the interface of the sand and iron and the first sampling port (H<sub>2</sub>-P2). Assuming similar treatment efficiency for 100% iron as in the 10% iron/90% sawdust mixture, the iron in the first 1.5cm of the treatment zone could remove approximately 100g of uranium, and treat 500 L the influent water. The assumption that the treatment efficiency, defined as mass of contaminant removed per mass of iron, of pure granular iron could be equivalent to that of 10% iron in mixed media is likely a conservative one. It is reasonable to expect that improved treatment efficiency for uranium could be achieved by a reactive medium consisting of 100% iron.

Robertson et al. (1999) have employed iron-free media in permeable reactive barriers to treat nitrate in plumes associated with domestic septic systems and agriculture in Ontario. The nitrate removal efficiencies have ranged from 15 to 30 mg NO<sub>3</sub>-N L<sup>-1</sup> day<sup>-1</sup>, and have sustained this removal efficiency over periods of as much as six years. The sawdust media (Column H<sub>1</sub>) used in this study did not achieve this level of treatment efficiency, but the iron/sawdust mixture achieved a level of treatment in the lower part of the range. The reason the sawdust did not achieve anticipated levels of treatment has yet to be confirmed, but it could be that trace constituents such as phosphate were not present in the influent water or the sawdust media at sufficient concentrations to enhance the activity of denitrifying microbial populations. Phosphate is present in significant concentrations in most domestic and agricultural wastewater, so no comparable deficiency would have existed for the previous field applications.

For application at the Rocky Flats Environmental Technology Site, the potential composition of the reactive media to promote denitrification of the nitrate associated with

Solar Ponds Plume was described in a letter to Rocky Mountain Remediation Services on May 19, 1999. It was recommended that the nitrate treatment consist of a mixture of iron and sawdust similar to that used in Column I, and that the treatment media be modified using a nutrient mulch consisting of 80% leaf mulch, 15% organic soil and sediment, and as much as 5% bone meal. The proportions for the reactive media would be 10% iron, 80% hardwood sawdust and 10% nutrient mulch.



**Figure 1:** A schematic diagram of the column-testing apparatus. Two column treatment systems were used, both supplied from a common input source. Sequential treatment by two reactive media (sawdust and iron) occurred in Columns H<sub>1</sub> and H<sub>2</sub>. The reactive media in Column I included a mixture of iron and sawdust.

## References:

1. American Public Health Association, 1992. Standard Methods for the Examination of Water and Wastewater (17<sup>th</sup> Edition). Edited by A.E. Greenberg, L. S. Clesceri and A.D. Eaton. Published by the American Public Health Association, American Water Works Association, and Water Environment Federation.
2. Blowes, D.W., R.W. Puls, T.A. Bennett, R.W. Gillham, C.J. Hanton-Fong and C.J. Ptacek, 1997a. In-situ porous reactive wall for treatment of Cr(VI) and trichloroethylene in groundwater. In Proceedings of the 1997 International Containment Technology Conference and Exhibition, February 9-12, St. Petersburg, Florida, pp. 851-857.
3. Robertson, W.D., D.W. Blowes, C.J. Ptacek, and J.A. Cherry, 1999. Long-term performance of in situ reactive barriers for nitrate remediation. Draft paper submitted to Ground Water (copy provided to RMRS).
4. Robertson, W.D. and J.A. Cherry, 1997. Long-term performance of the Waterloo denitrification barrier. Land Contamination and Reclamation, V. 5, pp. 183-188.
5. United States Environmental Protection Agency, 1991. Methods for the Determination of Metals in Environmental Samples. EPA/600/4-91/010 (June).
6. United States Environmental Protection Agency, 1993. Methods for the Determination of Inorganic Substances in Environmental Samples. EPA/600/R-93/100 (August).

## APPENDIX I: Chemical Data

### Notes:

1. Samples are coded according to sampling point and time. 'Input' refers to the common source water for both column treatment schemes. 'I-Output' is the effluent from Column I (sawdust/ iron mixture). 'H1/H2' is the water intermediate to Columns H1 (sawdust) and H2 (iron); it is the effluent from H1, but the influent for H2. 'H2-Output' is the effluent from Column H2. Ports sampled in Columns I and H1 are numbered (eg. P2) according to their position from the base of the columns. The ports are separated by approximately 2.5 cm, and the sand filter/ treatment media interface occurs between Ports 1 and 2 in each column.
2. The numerical code was intended to correspond with the number of days between the time of sampling and the start of the column tests. The date and time for all sampling was recorded. The numerical codes deviate from the actual number of days in the following manner:
  - Code 39 was Day 39
  - Code 47 was Day 46
  - Code 54 was Day 51
  - Code 62 was Day 59
  - Code 70 was Day 66
  - Code 75 was Day 71
  - Code 81 was Day 77
  - Code 88 was Day 84
  - Code 96 was Day 92
  - Code 98 was Day 102
  - Code 105 was Day 109
3. All concentrations are reported as mg/L except U, which is reported as  $\mu\text{g/L}$ .

## **APPENDIX II: Quality Control/ Quality Assurance**

## AII-1. Quality Control- Quality Assurance Narrative

Sampling of the columns was performed at intervals of approximately one week for the duration of the experiment. Samples were collected in glass syringes that were connected directly to valves or sampling ports associated with each column. The syringes were flushed with deionized water seven times prior to the collection of each sample. Each column had dedicated tubing, valves and sample cells. Routine monitoring included the collection of a sample of the input water, samples from the two effluent cells, and a sample of the water intermediate to Columns H<sub>1</sub> and H<sub>2</sub>. All sample containers and syringe filters were removed from their packages immediately prior to use, and none were reused. Analytical grade acids were used for sample preservation.

Alkalinity (as CaCO<sub>3</sub>) was measured in the laboratory using a Hach digital titrator. The measurement was undertaken using between 2 and 3 mL of sample within several minutes of removal of the sample syringe from the column, valve or cell. Two drops of a methyl red-bromocresol green indicator were inserted in a sample vial, the mass of the sample was measured, and the volume of 0.16N H<sub>2</sub>SO<sub>4</sub> necessary to achieve a change in color from blue to pink was recorded.

Eh and pH measurements were undertaken in the laboratory using Orion and Orion Ross electrodes, respectively, immediately after the sample had been collected in the syringe. Approximately 3 to 5 mL of sample were injected from the sample-collection syringe through valves at the tips of modified plastic syringes from which the plungers had been removed. The electrodes were inserted into the interior of the syringe. The barrels of the electrodes were sealed to the upper end of the syringe casing by flexible rubber tubing. Exposure of the sample to the atmosphere was minimal prior to and during the measurement period. The measurements were typically monitored at least 12 times during a 20 to 25-minute period to achieve stable values. The Eh calibration was checked prior to each sample measurement using standard Zobell and Light solutions. The calibration of the pH meter was checked using the pH 7 and pH 4 standards prior to use for each sample.

Each laboratory implemented Quality Assurance measures. For the ICP-AES analyses at the Water Quality Laboratory, UW, the instrument (Thermo Jarrell Ash IRIS Plasma Spectrometer) conditions were set according to manufacturer's instructions. Prepared mixed standards, with element concentrations of 10 mg/L, were run after every 10 samples. A commercial mixed standard was used to verify the prepared standards on a regular basis. Samples were run in duplicate, and were usually diluted due to the small sample volume available from the columns. Sample analyses were repeated if the relative difference on the prepared standards exceeded 3%.

At UW anions were analyzed using a Dionex System 2000 Ion Chromatograph or a Waters Ion Chromatograph with conductivity detectors. The samples were analyzed a minimum of two times and at different dilution ratios to verify sample reproducibility and linearity of calibration. The instruments were evaluated daily for calibration linearity using three standards:

1. A prepared mixed standard containing 2 mg/L Cl, 5 mg/L Br, 10 mg/L SO<sub>4</sub>, 5 mg/L NO<sub>3</sub>, and 10 mg/L PO<sub>4</sub>.
2. A prepared mixed standard containing 0.4 mg/L Cl, 1 mg/L Br, 2 mg/L SO<sub>4</sub>, 1 mg/L NO<sub>3</sub>, and 2 mg/L PO<sub>4</sub>.
3. A commercial setpoint mixed standard at ion concentrations similar to standard 1.

The two prepared samples were run after every eleven samples. The setpoint standard was run at least twice per day. Analytical blanks were also run twice per day. Sample analyses were repeated if the relative difference on the setpoint standard exceeded 5%.

Philip Analytical Services Corporation analyzed anions using Ion Chromatography methods based on 'Standard Methods for the Examination of Water and Wastewater'. The Philip ELAP Identification Number for New York State is 10756.

Ammonium was analyzed using an Alpkem Perstorp Analytical Environmental flow Solution System. This colorimetric method measures absorbance at specific wavelengths. Analytical protocols involved the generation of a response curve from the analysis of known standards prior to the analysis of samples, and after the analysis of

each 20 samples. One standard blank sample was included with the analysis of each 10 samples.

The analysis for nitrate and ammonium was also performed using colorimetry with a Hach DR/2000 Spectrophotometer (Hach Method 8039 and Hach Method 8155, respectively). The analyses required the incorporation of reagents from powder pillows supplied by Hach to cells containing the sample and nanopure deionized water, and the subsequent comparison of absorbance by each of the cells. Analyses were repeated with appropriate dilutions if initial results indicated concentrations outside the ranges of the analytical methods.

Total Uranium analyses were performed at the General Engineering Laboratories (Charleston, SC) using phosphorescence analysis (KPA- ASTM D5174). Standard quality control procedures incorporate the analysis of laboratory blanks, duplicates and known standards in accordance with the recommendations of the method.

The detailed records of analytical QA/QC measures are contained in a separate addendum to this report.

Output from Column I

Column I- Output

Sample I.D.	Date (mm/dd/yy)	pH	Eh (Cor.) (mV)	Alkalinity (mg L <sup>-1</sup> CaCO <sub>3</sub> )	Al (mg L <sup>-1</sup> )	As (mg L <sup>-1</sup> )	B (mg L <sup>-1</sup> )	Ba (mg L <sup>-1</sup> )	Ca (mg L <sup>-1</sup> )	Cd (mg L <sup>-1</sup> )	Co (mg L <sup>-1</sup> )	Cr (mg L <sup>-1</sup> )	Cu (mg L <sup>-1</sup> )	Fe (mg L <sup>-1</sup> )	K (mg L <sup>-1</sup> )	Li (mg L <sup>-1</sup> )	Mg (mg L <sup>-1</sup> )	Mn (mg L <sup>-1</sup> )	Mo (mg L <sup>-1</sup> )	Na (mg L <sup>-1</sup> )
I-6 OUT	24-Feb-99	8.63	-203.6	172	<.1000	<.0500	0.1983	0.0375	40.04	<.0100	0.0203	<.0100	<.0100	88.98	7.595	-	10.38	0.6567	<.2000	65.99
I-11 OUT	01-Mar-99	6.77	-239.7	191	<.1000	<.0500	0.1529	0.0328	41.71	<.0100	<.0200	<.0100	<.0100	71.04	6.407	-	15.72	0.6027	<.2000	65.8
I-18 OUT	08-Mar-99	6.83	-324.5	283	<.1000	<.0500	0.2995	0.0499	75.28	<.0100	<.0200	0.0525	<.0100	84.22	6.045	0.0487	19.11	0.3588	<.2000	67.81
I-25 OUT	15-Mar-99	6.81	-288.5	189	<.1000	<.0500	0.2158	0.0384	57.44	<.0100	0.0225	0.0175	<.0100	49.54	6.059	0.038	14.93	0.2083	<.2000	66.17
I-33 OUT	23-Mar-99	7.19	78.7	199	<.1000	<.0500	0.136	0.0321	51.58	<.0100	<.0200	0.037	<.0100	16.8	6.194	0.0487	16.51	0.119	<.2000	70.8
I-39 OUT	29-Mar-99	7.08	36.5	200	<.1000	<.0500	0.1845	0.0416	50.88	<.0100	<.0200	0.0202	<.0100	26.58	6.485	0.0496	16.29	0.1604	<.2000	65.78
I-46 OUT	06-Apr-99	7.25	27.8	276	<.1000	<.0500	0.1249	0.0507	82.85	<.0100	<.0200	0.035	<.0100	24.07	7.484	0.0335	20.08	0.1853	<.2000	98.22
I-51 OUT	13-Apr-99	8.37	35.7	351	<.1000	0.1884	0.0818	0.0167	36.46	<.0100	<.0200	0.0347	<.0100	0.2652	5.942	0.0354	22.47	0.0307	<.2000	147
I-59 OUT	21-Apr-99	7.90	122.3	299	<.1000	<.0500	0.0872	0.0262	46.17	<.0100	<.0200	0.0322	<.0100	0.1239	6.288	0.056	16.61	0.0535	<.2000	158.5
I-66 OUT	29-Apr-99	7.87	144.1	333	<.1000	<.0500	0.0912	0.0264	47.91	<.0100	<.0200	0.0294	<.0100	0.0775	6.728	0.0657	15.09	0.0561	<.2000	167.1
I-71 OUT	04-May-99	7.81	155.5	287	<.1000	<.0500	0.1062	0.0218	39.95	<.0100	<.0200	0.0113	<.0100	0.0639	6.95	0.0684	14.66	0.0638	<.2000	171.6
I-78 OUT	09-May-99	7.88	207.6	315	<.1000	0.0583	0.0812	0.0213	50.4	<.0100	<.0200	0.0301	<.0100	<.0200	6.889	0.0669	20.84	0.0697	<.2000	207.6
I-84 OUT	17-May-99	8.00	203.5	305	<.1000	<.0500	0.0911	0.0216	49.54	<.0100	<.0200	0.0327	<.0100	<.0200	6.535	0.0662	23.35	0.0467	<.2000	207.8
I-92 OUT	25-May-99	8.05	205.4	283	<.1000	<.0500	0.0928	0.015	49.86	<.0100	<.0200	0.015	<.0100	<.0200	6.113	0.0527	18.08	0.0437	<.2000	188.7
I-98 OUT	31-May-99	7.92	152.1	295	<.1000	<.0500	0.1132	0.0154	48.5	<.0100	<.0200	<.0100	<.0100	<.0200	6.154	0.0457	16.48	0.0438	<.2000	203.3
I-105 OUT	07-Jun-99	7.85	89.3	269	<.1000	0.0779	0.0989	0.0103	48.81	<.0100	<.0200	<.0100	<.0100	<.0200	6.422	0.0588	15.69	0.039	<.2000	200
I-133-OUT	05-Jul-99	7.77	182.8	370	<.1000	<.0500	0.1773	0.0178	52.54	<.0100	<.0200	<.0100	<.0100	1.945	6.388	0.0539	17.55	0.1509	<.2000	197.2

Input Solution for Column I and Column H1

Sample I.D.	Date (mm/dd/yy)	pH	Eh (Cor.) (mV)	Alkalinity (mg L <sup>-1</sup> CaCO <sub>3</sub> )	Al (mg L <sup>-1</sup> )	As (mg L <sup>-1</sup> )	B (mg L <sup>-1</sup> )	Ba (mg L <sup>-1</sup> )	Ca (mg L <sup>-1</sup> )	Cd (mg L <sup>-1</sup> )	Co (mg L <sup>-1</sup> )	Cr (mg L <sup>-1</sup> )	Cu (mg L <sup>-1</sup> )	Fe (mg L <sup>-1</sup> )	K (mg L <sup>-1</sup> )	Li (mg L <sup>-1</sup> )	Mg (mg L <sup>-1</sup> )	Mn (mg L <sup>-1</sup> )	Mo (mg L <sup>-1</sup> )	Na (mg L <sup>-1</sup> )	Ni (mg L <sup>-1</sup> )	P (mg L <sup>-1</sup> )	Pb (mg L <sup>-1</sup> )
INPUT-0	18-Feb-99	6.97	339.9	193	<.1000	0.0796	0.0853	0.1432	82.46	<.0100	<.0200	0.0359	<.0100	<.0200	5.883	0.022	18.42	<.0200	<.2000	64.79	0.0274	0.0658	0.1874
INPUT-6	24-Feb-99	7.83	407.4	207	<.1000	0.0853	0.098	0.1643	84.81	<.0100	<.0200	0.0262	<.0100	<.0200	7.002	-	19.24	<.0200	<.2000	65.56	0.0265	-	<.1000
INPUT-11	01-Mar-99	8.10	370.5	214	<.1000	0.1541	0.087	0.137	76.69	<.0100	<.0200	<.0100	<.0100	<.0200	6.118	-	18.42	<.0200	<.2000	64.34	<.0200	-	<.1000
INPUT-18	08-Mar-99	8.46	360.3	188	<.1000	<.0500	0.0886	0.1365	71.93	<.0100	0.0209	0.0475	<.0100	<.0200	5.997	0.0428	18.64	<.0200	<.2000	64.83	<.0200	0.0744	0.1615
INPUT-25	15-Mar-99	7.86	224.7	167	<.1000	<.0500	0.0872	0.124	54.94	<.0100	<.0200	0.0431	<.0100	<.0200	5.959	0.0431	18.03	<.0200	<.2000	64.28	<.0200	0.106	<.1000
INPUT-33	23-Mar-99	8.00	223	136	<.1000	0.05	0.0827	0.1187	44.3	<.0100	<.0200	0.0451	<.0100	<.0200	5.94	0.0442	17.85	<.0200	<.2000	66.97	<.0200	<.0000	0.2153
INPUT-39	29-Mar-99	7.94	121.4	114	<.1000	<.0500	0.0913	0.1055	34.19	<.0100	<.0200	0.0405	<.0100	<.0200	6.437	0.0263	17.13	<.0200	<.2000	64.69	<.0200	0.1362	<.1000
INPUT-46	06-Apr-99	7.52	208.6	254	<.1000	<.0500	0.0854	0.1542	79.19	<.0100	<.0200	0.0361	<.0100	<.0200	5.997	0.0258	17.77	<.0200	<.2000	147.3	<.0200	0.11	0.192
INPUT-51	13-Apr-99	8.34	96.9	215	<.1000	<.0500	0.0846	0.1346	73.83	<.0100	<.0200	0.0373	<.0100	<.0200	4.694	0.0305	17.88	<.0200	<.2000	148.5	<.0200	0.0888	0.1875
INPUT-59	21-Apr-99	8.18	83	204	<.1000	<.0500	0.0872	0.1282	65.25	<.0100	<.0200	0.0469	<.0100	<.0200	6.239	0.0476	19.09	<.0200	<.2000	156.1	0.0384	0.1535	0.1462
INPUT-66	29-Apr-99	8.31	293.3	143	<.1000	0.2113	0.0896	0.1246	48.48	<.0100	<.0200	0.0428	<.0100	<.0200	6.711	0.0578	19.3	<.0200	<.2000	163.2	<.0200	0.1729	<.1000
INPUT-71	04-May-99	8.25	209.4	148	<.1000	<.0500	0.095	0.127	45.11	<.0100	<.0200	0.0292	<.0100	<.0200	6.772	0.0618	19.53	<.0200	<.2000	169.2	<.0200	0.1082	<.1000
INPUT-76	09-May-99	7.84	285.5	200	<.1000	0.1051	0.0858	0.1453	78.36	<.0100	<.0200	0.028	<.0100	<.0200	6.339	0.0646	19.31	<.0200	<.2000	195	<.0200	<.0000	<.1000
INPUT-84	17-May-99	7.77	285.5	187	<.1000	<.0500	0.0892	0.1393	74.05	<.0100	<.0200	0.0366	0.0188	<.0200	6.912	0.0585	18.92	<.0200	<.2000	193.1	0.0898	<.0000	0.1637
INPUT-92	25-May-99	7.74	272.9	167	<.1000	<.0500	0.0805	0.1255	62.67	<.0100	<.0200	0.0315	<.0100	<.0200	6.073	0.046	17.9	<.0200	<.2000	190.3	<.0200	0.1435	<.1000
INPUT-98	31-May-99	7.78	210.1	146	<.1000	0.0972	0.0799	0.1217	52.66	<.0100	<.0200	0.0217	<.0100	<.0200	6.265	0.0473	18.26	<.0200	<.2000	200.5	0.0488	0.0037	<.1000
INPUT-105	07-Jun-99	7.76	170.7	117	<.1000	0.1399	0.08	0.1137	43.92	<.0100	<.0200	0.0119	<.0100	<.0200	6.144	0.0421	18.04	<.0200	<.2000	199.5	0.0523	<.0000	<.1000
INPUT-133	05-Jul-99	7.89	303.8	200	<.1000	<.0500	0.0885	0.1375	77.96	<.0100	<.0200	<.0100	<.0100	<.0200	6.23	0.0469	18.74	<.0200	<.2000	193	<.0200	0.2356	<.1000

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Input Solution for Column I and Column H1

Sample I.D.	Date (mm/dd/yy)	S (mg L <sup>-1</sup> )	Se (mg L <sup>-1</sup> )	Si (mg L <sup>-1</sup> )	Sr (mg L <sup>-1</sup> )	Ti (mg L <sup>-1</sup> )	V (mg L <sup>-1</sup> )	Zn (mg L <sup>-1</sup> )	color	HACH	F (mg L <sup>-1</sup> )	Br (mg L <sup>-1</sup> )	Cl (mg L <sup>-1</sup> )	IC	HACH	IC	PO4 (mg L <sup>-1</sup> )	SO4 (mg L <sup>-1</sup> )	U total (ug L <sup>-1</sup> )
									NH4 (mg L <sup>-1</sup> )	NH4-N (mg L <sup>-1</sup> )				NO3 (mg L <sup>-1</sup> )	NO3-N (mg L <sup>-1</sup> )	NO2 (mg L <sup>-1</sup> )			
INPUT-0	18-Feb-99	18.57	<.2000	7.519	0.504	-	-	<.0100				0.32	91	0.94		<0.05	<0.1	51.3	
INPUT-6	24-Feb-99	-	0.4302	6.656	0.5382	<.0100	0.0264	0.0116											3.9
INPUT-11	01-Mar-99	-	0.4814	6.668	0.4746	<.0100	<.0200	<.0100											3.75
INPUT-18	08-Mar-99	17.63	<.2000	7.053	0.4987	-	-	<.0100				<0.05	92.9	<0.05		<0.05	<0.10	53.2	3.79
INPUT-25	15-Mar-99	17.42	<.2000	7.212	0.4741	-	-	<.0100	< 0.03		0.11	<0.50	89	<0.25		<0.25	<0.50	47	3.71
INPUT-33	23-Mar-99	18.68	<.2000	7.211	0.456	-	-	<.0100	< 0.03	< 0.00	0.11	<0.50	92	<0.25	1.09	<0.25	<0.50	44	
INPUT-39	29-Mar-99	18.23	0.5253	7.099	0.448	-	-	<.0100		< 0.00					1.87				
INPUT-46	06-Apr-99	18.65	0.3774	7.477	0.4962	-	-	0.0138	<0.4	< 0.00	-	<0.05	89.7	208	51.2	<0.05	<0.1	54.2	239
INPUT-51	13-Apr-99	18.14	0.307	7.787	0.4939	-	-	<.0100	<0.4	0.18	-	<0.05	92.9	215	42.5	<0.05	<0.1	53.4	239
INPUT-59	21-Apr-99	18.5	0.3435	7.977	0.5064	-	-	0.0256	<0.4	0.18	-	<0.05	94.0	218	54.74	<0.05	<0.1	53.7	239
INPUT-66	29-Apr-99	19.25	<.2000	8.126	0.487	-	-	0.0137	<0.4	0.68	-	<0.05	91.1	224	48.04	<0.05	<0.1	54.2	282
INPUT-71	04-May-99	19.51	<.2000	8.277	0.5047	-	-	0.0283	<0.4	0.45	-	<0.05	86.7	217	45.4	<0.05	<0.1	53.3	300
INPUT-76	09-May-99	18.45	0.53	7.823	0.5247	-	-	0.0212	<0.4	1.09	-	<0.05	94.0	315	67.55	<0.05	<0.1	51.1	232
INPUT-84	17-May-99	18.8	0.53	7.744	0.5181	-	-	0.1396	<0.4	0.929	-	<0.05	91.3	317	77.29	<0.05	<0.1	51.2	176
INPUT-92	25-May-99	18.02	0.2301	7.71	0.4813	-	-	0.0365		0.464	-	<0.05	96.7	301	75.16	<0.05	<0.1	53.6	
INPUT-98	31-May-99	18.55	<.2000	7.882	0.4791	-	-	0.128		0.461	-	<0.05	88.5	305	75.86	<0.05	<0.1	55	
INPUT-105	07-Jun-99	18.72	<.2000	7.743	0.4635	-	-	0.0227		0.036	-	<0.05	83.2	309	70.40	<0.05	<0.1	54.5	
INPUT-133	05-Jul-99	18.68	<.2000	7.799	0.5028	-	-	0.0257			<.50	<1.0	95	297		<0.05	<1.0	53	211

Output from Column I

Column I- Output

Sample I.D.	Date (mm/dd/yy)	N (mg L <sup>-1</sup> )	P (mg L <sup>-1</sup> )	Pb (mg L <sup>-1</sup> )	S (mg L <sup>-1</sup> )	Se (mg L <sup>-1</sup> )	Si (mg L <sup>-1</sup> )	Sr (mg L <sup>-1</sup> )	Tl (mg L <sup>-1</sup> )	V (mg L <sup>-1</sup> )	Zn (mg L <sup>-1</sup> )	color NH4 (mg L <sup>-1</sup> )	HACH NH4-N (mg L <sup>-1</sup> )	F (mg L <sup>-1</sup> )	Br (mg L <sup>-1</sup> )	Cl (mg L <sup>-1</sup> )	IC NO3 (mg L <sup>-1</sup> )	HACH NO3-N (mg L <sup>-1</sup> )	IC NO2 (mg L <sup>-1</sup> )	IC PO4 (mg L <sup>-1</sup> )	SO4 (mg L <sup>-1</sup> )	U total (ug L <sup>-1</sup> )
I-6 OUT	24-Feb-99	<.0200	-	0.1076	-	<.2000	7.269	0.1672	<.0100	0.0414	0.441											<.095
I-11 OUT	01-Mar-99	<.0200	-	<.1000	-	<.2000	6.14	0.1674	<.0100	<.0200	0.2813											<.095
I-18 OUT	08-Mar-99	<.0200	0.3476	<.1000	18.8	<.2000	8.42	0.4328	-	-	0.3111											<.095
I-25 OUT	15-Mar-99	<.0200	0.0879	0.1568	15.19	<.2000	7.868	0.3543	-	-	0.1877	< 0.03		0.50	<.05	91.9	<.05		<.05	<.10	52.1	<.095
I-33 OUT	23-Mar-99	<.0200	0.1759	<.1000	3.364	<.2000	7.819	0.342	-	-	<.0100	< 0.03	< 0.00	0.47	<.05	89	<.05		<.25	<.50	34	<.095
I-39 OUT	29-Mar-99	<.0200	0.0253	<.1000	8.005	0.2847	7.732	0.3422	-	-	0.0149		< 0.00		<.05	88	<.05	2.25	<.25	<.50	2.1	
I-48 OUT	08-Apr-99	<.0200	0.2084	0.1384	17.03	0.2011	6.677	0.4348	-	-	0.0214	6.47	0.02	-	<.05	93.6	<.05	20.05	30.5	<.1	48.5	0.171
I-51 OUT	13-Apr-99	<.0200	0.0723	0.16	17.85	0.5598	1.825	0.3157	-	-	<.0100	13.9	0.16	-	<.05	92	<.05	1.12	<.05	<.1	50.1	0.171
I-59 OUT	21-Apr-99	0.0466	0.1569	0.1767	18.89	0.4383	1.9	0.4393	-	-	0.018	6.26	1.5	-	<.05	91.4	20.4	7.38	3.23	<.1	52.5	0.171
I-66 OUT	29-Apr-99	<.0200	0.2405	<.1000	19.77	<.2000	1.849	0.3809	-	-	0.0281	5.52	1.13	-	<.05	94.1	18.1	6.79	<.05	<.1	53.5	<.09
I-71 OUT	04-May-99	<.0200	0.1713	<.1000	19.88	0.2759	1.785	0.3263	-	-	<.0100	6.23	1.46	-	<.05	95.7	15.8	6.85	<.05	<.1	56.4	<.09
I-76 OUT	09-May-99	<.0200	0.4707	<.1000	18.35	0.3861	1.977	0.3595	-	-	0.0253	7.06	1.07	-	<.05	91.2	100	27.09	<.05	<.1	53.8	<.09
I-84 OUT	17-May-99	<.0200	<.0000	<.1000	18.92	0.5953	2.216	0.3699	-	-	0.0253	6.54	4.178	-	<.05	59.3	127	33.5	<.05	<.1	53.2	0.017
I-92 OUT	25-May-99	<.0200	<.0000	<.1000	18.92	0.4961	2.177	0.4575	-	-	0.0445		3.125	-	<.05	82.1	133	28.79	<.05	<.1	57.9	
I-98 OUT	31-May-99	<.0200	0.2516	0.1795	20.78	<.2000	2.176	0.5244	-	-	<.0100		2.201	-	<.05	86.4	111	25.26	<.05	<.1	62.3	
I-105 OUT	07-Jun-99	<.0200	0.015	<.1000	21.75	0.2246	1.853	0.4767	-	-	0.0142		3.704	-	<.05	84.6	109	29.02	<.05	<.1	62	
I-133-OUT	05-Jul-99	<.0200	0.1406	0.1975	19.35	<.2000	3.579	0.4227	-	-	0.0213			1.2	<.1	98	70.8	<.05	<.1	45		<.095

Output from Column H1/ Input to Column H2

Sample I.D.	Date (mm/dd/yy)	pH	Eh (Cor.) (mV)	Alkalinity (mg L <sup>-1</sup> CaCO <sub>3</sub> )	Al (mg L <sup>-1</sup> )	As (mg L <sup>-1</sup> )	B (mg L <sup>-1</sup> )	Ba (mg L <sup>-1</sup> )	Ca (mg L <sup>-1</sup> )	Cd (mg L <sup>-1</sup> )	Co (mg L <sup>-1</sup> )	Cr (mg L <sup>-1</sup> )	Cu (mg L <sup>-1</sup> )	Fe (mg L <sup>-1</sup> )	K (mg L <sup>-1</sup> )	Li (mg L <sup>-1</sup> )	Mg (mg L <sup>-1</sup> )	Mn (mg L <sup>-1</sup> )	Mo (mg L <sup>-1</sup> )	Na (mg L <sup>-1</sup> )	Ni (mg L <sup>-1</sup> )	P (mg L <sup>-1</sup> )	Pb (mg L <sup>-1</sup> )
H1/H2-6	24-Feb-99	5.85	434.2	130	<.1000	<.0500	0.0278	0.081	67.34	<.0100	<.0200	0.0164	<.0100	0.7552	6.598	-	17.09	0.0857	<.2000	65.49	0.0489	-	<.1000
H1/H2-11	01-Mar-99	6.12	354.8	125	<.1000	0.5813	0.0424	0.0694	67.61	<.0100	<.0200	0.0107	<.0100	0.3982	6.217	-	16.88	0.084	<.2000	64.89	0.0397	-	<.1000
H1/H2-18	08-Mar-99	6.69	292	193	<.1000	0.3867	0.0566	0.082	75.46	<.0100	<.0200	0.0698	<.0100	0.1755	6.556	0.0443	17.42	0.0804	<.2000	65.18	<.0200	0.1274	<.1000
H1/H2-25	15-Mar-99	6.69	285.3	161	<.1000	0.15	0.1006	0.0799	67.13	<.0100	<.0200	0.0291	<.0100	0.156	5.868	0.0412	15.31	0.0228	<.2000	64.64	<.0200	<.0000	0.1125
H1/H2-33	23-Mar-99	6.46	35.9	160	<.1000	0.12	0.1049	0.0774	54.83	<.0100	<.0200	0.0236	<.0100	0.1638	5.135	0.0488	15.43	<.0200	<.2000	67.25	<.0200	0.0067	<.1000
H1/H2-39	29-Mar-99	6.67	-53.3	163	<.1000	<.0500	0.1051	0.0757	45.76	<.0100	<.0200	0.0278	<.0100	1.016	6.035	0.0736	14.33	<.0200	<.2000	65.61	<.0200	0.0779	<.1000
H1/H2-46	06-Apr-99	6.74	-76.1	-	<.1000	<.0500	0.0831	0.1343	75.48	<.0100	<.0200	0.0647	<.0100	0.4818	7.697	0.0382	28.3	<.0200	<.2000	116.6	<.0200	0.251	0.1704
H1/H2-50	13-Apr-99	7.12	307	268	<.1000	<.0500	0.0641	0.1353	67.89	<.0100	<.0200	0.0475	<.0100	0.0584	5.729	0.0596	23.12	<.0200	<.2000	154.5	0.0841	0.1843	<.1000
H1/H2-59	21-Apr-99	7.19	104.3	228	<.1000	<.0500	0.1046	0.1255	55.94	<.0100	<.0200	0.0186	<.0100	0.0485	6.43	0.0558	16.43	<.0200	<.2000	164.2	<.0200	0.216	<.1000
H1/H2-66	30-Apr-99	7.15	168.8	235	<.1000	0.1097	0.304	<.0050	2.262	<.0100	<.0200	<.0100	<.0100	<.0200	6.418	0.0432	0.1281	<.0200	<.2000	156.1	<.0200	0.2078	<.1000
H1/H2-71	04-May-99	7.12	174.5	183	<.1000	<.0500	0.128	0.1174	51.89	<.0100	<.0200	0.0309	0.027	0.1	6.684	0.068	16.5	<.0200	<.2000	164	0.1122	0.2342	<.1000
H1/H2-76	09-May-99	7.15	229.7	325	<.1000	0.1129	0.0895	0.1428	68.36	<.0100	<.0200	0.0354	<.0100	<.0200	6.961	0.0643	26.23	<.0200	<.2000	193.7	<.0200	0.0468	0.1375
H1/H2-84	17-May-99	7.24	294.3	243	<.1000	<.0500	0.0747	0.154	72.17	<.0100	<.0200	0.044	<.0100	<.0200	6.461	0.0644	21.31	<.0200	<.2000	194.4	<.0200	<.0000	<.1000
H1/H2-92	25-May-99	7.19	235.2	220	<.1000	<.0500	0.0881	0.1469	68.49	0.0131	0.0212	0.0373	<.0100	<.0200	6.284	0.0604	17.17	<.0200	<.2000	193.5	0.0294	0.0005	<.1000
H1/H2-98	31-May-99	7.15	183.3	222	<.1000	0.2956	0.1096	0.123	58.61	<.0100	<.0200	<.0100	<.0100	0.0248	5.803	0.0459	16.06	<.0200	<.2000	188.4	0.0324	0.4152	0.1093
H1/H2-105	07-Jun-99	7.10	126.8	168	<.1000	<.0500	0.1662	0.0091	4.769	<.0100	<.0200	0.0188	<.0100	<.0200	6.607	0.0534	15.95	<.0200	<.2000	199.6	0.043	<.0000	<.1000
H1/H2-133	05-Jul-99	7.13	203.1	276	<.1000	<.0500	0.0829	0.1494	67.74	<.0100	<.0200	0.0109	<.0100	<.0200	6.355	0.0516	21.71	<.0200	<.2000	188.4	0.0303	0.1814	0.2105

Output from Column H1/ Input to Column H2

Sample I.D.	Date (mm/dd/yy)	S (mg L <sup>-1</sup> )	Se (mg L <sup>-1</sup> )	Si (mg L <sup>-1</sup> )	Sr (mg L <sup>-1</sup> )	Ti (mg L <sup>-1</sup> )	V (mg L <sup>-1</sup> )	Zn (mg L <sup>-1</sup> )	color		F (mg L <sup>-1</sup> )	Br (mg L <sup>-1</sup> )	Cl (mg L <sup>-1</sup> )	IC		HACH		PO4 (mg L <sup>-1</sup> )	SO4 (mg L <sup>-1</sup> )	U total (ug L <sup>-1</sup> )	
									NH4 (mg L <sup>-1</sup> )	NH4-N (mg L <sup>-1</sup> )				NO3 (mg L <sup>-1</sup> )	NO3-N (mg L <sup>-1</sup> )	NO2 (mg L <sup>-1</sup> )					
H1/H2-6	24-Feb-99	-	<.2000	7.308	0.2663	<.0100	0.0399	2.623													
H1/H2-11	01-Mar-99	-	0.3691	6.595	0.2747	<.0100	<.0200	1.771													<0.095
H1/H2-18	08-Mar-99	19.43	<.2000	7.808	0.4057	-	-	0.4956				<0.05	99.9	<0.05		<0.05	<0.10	50.1			<0.095
H1/H2-25	15-Mar-99	16.52	<.2000	7.367	0.4058	-	-	<.0100	< 0.03		0.11	<0.50	87	<0.25		<0.25	<0.50	39			<0.095
H1/H2-33	23-Mar-99	54.95	0.2471	7.395	0.349	-	-	<.0100	< 0.03		0.11	<0.50	87	<0.25		<0.25	<0.50	28			<0.095
H1/H2-39	29-Mar-99	54.48	<.2000	7.165	0.3175	-	-	<.0100													
H1/H2-46	06-Apr-99		<.2000	7.61	0.5844	-	-	<.0100	2.45	0.41		<0.05	82.2	132	4.6	7.6	<0.05	<0.1	51.1		<0.095
H1/H2-50	13-Apr-99	20.6	0.4025	8.023	0.7179	-	-	0.0112	0.82	0.22		<0.05	92.1	145	34.2	<0.05	<0.1	57.3			<0.095
H1/H2-59	21-Apr-99	19.88	<.2000	8.063	0.3905			0.1163	0.7	0.53		<0.05	92.8	144	34.64	<0.05	<0.1	53.6			<0.095
H1/H2-66	30-Apr-99	18.98	<.2000	1.01	0.0109			0.0217	0.75	0.56		<0.05	101	161	39.68	<0.05	<0.1	55.7			1.14
H1/H2-71	04-May-99	19.99	<.2000	8.235	0.3874			0.2306	0.65	0.66		<0.05	95.6	153	36.61	<0.05	<0.1	54.4			0.22
H1/H2-76	09-May-99	19.44	0.6804	7.908	0.5552			0.0204	<0.80	0.75		<0.05	90.5	245	68.25	1.11	<0.1	50.2			0.29
H1/H2-84	17-May-99	18.7	0.4187	7.958	0.6628			0.0388	<0.20			<0.05	77.5	235	2.02	<0.1	<0.1	48.6			0.26
H1/H2-92	25-May-99	18.43	0.7189	7.355	0.508			0.1061		0.873		<0.05	82.6	251	53.69	<0.05	<0.1	53.5			
H1/H2-98	31-May-99	17.32	<.2000	7.525	0.436			0.1189		0.9		<0.05	81.3	213	49	<0.05	<0.1	53.4			
H1/H2-105	07-Jun-99	18.03	<.2000	0.5613	0.0272			<.0100		0.205				225	51.1						
H1/H2-133	05-Jul-99	18.76	<.2000	7.827	0.6527			0.0463			<0.5	<0.1	94	226	51	1.17	<1.0	53			4.41

Output from Column H2

Column H2-OUT

Sample I.D.	Date (mm/dd/yy)	pH	Eh (Cor.) (mV)	Alkalinity (mg L <sup>-1</sup> CaCO <sub>3</sub> )	Al (mg L <sup>-1</sup> )	As (mg L <sup>-1</sup> )	B (mg L <sup>-1</sup> )	Ba (mg L <sup>-1</sup> )	Ca (mg L <sup>-1</sup> )	Cd (mg L <sup>-1</sup> )	Co (mg L <sup>-1</sup> )	Cr (mg L <sup>-1</sup> )	Cu (mg L <sup>-1</sup> )	Fe (mg L <sup>-1</sup> )	K (mg L <sup>-1</sup> )	Li (mg L <sup>-1</sup> )	Mg (mg L <sup>-1</sup> )	Mn (mg L <sup>-1</sup> )	Mo (mg L <sup>-1</sup> )	Na (mg L <sup>-1</sup> )	Ni (mg L <sup>-1</sup> )	P (mg L <sup>-1</sup> )
H2-6 OUT	25-Feb-99	6.16	-85.6	54	<.1000	<.0500	0.0278	0.081	75.06	<.0100	<.0200	0.0164	<.0100	0.7552	6.598	-	17.97	0.0857	<.2000	72.14	0.0489	-
H2-11 OUT	01-Mar-99	6.54	-15.2	91	<.1000	0.0534	0.2998	0.0868	49.76	<.0100	<.0200	0.0164	<.0100	3.355	8.737	-	11.16	2.367	<.2000	68.31	<.0200	-
H2-18 OUT	08-Mar-99	6.71	-284.3	68	<.1000	<.0500	0.293	0.0459	38.43	<.0100	<.0200	0.0171	<.0100	0.6203	7.401	0.0359	8.6	0.9449	<.2000	67.36	<.0200	0.0112
H2-25 OUT	15-Mar-99	7.05	-306.3	68	<.1000	0.2133	0.296	0.0381	31.85	0.0101	<.0200	0.0136	<.0100	0.1352	6.279	0.0321	8.109	0.5642	<.2000	65.02	<.0200	<.0000
H2-33 OUT	23-Mar-99	6.70	-42.2	47	<.1000	0.06	0.3172	0.035	22.96	<.0100	<.0200	<.0100	<.0100	0.0438	6.197	0.0391	6.458	0.3446	<.2000	65.11	<.0200	0.1872
H2-39 OUT	29-Mar-99	6.71	-306.4	31	<.1000	<.0500	0.3454	0.0244	15.86	<.0100	<.0200	<.0100	<.0100	0.0217	5.983	<.0000	4.228	0.2311	<.2000	63.54	<.0200	0.043
H2-46 OUT	06-Apr-99	7.08	118.8	50	<.1000	<.0500	0.3469	0.0269	19.08	<.0100	<.0200	<.0100	<.0100	0.056	6.512	0.0238	4.651	0.2749	<.2000	67.81	<.0200	0.0575
H2-51 OUT	13-Apr-99	10.29	42	237	<.1000	<.0500	0.6475	<.0050	1.046	<.0100	<.0200	<.0100	<.0100	<.0200	6.674	0.0187	0.1221	<.0200	<.2000	146.6	0.0338	0.405
H2-59 OUT	21-Apr-99	10.11	46.4	268	<.1000	<.0500	0.3555	<.0050	2.346	<.0100	<.0200	<.0100	<.0100	<.0200	6.147	0.0436	0.1728	<.0200	<.2000	154.4	0.0271	0.2617
H2-66 OUT	29-Apr-99	10.24	80.3	285	<.1000	0.1097	0.304	<.0050	2.262	<.0100	<.0200	<.0100	<.0100	<.0200	6.418	0.0432	0.1281	<.0200	<.2000	153.2	<.0200	0.2078
H2-71 OUT	04-May-99	10.35	77.5	283	<.5000	<.2500	0.2722	<.0250	2.148	<.0500	<.1000	<.0500	<.0500	<.1000	6.54	0.0884	<.1000	<.1000	<.1000	165.4	<.1000	0.9349
H2-77 OUT	09-May-99	10.35	139.7	262	<.1000	0.0583	0.2249	0.0067	2.097	<.0100	<.0200	<.0100	<.0100	<.0200	7.084	0.0624	0.1037	<.0200	<.2000	179.2	<.0200	0.0624
H2-84 OUT	17-May-99	10.65	186.3	351	<.1000	<.0500	0.1852	<.0050	1.087	<.0100	<.0200	<.0100	<.0100	<.0200	7.212	0.0586	0.0428	<.0200	<.2000	212	<.0200	0.1846
H2-92 OUT	25-May-99	9.94	187	347	<.1000	0.0527	0.34	0.009	4.398	<.0100	<.0200	<.0100	<.0100	<.0200	5.965	0.0416	2.048	<.0200	<.2000	186	<.0200	0.1533
H2-98 OUT	31-May-99	9.65	160.9	258	<.1000	0.1865	0.1539	0.0101	5.001	<.0100	<.0200	<.0100	<.0100	<.0200	7.473	0.0481	8.889	<.0200	<.2000	197.1	<.0200	0.134
H2-105 OUT	07-Jun-99	9.54	134.1	250	<.1000	<.0500	0.1662	0.0091	4.769	<.0100	<.0200	0.0188	<.0100	<.0200	6.607	0.0534	15.95	<.0200	<.2000	197.9	0.043	<.0000
H2-133 OUT	5-Jul-99	9.30	179	250	<.1000	<.0500	0.1806	<.0050	5.158	<.0100	<.0200	0.0187	<.0100	<.0200	6.481	0.0468	24.51	0.0299	<.2000	191.4	<.0200	0.1349

Output from Column H2

Column H2-OUT

Sample I.D.	Date (mm/dd/yy)	Pb (mg L <sup>-1</sup> )	S (mg L <sup>-1</sup> )	Se (mg L <sup>-1</sup> )	SI (mg L <sup>-1</sup> )	Sr (mg L <sup>-1</sup> )	Ti (mg L <sup>-1</sup> )	V (mg L <sup>-1</sup> )	Zn (mg L <sup>-1</sup> )	Color.		F (mg L <sup>-1</sup> )	Br (mg L <sup>-1</sup> )	Cl (mg L <sup>-1</sup> )	IC		HACH		PO4 (mg L <sup>-1</sup> )	SO4 (mg L <sup>-1</sup> )	U total (ug L <sup>-1</sup> )	
										NH4 (mg L <sup>-1</sup> )	NH4-N (mg L <sup>-1</sup> )				NO3 (mg L <sup>-1</sup> )	NO3-N (mg L <sup>-1</sup> )	NO2-N (mg L <sup>-1</sup> )					
H2-6 OUT	25-Feb-99	<.1000	-	<.2000	7.308	0.2912	<.0100	0.0399	2.623													<.095
H2-11 OUT	01-Mar-99	<.1000	-	0.2571	0.2545	0.2294	<.0100	0.0258	0.0144													0.241
H2-18 OUT	08-Mar-99	0.1298	22.49	<.2000	0.2869	0.1813	-	-	<.0100				<.05	93.6	<.05		<.05	<.10	68.3			<.095
H2-25 OUT	15-Mar-99	0.1332	20.3	0.2411	0.2619	0.1647	-	-	<.0100	0.08		0.09	0.50	87	<.25		<.25	<.50	55			<.095
H2-33 OUT	23-Mar-99	<.1000	16.58	<.2000	0.2402	0.1359	-	-	<.0100	0.03	<.00	0.44	<.50	89	<.25	0.619	<.25	<.50	43			
H2-39 OUT	29-Mar-99	<.1000	11.18	<.2000	0.2398	0.094	-	-	<.0100		<.00					0.76						
H2-46 OUT	06-Apr-99	0.206	7.984	0.3243	0.2913	0.1075	-	-	<.0100	<.4	<.00	-	<.05	103	<.05	0.82	<.05	<.1	16.4			0.526
H2-51 OUT	13-Apr-99	<.1000	38.05	0.2952	0.9452	<.0100	-	-	<.0100	32.2	<.00	-	<.05	95.5	<.05	1.35	<.05	<.1	63.8			0.526
H2-59 OUT	21-Apr-99	<.1000	24.78	0.2131	0.9238	0.0104	-	-	<.0100	31	1.88	-	<.05	95.4	0.46	1.68	<.05	<.1	57.9			0.526
H2-66 OUT	29-Apr-99	<.1000	18.96	<.2000	1.01	0.0109	-	-	0.0217	36.9	9.88	-	<.05	94.8	1.1	1.85	<.05	<.1	55.2			0.0342
H2-71 OUT	04-May-99	<.5000	20.62	<.1000	1.124	<.0500	-	-	<.0500	33.1	3.83	-	<.05	89.1	1.34	1.76	<.05	<.1	56.3			<.095
H2-77 OUT	09-May-99	0.1293	19.91	0.2683	1.02	0.0105	-	-	<.0100	32.9	1.74	-	<.05	94.2	6.97	4.01	<.05	<.1	56.6			0.0258
H2-84 OUT	17-May-99	0.1077	18.38	0.412	1.388	<.0100	-	-	<.0100	33.5	7.657	-	<.05	86.3	49.4	18.47	<.05	<.01	52.3			<.095
H2-92 OUT	25-May-99	<.1000	16.85	<.2000	0.6065	0.0251	-	-	<.0100		57.555	<.05	86.3	105	24.35	<.05	<.1	50.4				
H2-98 OUT	31-May-99	<.1000	18.05	<.2000	0.6402	0.0318	-	-	<.0100		39.112	<.05	82.3	130	31.44	<.05	<.1	53.6				
H2-105 OUT	07-Jun-99	<.1000	18.03	<.2000	0.5613	0.0272	-	-	<.0100		21.671	<.05	90	163	37.14	<.05	<.1	52				
H2-133 OUT	5-Jul-99	0.1424	17.49	<.2000	0.6009	0.0238	-	-	0.0137			<.50	<.1	97	164	<.5	<.10	49				<.095

Water Chemistry from Sample Ports: Column I

Sample Ports- Column I

Sample I.D.	Date / Time (mm/dd/yy)	pH	Eh(Cor) (mV)	Alkalinity (mg L-1 CaCO3)	Al (mg L-1)	As (mg L-1)	B (mg L-1)	Ba (mg L-1)	Ca (mg L-1)	Cd (mg L-1)	Co (mg L-1)	Cr (mg L-1)	Cu (mg L-1)	Fe (mg L-1)	K (mg L-1)	Li (mg L-1)	Mg (mg L-1)	Mn (mg L-1)	Mo (mg L-1)	Na (mg L-1)	Ni (mg L-1)	P (mg L-1)	Pb (mg L-1)
I-P2-107	JUNE9-99				<.1000	<.0500	0.0854	0.0987	45.14	<.0100	<.0200	0.0338	<.0100	0.2676	6.51	0.0592	18.13	0.0479	<.2000	198.5	0.0748	<.0000	<.1000
I-P2-134	JULY6-99	7.52	334.5	201	<.1000	<.0500	0.0917	0.1121	78.07	<.0100	<.0200	<.0100	<.0100	0.1426	6.262	0.0513	18.71	0.0364	<.2000	190.7	0.0369	0.3758	<.1000
I-P3-25	MAR16-99	7.27	220.4	179																			
I-P3-135	JULY7-99	7.69	316.4	207	<.1000	0.1431	0.0909	0.0806	76.57	<.0100	<.0200	<.0100	<.0100	0.0373	6.207	0.0486	18.53	0.0955	<.2000	192.2	<.0200	0.0091	0.1424
I-P4-136	JULY8-99	7.87	291.7	229	<.1000	0.0612	0.0916	0.0612	71.08	<.0100	<.0200	<.0100	<.0100	0.0356	5.944	0.049	17.54	0.1147	<.2000	180.4	<.0200	0.1891	0.1049
I-P5-137	JULY9-99	7.8	113.9	229	<.1000	<.0500	0.0846	0.0409	71.51	<.0100	<.0200	<.0100	<.0100	<.0200	6.17	0.0517	17.73	0.0956	<.2000	180.7	<.0200	0.1983	0.1093
I-P6-51	APR04-99	7.94	88.4	254																			
I-P6-66	APR29-99	8.23	120.1	223	<.1000	<.0500	0.1166	0.0438	43.09	<.0100	<.0200	0.0412	<.0100	0.0479	6.55	0.0519	16.43	0.0348	<.2000	161.6	<.0200	0.1522	<.1000
I-P6-137	JULY10-99	7.87	294.7	229	<.1000	0.1807	0.1003	0.0374	72.32	<.0100	<.0200	<.0100	<.0100	<.0200	6.937	0.0541	18.02	0.0807	<.2000	185.1	<.0200	0.1397	<.1000

Water Chemistry from Sample Ports: Column I

Sample Ports- Column I

Sample I.D.	Date / Time (mm/dd/yy)	S (mg L-1)	Se (mg L-1)	Si (mg L-1)	Sr (mg L-1)	Ti (mg L-1)	V (mg L-1)	Zn (mg L-1)	color		F (mg L-1)	Br (mg L-1)	Cl (mg L-1)	IC (mg L-1)	HACH		NO2 (mg L-1)	IC		PO4-P (mg L-1)	SO4 (mg L-1)	U total (ug L-1)	
									NH4 (mg L-1)	NH4-N (mg L-1)					NO3 (mg L-1)	NO3-N (mg L-1)		NO2-N (mg L-1)	NO2-N (mg L-1)				
I-P2-107	JUNE9-99	19.06	<.2000	6.515	0.4615			0.0646															
I-P2-134	JULY6-99	19.01	<.2000	7.065	0.5085			0.0743				<.05	89.4	301			<.05	<.05	<.10		53.9		
I-P3-25	MAR16-99																						
I-P3-135	JULY7-99	18.98	0.2352	6.463	0.5007			<.0100		0.1	<.5	90			<.25		<.25	<.5	<.10	44	52	16.6	0.282
I-P4-136	JULY8-99	18.83	<.2000	5.149	0.477			<.0100		0.94	<.10	110			59		<.5	<.10		52	410	3.14	
I-P5-137	JULY9-99	19.98	<.2000	4.276	0.5016			<.0100		0.79	<.10	100			55		<.5	<.10		53	53	1.19	
I-P6-51	APR04-99																						
I-P6-66	APR29-99	18.98	<.2000	2.328	0.3548			0.0124	4.84						40.7								
I-P6-137	JULY10-99	20.02	<.2000	3.744	0.485			<.0100			<.05	94.6	131				<.05				53	51	0.674
										1.2	<.10	92			48		<.5	<.10		51	51	0.483	

Water Chemistry from Sample Ports: Column H1

Column H1- Sample Ports

Sample I.D.	Date (mm/dd/yy)	pH	Eh (Cor.) (mV)	Alkalinity (mg L-1 CaCO3)	Al (mg L-1)	As (mg L-1)	B (mg L-1)	Ba (mg L-1)	Ca (mg L-1)	Cd (mg L-1)	Co (mg L-1)	Cr (mg L-1)	Cu (mg L-1)	Fe (mg L-1)	K (mg L-1)	Li (mg L-1)	Mg (mg L-1)	Mn (mg L-1)	Mo (mg L-1)	Na (mg L-1)	Ni (mg L-1)	P (mg L-1)	Pb (mg L-1)	S (mg L-1)
H1-P2-107	JUN09,99	7.28	157	254	<.1000	0.4555	0.0979	0.1107	40.09	<.0100	<.0200	<.0100	<.0100	<.0200	6.028	0.0489	18.27	<.0200	<.2000	204.2	0.0603	0.3474	<.1000	18.12
H1-P2-134	JUL 08,99	7.40	280.6	213	<.1000	0.109	0.1366	0.1532	78.63	<.0100	<.0200	<.0100	<.0100	<.0200	6.69	0.0496	18.97	<.0200	<.2000	185.4	<.0200	0.0946	<.1000	18.56
H1-P3-136	JUL 08,99	7.38	257.9	208	<.1000	0.0851	0.0949	0.1411	78.54	<.0100	<.0200	<.0100	<.0100	<.0200	6.272	0.0496	18.64	<.0200	<.2000	186.9	<.0200	0.2409	<.1000	18.99
H1-P4-25	MAR16,99	7.06	334.3	159																				
H1-P4-136	JUL 08,99	7.37	201.5	223	<.1000	0.051	0.0912	0.1418	76.08	<.0100	<.0200	<.0100	<.0100	<.0200	6.314	0.0484	18.17	<.0200	<.2000	181.3	<.0200	0.1688	<.1000	18.39
H1-P5-140	JUL 12,99	7.35	123.1	227	<.1000	0.1637	0.1145	0.1449	73.42	<.0100	<.0200	<.0100	<.0100	<.0200	6.063	0.05	17.63	<.0200	<.2000	184.1	<.0200	0.1508	0.1461	18.22
H1-P6-51	APR 13,99	7.32	81.2	221																				
H1-P6-68	APR 30,99	7.17	360.3	147	<.1000	<.0500	0.1318	0.1079	46.26	<.0100	<.0200	0.0339	<.0100	<.0200	6.491	0.0494	17.62	<.0200	<.2000	171.7	<.0200	0.1123	<.1000	20.13
H1-P7-143	JUL 15,99	7.38	346.1	247	<.1000	0.15	0.1277	0.1518	72.56	<.0100	<.0200	<.0100	<.0100	<.0200	6.372	0.0533	17.81	<.0200	<.2000	190.5	<.0200	0.1036	0.1318	19.18

Water Chemistry from Sample Ports: Column H1

Column H1- Sample Ports

Sample I.D.	Date (mm/dd/yy)	Se (mg L-1)	Si (mg L-1)	Sr (mg L-1)	Ti (mg L-1)	V (mg L-1)	Zn (mg L-1)	color		F (mg L-1)	Br (mg L-1)	Cl (mg L-1)	IC		HACH		SO4 (mg L-1)	U total (ug L-1)
								NH4 (mg L-1)	NH4-N (mg L-1)				NO3 (mg L-1)	NO3-N (mg L-1)	NO2-N (mg L-1)	PO4-P (mg L-1)		
H1-P2-107	JUN09,99	<.2000	7.805	0.4713			0.2636				<1.0	85.0	303				53.7	
H1-P2-134	JUL 08,99	<.2000	7.631	0.5061			<.0100		<0.5	<1.0	86			59	<0.50	<1.0	49	222
H1-P3-136	JUL 08,99	<.2000	7.635	0.5077			0.0167		0.79	<1.0	94			63	<0.50	<1.0	53	260
H1-P4-25	MAR16,99								0.09	<0.5	89			<0.25	<0.25	<0.5	48	0.0787
H1-P4-136	JUL 08,99	<.2000	7.381	0.5028			<.0100		0.76	<1.0	94			63	<0.50	<1.0	53	268
H1-P5-140	JUL 12,99	<.2000	7.591	0.4919			0.011		<0.5	<1.0	89			58	<0.50	<1.0	50	243
H1-P6-51	APR 13,99																	
H1-P6-66	APR 30,99	<.2000	8.605	0.4238			0.0129	<.040			<1.0	91.1	195		<0.50	<1.0	52.7	1.93
H1-P7-143	JUL 15,99	<.2000	7.723	0.4902			0.0138		<0.5	<1.0	94			60	<0.50	<1.0	50	199