Title: Optimization of Bioreactor Cell Design for Treating Low-Flow Acid Mine Drainage in the Midwest: Model Development and Demonstration

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Abstract

A sulfate-reducing bioreactor cell (SRBC) was installed at the Midwestern reclamation site in Pike County, Indiana, to treat acid mine drainage (AMD) issuing from a nearby underground mine. Flow and rainfall monitoring instruments were installed to determine the SRBC's water budget and a network of pipes and water-sampling ports were strategically placed within the SRBC in order to collect water-chemistry data from a three-dimensional array. The parameters pH, temperature, specific conductivity, dissolved oxygen, and redox potential were measured in the field. Water samples were analyzed for alkalinity, acidity, dissolved sulfide, chemical oxygen demand, calcium, magnesium, iron, manganese, sodium, potassium, aluminum, sulfate, chloride, nitrate and orthophosphate. Total dissolved carbon and dissolved organic carbon were analyzed for some sampling events. Additional water from selected sampling ports was collected for stable sulfur-isotope analyses for both sulfide and sulfate. In addition to the above parameters, water samples at the inflow and outflow points of the SRBC were analyzed for ammonia, total dissolved solids, total suspended solids, and the trace elements of arsenic, cadmium, chromium, copper, lead, mercury, nickel, and selenium. The sampling schedule began in January2009 and is ongoing.

AMD discharge from the underground mine alone was insufficient to maintain the water level in the SRBC, primarily because of leakage at the base of the SRBC's earthen retaining dam. Additional recharge occurred by surface drainage through a preexisting ditch which intermittently had high-volume flows associated with snow melt and heavy rainfall, especially at times of high soil-saturation. Flow within the SRBC was primarily across the surface of the completely submerged substrate to a discharge pipe at the shallow end. A smaller amount of flow occurred within the SRBC's substrate, through and around the network of water-sampling pipes at the SRBC's base. The greatest amount of sulfate reduction occurred within zones of minimal flow in the deepest layers of the SRBC, creating pockets of highly reduced water where nearly complete sulfate reduction had occurred (average of 93 percent). This contrasted with the SRBC's discharge, which over a 7-month period averaged an approximately 50-percent reduction in sulfate concentration, compared with the average value of the AMD discharge from the mine. Analyses of stable sulfur isotopes of sulfate indicate that the inflow from the AMD discharge and that from the watershed drainage differed by approximately 3 parts per mil (-6.5 parts per mil, versus -9.8 parts per mil), so that it is possible to distinguish the two sources. The sulfur isotopic signature for the SRBC's discharge was initially intermediate between the two sources during winter and spring (-8.0 parts per mil), which indicates mixing, but as the temperature increased and discharge decreased through summer, the isotopic signature of the SRBC's discharge became heavier than either source (-2.0 parts per mil), indicating that bacterial fractionation was playing an important role.

The results of the study demonstrate that internal chemical monitoring can be used to identify zones of low flow and low levels of microbial activity. Sulfur-isotope data indicated where and when mixing of source waters occurred, and the extent to which bacterial reduction of sulfate occurred, based on the degree of fractionation in the remaining sulfate.

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INTRODUCTION

Acidic-mine drainage (AMD) derived from coal mining has been a detriment to the environment of Indiana since the 1800's. Reclaiming abandoned mine lands (AMLs) that have been discharging AMD is the responsibility of the Indiana Department of Natural Resources Division of Reclamation (IDNR-DOR). The IDNR-DOR has used a variety of methods to treat AMD but emphasis has been placed on the use of passive treatments that require minimal ongoing maintenance. Biotechnology can play an important role in sustaining such systems so that maintenance is seldom required. Constructed wetlands have become the most widely used passive treatments for AMD, but their use can be limited by the availability of land, and the quality and quantity of AMD at discharge sites. In situations where constructed wetlands are not feasible, other methods have been developed. Recently, greater use has been made of sulfate-reducing bioreactor cells (SRBC). This method combines the sulfate-reducing abilities of bacteria characteristic of anaerobic wetlands , with in situ chemical neutralization of the active acidity (pH) of AMD characteristic of anoxic limestone drains (ALD)(Hedin et al., 1994). This blending of biological and chemical treatments is being employed to improve AMD from low-flow, highly acidic seeps and springs in locations with insufficient areas to construct wetlands.

Anaerobic wetlands work adequately where there is sufficient area and water to allow for attenuation of the AMD through various mechanisms of precipitation, dilution, and sorption, without overloading the treatment system. A strong reducing environment develops within the wetland when pH values rise above 5, which is necessary for the appropriate bacteria to thrive (Jong and Parry, 2006). Initially, aerobic bacteria deplete the dissolved oxygen within the water as they decompose the organic substrate within the wetland. Sulfate-reducing bacteria thrive in areas where there is no available oxygen needed for metabolizing organic substrate by extracting it from an abundant sulfate concentration derived from metal sulfide oxidation at AMD sites. By combining the organic substrate components of a wetland with the neutralizing ability of an ALD, an SRBC is capable of neutralizing acidity and developing microbial growth in a compact setting, making it ideal for treating small discharges in difficult terrain.

A typical SRBC is composed of an organic substrate containing labile organic compounds that promote rapid, initial microbial development, and other organic components that decompose more slowly in order to sustain the microbial colonies over longer periods. Blended with this substrate is an acid neutralizing material, as well as decomposition-resistant materials that provide a framework so that the substrate does not compact as reactive components are depleted. The resulting blend is typically called a limestone buffered organic substrate (LBOS) (Thomas and Romanek, 2002).

The series of chemical and biochemical reactions that occurs within an SRBC begins with acid neutralization at the point where AMD enters the cell. This allows the pH to rise above 5 so that aerobic bacteria can become established just beyond the neutralization front in the cell. These microbes deplete the neutralized water of dissolved oxygen. The oxygen-deficient water, containing sulfate, continues to move through the organic-rich substrate, where anaerobic bacteria begin to grow by extracting oxygen from the sulfate to initiate the metabolic process. The resulting sulfide-rich water reacts with metals to precipitate as metal sulfides within the reactor. Simultaneously, alkalinity is developed through the neutralization of acidity by dissolution of a carbonate source and microbial-controlled oxidation of organic matter, generating a higher partial pressure of CO_2 which allows for the additional dissolution of carbonate material to form bicarbonate alkalinity. Additional alkalinity is generated in the anoxic zone from the bacterial reduction of sulfate coupled with organic compound degradation which produces

sulfide and bicarbonate (Hedin et al., 1994). Another source of alkalinity early in the life span of an SRBC is derived from water soluble organic complexes leached from the organic substrate providing noncarbonate alkalinity. As a result high levels of total alkalinity are generated within the bioreactor and discharged at the outflow point. As AMD advances through the SRBC both a pH and redox front develop, corresponding to the depletion of acid neutralizing material and organic substrate, respectively. When metal-rich, acid sulfate water is discharged from the cell, the reactive materials are spent and replenishment is necessary.

The construction of an SRBC takes in to consideration the available land for cell placement and the contaminant loadings of the AMD stream when sufficient land is available to afford various size options. The goal of providing long-term water quality improvements in a SRBC is dependent on the contaminant loading which influences the rate at which components are consumed during the neutralization/ reduction processes. If possible, sufficient size to achieve a life-span of 15 to 20 years is considered an optimal design criterion. Simple lifespan calculations have been determined using the daily acidity loading and the amount of carbonate material such as limestone needed in the reactor to neutralize the acidity. The size of the cell can be estimated based on the percent of limestone, in the blend of materials used in a SRBC, needed to neutralize a specified quantity of acidity for a given period of time. The homogenized mixture is then placed in an excavated cell designed to hold the determined amount of blended materials and, depending on the terrain, is fitted with plumbing features designed to maximize the flow distribution within the cell.

The problem with estimating the size and life-span of a SRBC based on the amount of acid-neutralization material is that there are factors that can cause these estimates to be off significantly. One error comes from the assumption that all of the acid-neutralization material is utilized in the acid-neutralizing process. The solubility of limestone, the most economic material used for this purpose, increases as the partial pressure of CO_2 increases, which is a naturally occurring phenomenon in decomposing organic rich substrates such as compost. This limestone dissolution reaction introduces an additional rate-dependent calculation component in determining the longevity of a SRBC. Another important factor in determining the potential lifespan of a SRBC is the uniformity of flow through the cell. If preferential flow patterns develop then much of the neutralizing material and reducing substrate will not be utilized, resulting in a reduced lifespan of the cell. These problems are addressed with this project by monitoring the hydrologic budget, determining chemical loadings and discharges, and installing an internal water sampling network (not previously conducted on this scale) in order to develop a three dimensional view of the internal reactions occurring over an extended period of time. These data-collecting methods and activities will provide the elements necessary to understand the complex internal interactions within a SRBC and provide much needed insight for the future design and construction of SRBCs for agencies and companies engaged in exploring options for treating AMD from small, acidic springs and seeps. The ultimate objective of our study of SRB cells is to amass sufficient data to develop a predictive model for determining the size, design and composition criteria necessary to achieve a specified longevity for a constructed SRBC. Such a product will provide increased economic benefits in the arena of treating AMD.

EXECUTIVE SUMMARY

Since the 1980s, a series of passive techniques have been developed to chemically and (or) biologically treat acidic mine drainage (AMD). These include aerobic wetlands, anaerobic wetlands, anoxic limestone drains (ALDs), vertical flow ponds (VFPs), successive alkaline producing systems (SAPS), and, most recently, permeable membrane barriers and sulfate-reducing bioreactor cells (SRBCs). Factors affecting the selection and implementation of these various methods include the flow and chemical character of the AMD that is being treated. Of particular chemical importance are pH, dissolved oxygen, oxidation-reduction potential, sulfate, iron speciation, and aluminum. Outflows of AMD that are characterized by exceptionally high acidity and low pH are especially challenging for most of the passive methods listed above. SRBCs have shown promise for treating low flows of such AMD, including those with exceptionally high concentrations of sulfate, iron, and aluminum. Also, SRBCs may be suitable in high-relief terrain and (or) where the area available for installation of the treatment system is relatively small. An SRBC is composed of an organic substrate, blended with an acid neutralizing material, as well as decomposition-resistant materials that provide an uncompressible framework.

Acid neutralization commences at the point where AMD enters the cell, allowing the pH to rise so that aerobic bacteria can become established. These microbes deplete the neutralized water of dissolved oxygen. The oxygen-deficient water, containing sulfate, continues to move through the substrate, where anaerobic bacteria begin to grow. The resulting sulfide-rich water reacts with metals to precipitate as metal sulfides. Simultaneously, alkalinity is developed through the neutralization of acidity by dissolution of a carbonate source (limestone) and microbial-controlled oxidation of organic matter. This generates a higher partial pressure of CO_2 which allows for the additional dissolution of carbonate material to form bicarbonate alkalinity. High levels of total alkalinity are generated and discharged at the outflow point. As AMD advances through the SRBC, both pH and redox fronts develop, corresponding to the depletion of acid neutralizing material and organic substrate, respectively. When metal-rich, acid sulfate water is discharged from the cell, the reactive materials are spent and replenishment is necessary.

If possible, a life-span of 15 to 20 years is considered an optimal design criterion for passive treatment systems. However, it is difficult to predict the lifespan of an SRBC, because such predictions are currently based on simple calculations of limestone dissolution due to acid neutralization. No methods have yet been developed to take into account the affect of the complex biologically driven reactions on the outflow, nor whether preferential flow patterns that might develop within a cell could reduce its lifespan.

Prior to reclamation, the Midwestern Mine Site (MMS) in south-central Indiana was discharging large quantities of AMD with high concentrations of dissolved metals into a tributary of the Patoka River. A variety of AMD sources were treated by the Indiana Department of Natural Resources, Division of Reclamation, using a variety of reclamation methods. In 2008, an SRBC was installed to capture and treat flow from a spring that issues from flooded underground mine workings. The SRBC consists of a trench that is approximately 400 feet long and 40 feet wide, and is filled with a mixture of straw, wood chips, compost, and crushed limestone. The depth of the trench varies from 7 feet at the inflow to less than 3 feet at the outflow. It was designed to handle an average flow of 30 gpm.

In order to address the questions related to internal biologically driven reactions and preferential flow paths, a three-dimensional network of interconnected pipes and sampling ports were installed as the

SRBC was being constructed. Water samples were initially collected on a biweekly schedule, and later on a monthly schedule, and analyzed for physical chemistry and isotopic analysis of sulfate and sulfide sulfur. Interpretation of the results was complicated by several aspects of the SRBC's design, including intermittent inflows of surface drainage unrelated to the AMD spring, the SRBC's geometry, and a volume of fill material that was insufficient to prevent free flow of AMD across the SRBC's surface. Also, some leakage was observed at the base of the impounding berm, which complicated calculation of the SRBC's water budget.

Sulfate concentrations in samples collected from the three-dimensional array of sampling ports indicated where the biological activity was occurring within the SRBC. Because of preferential flow across the surface of the SRBC, sharply defined acid-neutralization or redox fronts did not develop, and internal flow through the matrix was correspondingly reduced. Nevertheless, patterns of sulfate concentrations that were observed within the SRBC indicated that the most significant sulfate reduction occurred in the deepest portion of the thickest part of the cell, closest to the inflow. The amount of sulfate reduction decreased toward the outflow. Furthermore, precipitation of ferrous sulfide was incomplete toward the outflow. Based on the sulfate observations, the lifespan of the portion of the SRBC proximal to the inflow will be significantly longer than the distal portions, which may become depleted in a relatively short time, thereby reducing the SRBC's overall lifespan.

An unanticipated result of internal monitoring of the SRBC was an observation of high concentrations of potassium and chloride in the most reduced pockets of the bioreactor cell. Although the chemical cause of this correlation is not understood, observations of high potassium and chloride might serve as additional evidence for depletion of the organic substrate. Furthermore, based on sulfur-isotope analyses, we observed the development of an anaerobic bacteria front. By observing the migration of such a front, predictions of an SRBC's lifespan can be further refined. Thus, the three-dimensional array of sampling ports, combined with sulfur-isotope analyses as well as physical chemistry, was successful in providing indication of where flow and stagnation were occurring, with implications for predicting the SRBC's lifespan.

Based on our experience with this investigation, we can make several suggestions regarding the direction of future research on the design and performance of SRBCs:
(1) Although measurement of carbon isotopes was not included in this investigation, studies of C^{13} isotopes associated with bicarbonate alkalinity might yield important data regarding the rates and progression of limestone depletion, and possibly depletion of the organic substrate.
(2) Studies of patterns of ferrous sulfide precipitation need to be conducted to determine why precipitation is not complete within the SRBC, thereby allowing passage of this acid-generating and oxygen-depleting species into the discharge water.
(3) Studies of potassium and chloride within the reduced zone of the SRBC need to be conducted to determine the sources of these elements, which has implications regarding the differential depletion of various components of the substrate.

EXPERIMENTAL

Bioreactor Construction and Instrumentation

In 2008, a sulfate-reducing bioreactor cell was installed to capture and treat low-flow AMD springs that issue from the flooded workings of the Hartwell No. 2 Mine (Figure 1).

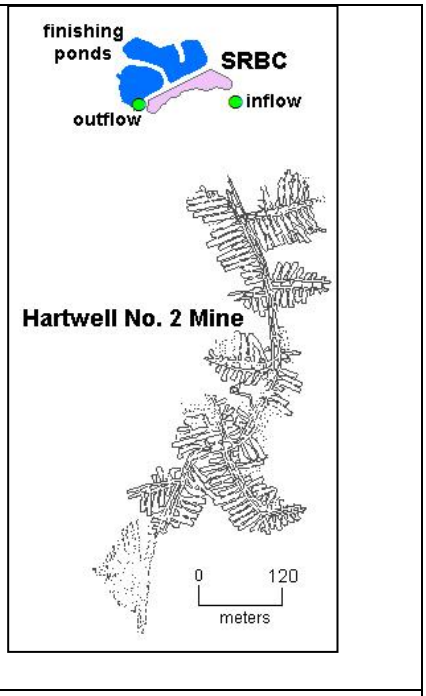

Figure 1. Map showing location of sulfate-reducing bioreactor cell relative to underground mine source of AMD.

Prior to construction, baseline information was collected from continuous flow monitoring of the seep and chemical analyses collected on a monthly basis from June, 2007 to November, 2007. These data were provided to the engineers at the IDNR-DOR to use in determining the size of the cell.

The cell, designed to handle an average flow of 30 gpm, consists of a trench that is approximately 400 feet long and 40 feet wide, and is filled with a mixture of straw (50 percent by volume), wood chips (30 percent), garden compost (10 percent), and crushed limestone (10 percent). The trench is about 7 feet deep at the north end where the AMD enters at the surface, but less than 3 feet deep at the south end, where the treated water discharges into an adjacent finishing pond (Figure 2).

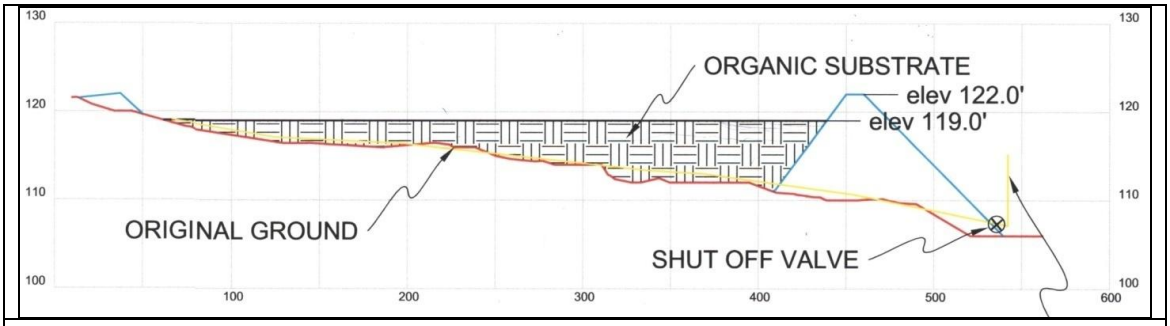

Figure 2. Cross sectional view of bioreactor, with outflow on the left and inflow on the right. Pipe network at the base of the cell is shown in yellow with the drain and shutoff valve used during construction and filling, extending to the right.

A pipe network was placed at the base of the reactor, containing 4 inch, perforated PVC pipe with a shutoff drain connected at the down dip location of the pipe near the AMD inflow, and an outlet connected at the opposite end of the cell in the up dip direction (Figure 3).

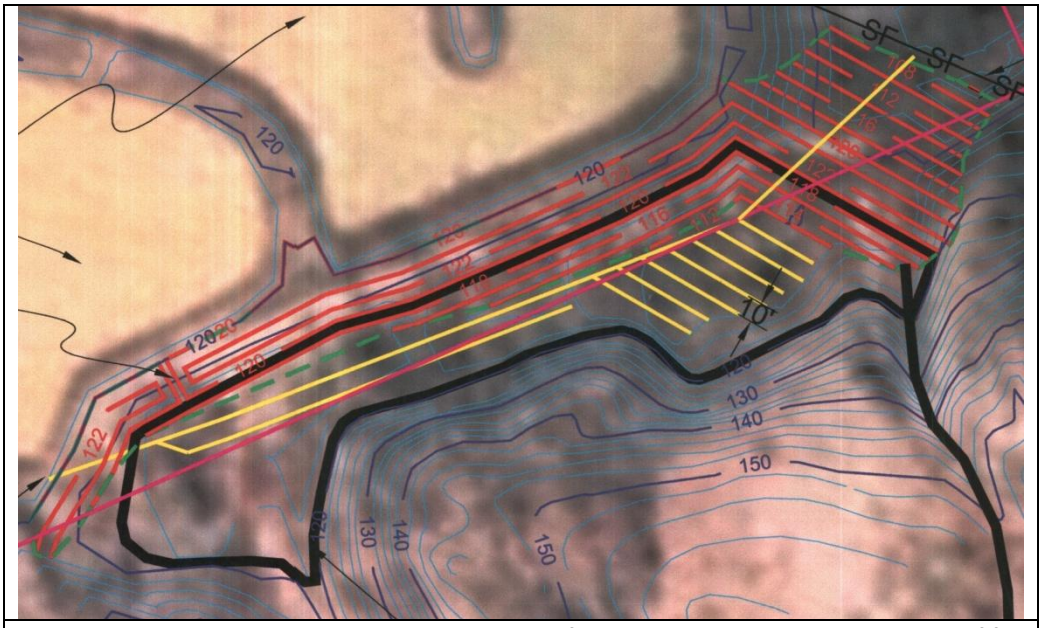

Figure 3. Map showing PVC pipe network in base of bioreactor shown in yellow. Extent of fill material is outlined in black.

The shutoff valve was installed for the purpose of draining the seep during the construction and fill phase of the bioreactor and was closed after completion.

Twelve (12) sampling ports were incorporated into the pipe network at the base of the SRBC. These samplers consist of 4”x4” “tees” fitted with a threaded ½” compression adapter (Figure 4). An additional

26 isolated sampling ports were installed at the same time the cell was filled with the reactive substrate. The isolated ports consist of a 1”x1”x½” “tee” with an eight inch long piece of 1” slotted PVC well screen (with capped ends) inserted on either side and a threaded compression fitting (Figure 4).

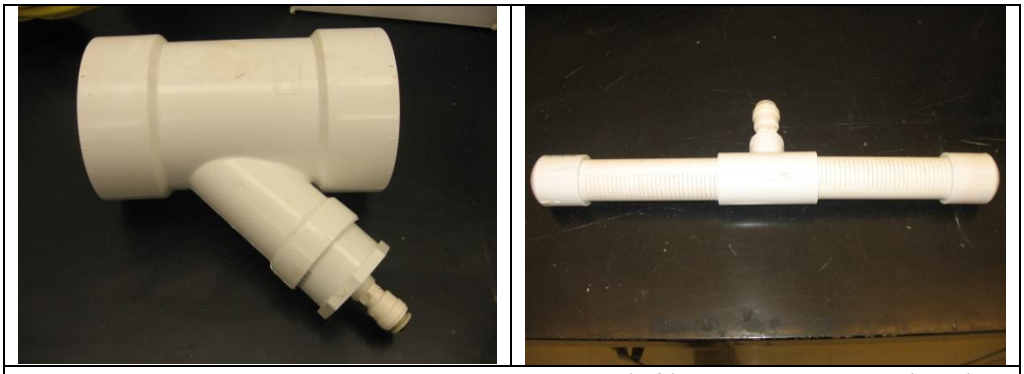

Figure 4. Photographs showing pipe network sampler (left), and matrix sampler (right).

The internal sampling ports were distributed throughout the cell and at varying depths so as to observe three-dimensional trends in activity occurring within the system (Figures 5 and 6).

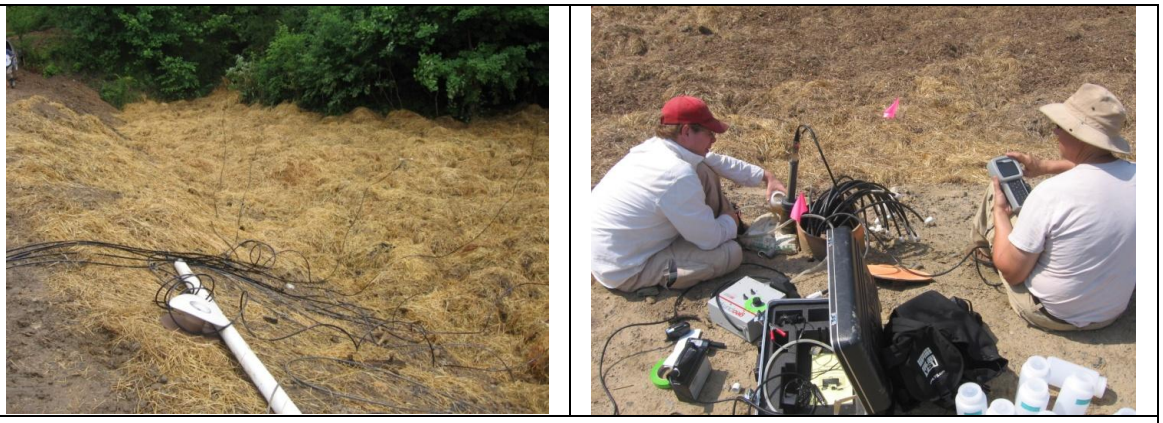

Figure 5. Photographs showing sample-port tubing network and distribution of samplers and tubing (left), and lockbox for containing tubing with connectors that attach to sampling equipment (right).

At the northeast end of the SRBC, where the LBOS is thicker, samplers were placed approximately three feet above the pipe network (“mid-level” in Figure 6). “Shallow” samplers were placed within two feet of the surface of the LBOS throughout the rest of the SRBC (Figure 6). To ease the sample collection process, tubing for each of the samplers is routed to one of four lockboxes along the edge of the bioreactor.

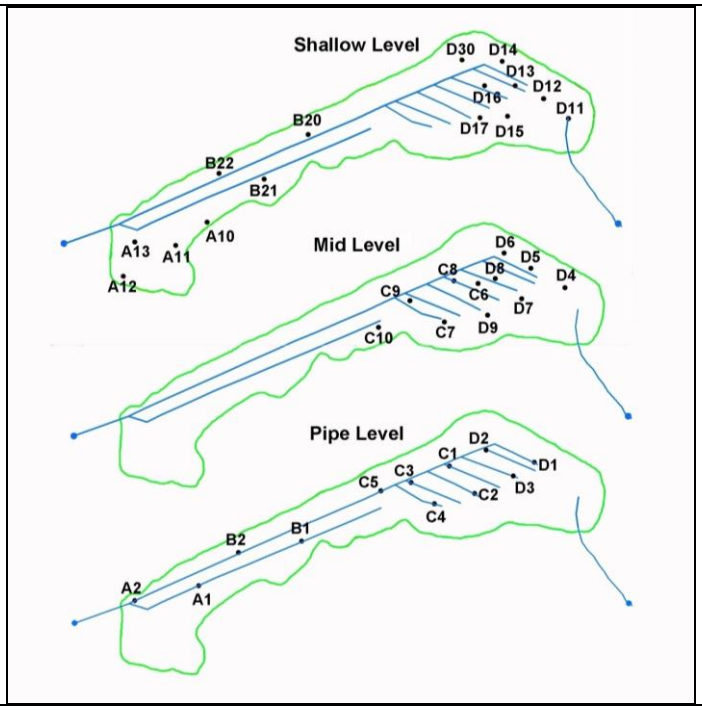

Figure 6. Maps showing sampler locations within bioreactor cell. Mid level samplers were only installed at the deeper end of the cell where sufficient depth allowed for three levels of samplers to be emplaced. AMD seep flows in at the right, discharge is to the left.

Hydrologic Monitoring

A v-notch weir was installed downstream of the AMD seep in order to establish a water budget for the system and observe seasonal variations in AMD loading rates prior to the water entering the SRBC. A solar-powered data logger located adjacent to the weir is equipped with a pressure transducer (for measuring continuous flow through the weir), a specific conductance/temperature sensor, and a rain gauge. Measurements are made every hour and stored as the daily average (daily total for the rain gauge). The outlet of the SRBC is equipped with a sensor that measures the flow rate and temperature of the water leaving the system.

Water Chemistry Sampling

Samples collected at the weir flow-monitoring station for untreated seep water and at the cell outflow pipe were obtained using the grab sample method. Field data collected from these two sites were obtained by submerging a YSI Multiparameter sonde into the stream of water and recording data on a YSI 650 MDS display/logging unit. Water samples and field data collected from the sampling ports located within the cell were obtained by using a peristaltic pump connected to a flow-thru cell in which the sonde was placed and field parameters monitored. When temperature and conductivity parameters stabilized field data were recorded and samples collected in 1L bottles and placed in a portable refrigerator for transport back to the lab where they were filtered, separated into aliquots for various analyses and preserved per standard protocol. Commencing in May, 2009 unfiltered sample aliquots for iron and sulfide analyses were collected in the field, preserved with HCl and NaOH respectively, and placed in refrigeration for transportation.

Isotope Sampling

Samples for sulfur isotopic analysis were collected in a separate 250ml bottle pretreated with $CdCl_2$ (to preserve dissolved sulfide) according to the procedure described by Clark and Fritz (1997). The samples were prepared for analysis following the method outlined by Carmody *et al.* (1998). Sulfur isotopes were measured on a Finnigan MAT 252 mass spectrometer equipped with an elemental analyzer in the Indiana University Department of Geological Sciences.

Water Chemistry Analysis

The most important parameters monitored for AMD are typically sulfate, iron, aluminum and manganese. In addition, pH, acidity, alkalinity and temperature are considered important parameters to measure the success of AMD treatment systems. To determine the effectiveness of the SRBC constructed at the Midwestern site, the following parameters listed in table 1 were monitored for all sampling locations.

Table 4. Chemical parameters determined for all water samples.

Field parameters	Wet lab parameters	Titrations	Ion Chromatography	Inductively Coupled Plasma
Temperature	Acid-volatile sulfide	Alkalinity	Chloride	Calcium
Specific Conductivity	Chemical Oxygen Demand	Acidity	Nitrate	Magnesium
pH		Ferrous Iron	Ortho Phosphate	Total Iron
Dissolved Oxygen			Sulfate	Manganese
Oxidation-Reduction Potential				Aluminum
				Potassium
				Sodium

A more extensive array of parameters was analyzed for the inflow and outflow for the SRBC. In addition to those listed in table 1 above, the parameters listed in table 2 below were determined for inflow and outflow water samples.

Table 5. Chemical parameters determined for inflow and outflow samples (AMD seep, watershed drainage, bioreactor cell discharge).

Wet lab parameters	Graphite Furnace Atomic Absorbance
Total suspended solids	Antimony
Total dissolved solids	Arsenic
Ammonia nitrogen (outflow only)	Cadmium
	Chromium
	Copper
	Lead
	Mercury
	Molybdenum
	Nickel
	Selenium

The sampling schedule was designed to monitor more frequently the areas within the cell closest to where water entered the cell. The frequency of sampling was placed on a two week schedule but subject to inclement weather conditions. When a second recharge point from the overland runoff was discovered to have a major impact on the recharge rate of the cell, the number of frequently sampled monitoring points was expanded to include the sampling ports closest to this source of recharge. In

addition, samples collected from this recharge point were subjected to the more complete analysis performed on AMD seep inflow and SRB cell outflow samples.

RESULTS AND DISCUSSION

Traditional monitoring methods

The traditional way to evaluate a field scale AMD treatment project is to compare changes in water quality between the inflow and outflow of a treatment system. The hydrologic and chemical data is typically employed to determine the mass changes that have occurred within a system and predictions on the lifespan of the system are calculated. For the SRBC at the Midwestern reclamation site, an attempt was made to calculate the differences in chemical components. One complication encountered was due to the multiple recharge points entering the cell. The result was a discharge flow much greater than the AMD seep entering the cell during periods of high and frequent precipitation (Figure 7).

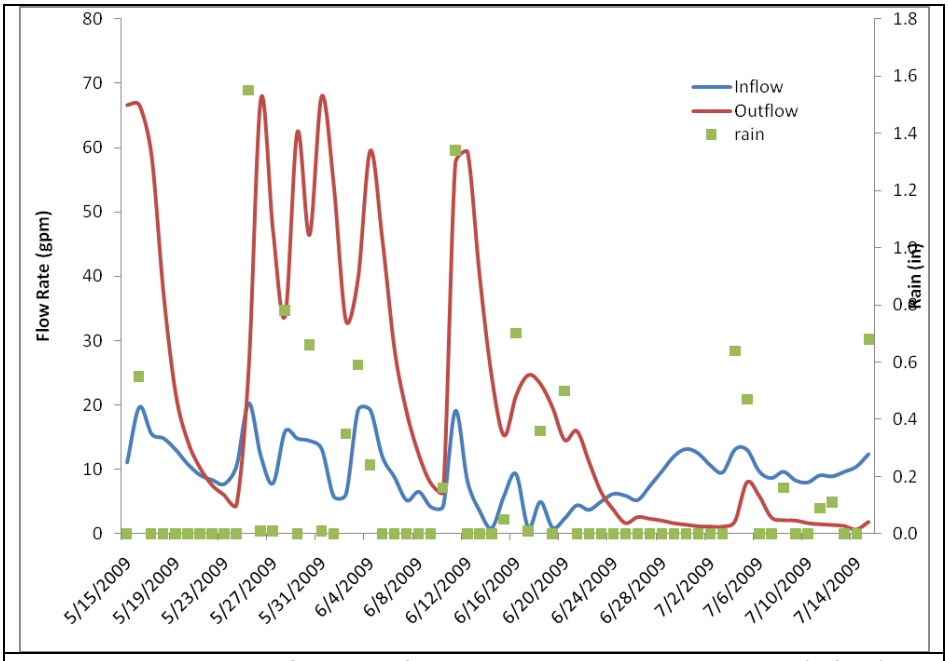

Figure 7. Graph showing flow rates for AMD seep being treated by SRBC (Inflow) and the discharge from the SRBC (Outflow) along with rainfall amounts and times.

The ability to calculate the chemical loading of the bioreactor was hampered by a lack of flow measurements from a watershed drainage ditch despite efforts to install a flow monitoring station. The magnitude of overland flow during periods of heavy rainfall was sufficient to modify the flow path of runoff within the drainage ditch, allowing recharge water to repeatedly circumvent the temporary flow monitoring installation. Because the SRBC leaked, its discharge sometimes decreased to volumes that were less than the AMD's inflow rate, and there was often no discharge during extended periods without any rainfall (Figure 7). In spite of these shortcomings an attempt was made to quantify the changes occurring due to the loading differences between the inflow and outflow of the cell. Table 3 summarizes the data collected from January through July, 2009 for the AMD seep, watershed drainage into the SRBC, and the SRBC discharge. Because fluctuations in flow were greater for the SRBC discharge than the AMD seep, the average difference was attributed to the watershed runoff into the SRBC for illustration purposes. The data indicates that there is a net increase in alkalinity, and net reductions for acidity, and corresponding components contributing to acidity: iron and aluminum. There is also a net loss of sulfate, attributed primarily to sulfate reduction. However, a net loss of calcium suggests that some of the sulfate may have been fixed as gypsum within the bioreactor, in an area of the cell beyond the pH neutralization boundary where excess calcium would have been mobilized as limestone

dissolution neutralized the AMD. Simple calculations designed to predict the longevity of the SRBC can be made from limestone depletion based on acid neutralization. By calculating the amount of acidity contributed by ferric iron, aluminum, and hydrogen ion (from pH) on a daily basis derived from the average component concentrations and daily flow, a prediction of 18 kg/day or 8 lbs/day of limestone is being consumed through acid neutralization. This assumes that all of the alkalinity needed for neutralizing the AMD is derived from limestone, and none from sulfate reduction, which generates alkalinity through the following example reaction mechanism:

$$SO_4^{-2} + 2CH_2O \rightarrow S^{-2} + 2HCO_3^- + 2H^+ \quad (1)$$

In order for biological sulfate reduction to proceed, a minimum of pH 5 must first be attained, indicating that neutralization must first occur, supporting the supposition that limestone is the source of the initial acid neutralization of the seep as it enters the bioreactor cell. However, in addition to AMD neutralization, limestone can be dissolved under conditions of increased partial pressure of CO_2 gas, which leads to the formation of carbonic acid, H_2CO_3 through the sulfate-reducing reaction above and the following generalized organic matter oxidation reaction:

$$CH_2O + O_2 \rightarrow HCO_3^- + H^+ \quad (2)$$

The H^+ generated in the dissociation of carbonic acid to bicarbonate initiates the dissolution of limestone as defined in the following two reactions:

$$2H^+ + CaCO_3 = Ca^{+2} + H_2CO_3 \quad (3)$$

$$H_2CO_3 + CaCO_3 = Ca^{+2} + 2HCO_3^- \quad (4)$$

The net effect of these reactions is the generation of excess alkalinity which discharges from the bioreactor (Table 3), some of which is derived from bacterial oxidation of organic matter, and the remainder from the dissolution of limestone. The loss of limestone in the reducing zone of the SRBC from reactions (3) and (4) leads to the reduction of available limestone in the cell for acid-neutralization as the neutralization front advances through the SRBC. This would add to the 18 kg/day loss of limestone within the cell, decreasing the life expectancy of the bioreactor even more than the acid-consuming rate predicts. However, without being able to quantify the contributions of the biological conversion of organic carbon to bicarbonate through reactions (1) and (2) above, it is not possible to determine how much additional limestone is dissolved through reactions (3) and (4).

Table 6. Average loadings of chemical components into and out of the SRBC based on chemical concentrations and average daily flow rates.

Monitoring Site	Average daily flow rate (gpm)	Alkalinity kg/day	Acidity kg/day	SO4 kg/day	Ca kg/day	Fe(II) kg/day	Fe(III) kg/day	Al kg/day
AMD Seep	8.6	0	23	121	21	2.4	3.9	0.5
Watershed	10.0	5	4	79	20	1.9	0.0	0.0
Total daily input		5	27	200	41	4.4	3.9	0.5

SRBC Outflow	18.6	39	3	124	32	1.4	0.0	0.0
Removed daily			24	76	9	3.0	3.9	0.5

Evaluation of internal data from SRBC

The data collected from the sampling ports distributed throughout the SRBC (Figure 6) provide a better picture of how the AMD flow is moving through the bioreactor cell and where the reactions described above are actually occurring. Internally collected samples indicate where the biological activity is occurring within the cell as depicted in Figures 8-9 which show the seasonal changes within the pipe network at the base of the bioreactor and the shallow sub-surface of the bioreactor for sulfate concentration ranges. Sulfate was chosen because it is the most significantly impacted component due to biological activity within the cell, showing where biologically-induced sulfate-reducing zones are more prevalent. The patterns indicate that the most significant sulfate reduction is occurring where the LBOS is thickest in the bioreactor, characterized by the lowest sulfate concentrations. In both the pipe network at the base of the bioreactor and within the shallow subsurface (<1 ft) where the LBOS is thickest, sulfate concentrations are lower when compared to their counterparts in the thinner regions of the bioreactor, respectively, inferring possible correlations between flow patterns and subsequent residence times within certain areas of the bioreactor. Similarly, throughout the cell, the pipe level in general demonstrates a greater degree of sulfate reduction than the shallow zone. A possible explanation for this could be the flow of sulfate-rich AMD downward through the thick layer of LBOS, allowing for sufficient time to reduce sulfate prior to entering the basal pipe network. If the main flow path in the cell were through the pipe network, then there should be no increase in sulfate as sampling proceeds towards the discharge point in the pipe network. Sulfate concentrations were actually observed to increase within the pipe system moving away from the AMD source when compared to the lowest sulfate concentration zone in the pipe network near the inflow (Figure 8) suggesting flow is more complex with an apparent higher sulfate source infiltrating into the pipe network at the shallower end of the cell near the discharge point.

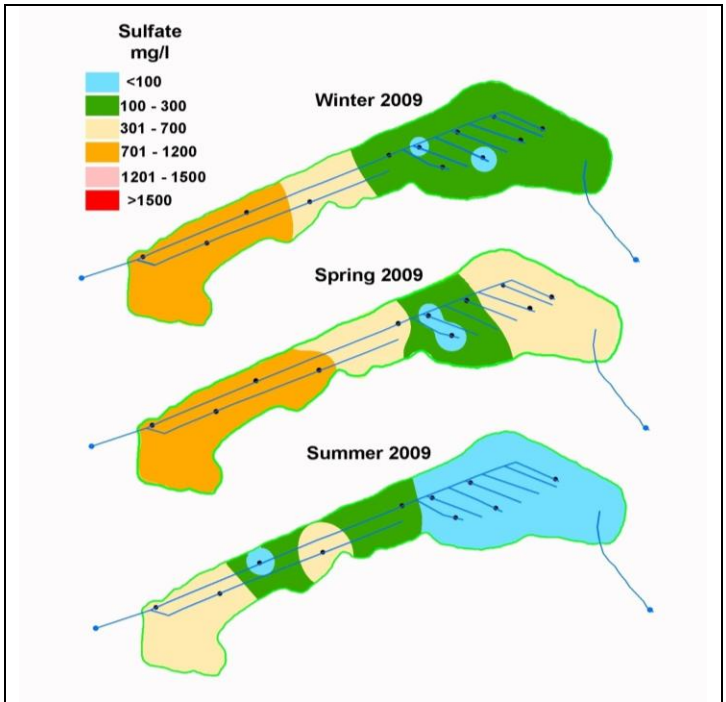

Figure 8. Maps showing sulfate concentration pattern for pipe

network samplers at base of bioreactor. Low concentrations indicate areas where rate of sulfate reduction is highest. Acid seep enters at right side of figure; discharge from cell is to the left.

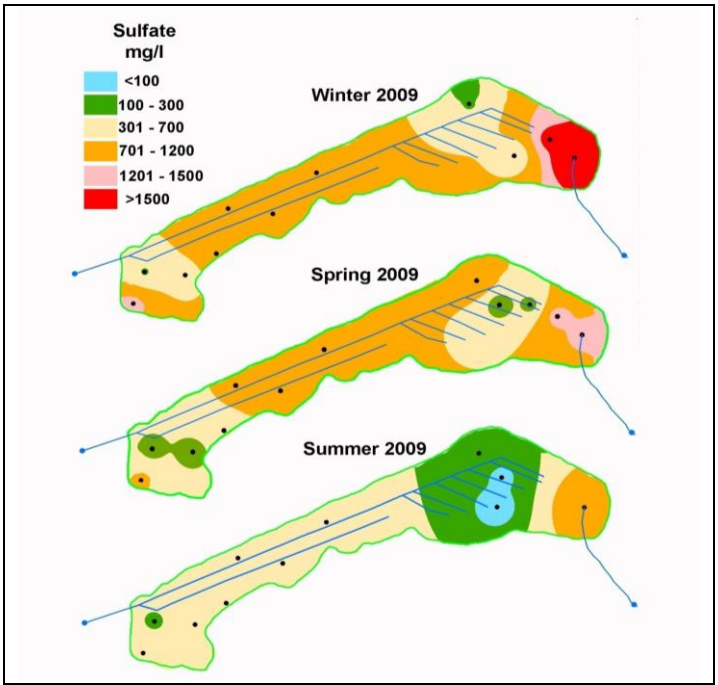

Figure 9. Maps showing sulfate concentration pattern for shallow samplers in bioreactor. Highest concentration zone in each season is where acid seep enters the bioreactor cell at the right side of the figure.

The general presence of higher sulfate concentrations in the shallow zone compared to the pipe level in the bioreactor cell along the entire length of the bioreactor is attributed to insufficient LBOS within the cell, allowing complete submergence of the LBOS material beneath a shallow depth of water that flows across the top of the bioreactor. This surficial water enters the drainage system closer to the discharge point, where the perforated pipe network lies under a thin veneer of LBOS of approximately 1 to 2 ft. Documentation of chemical alterations occurring in this surficial water component above the SRBC was performed by collecting data at two surface points in the cell, one close to the AMD seep inflow near shallow sampler D30 (labeled Surface 2 in Appendix D), the other closer to the cell discharge point near shallow sampler B22 (labeled Surface 1 in Appendix D). Figure 10 illustrates changes in pH from the monitoring point closer to the outflow, Surface 1, from the monitoring point closer to the inflow, Surface 2. The higher pH values for surface water closer to the outflow are attributed to inflow from the watershed drainage that feeds into the SRBC near this point during periods of high surface runoff. Both surface water monitoring points experience an increase in pH when there is no discharge from the cell, suggesting a diffusive interaction with the shallow zone LBOS throughout the SRBC.

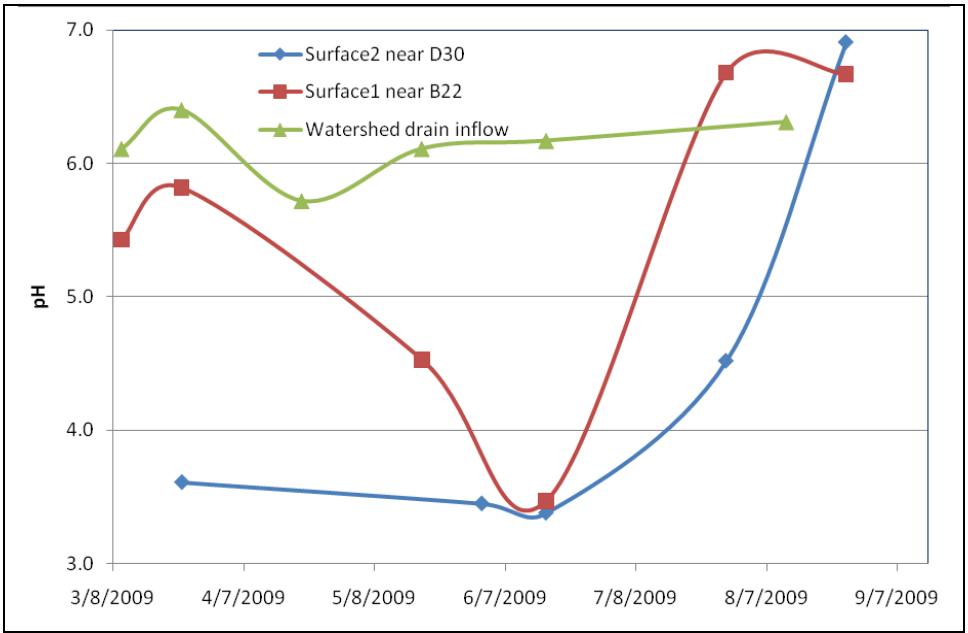

Figure 10. Graph showing comparison of surface water pH within bioreactor cell between the surface recharge from a watershed drain near the discharge of the cell, a point close to the bioreactor discharge (Surface1 near B22) and one near the AMD inflow (Surface2 near D30).

The occurrence of higher concentrations of sulfate in both the pipe level and shallow zone samplers down gradient from the AMD seep inflow can be explained by the influence of the watershed drainage that intersects the bioreactor cell between the shallow samplers labeled A10 and A11 and near pipe level sampler A1 (figure 6). A comparison of the AMD inflow, watershed drainage inflow, and SRBC discharge over an extended period of time illustrates how the sulfate concentration of the SRBC discharge closely follows that of the watershed inflow (Figure 11.).

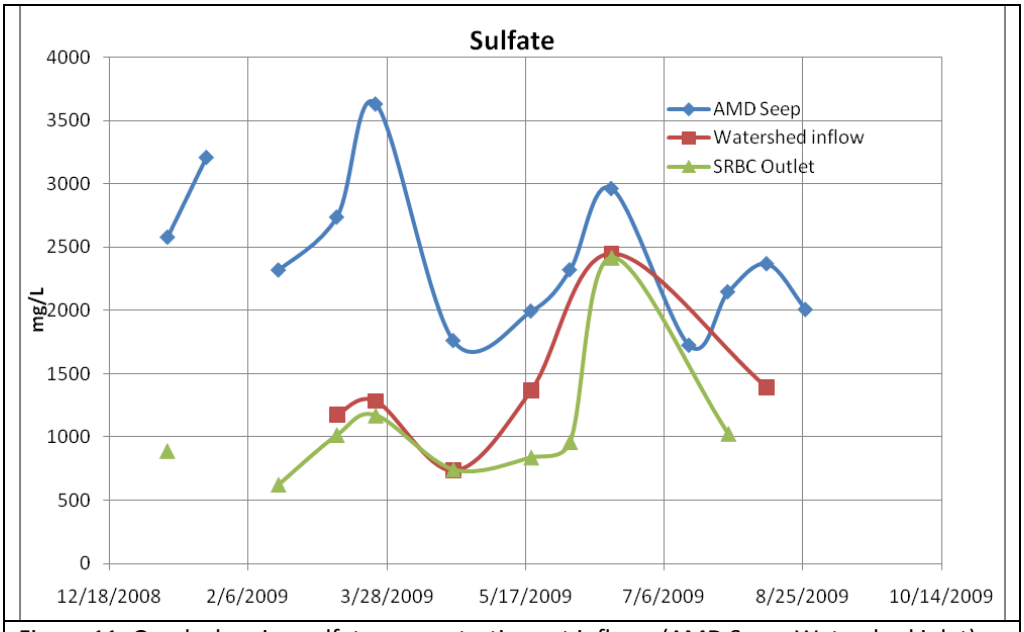

Figure 11. Graph showing sulfate concentrations at inflows (AMD Seep, Watershed inlet)

and outflow of SRBC.

This data reinforces the concept of additional sulfate being added to the SRBC from another source down gradient from the AMD seep inflow point into the bioreactor, closer to the discharge point as indicated from the internal monitoring network data in figures 8-9. Determining the extent of the watershed drainage influence on sulfate being discharged from the SRBC is further elaborated on in the sulfur isotopes section below.

Another goal of installing the sampling ports throughout the SRBC is to be able to identify the development of a neutralization front within the SRBC as limestone is depleted. Field data collected from the SRBC monitoring ports so far has not revealed a developing neutralization front within the bioreactor during the monitoring period. Even the port closest to the AMD inflow has yet to display a decrease in that would indicate a loss of neutralization material (Figure 12).

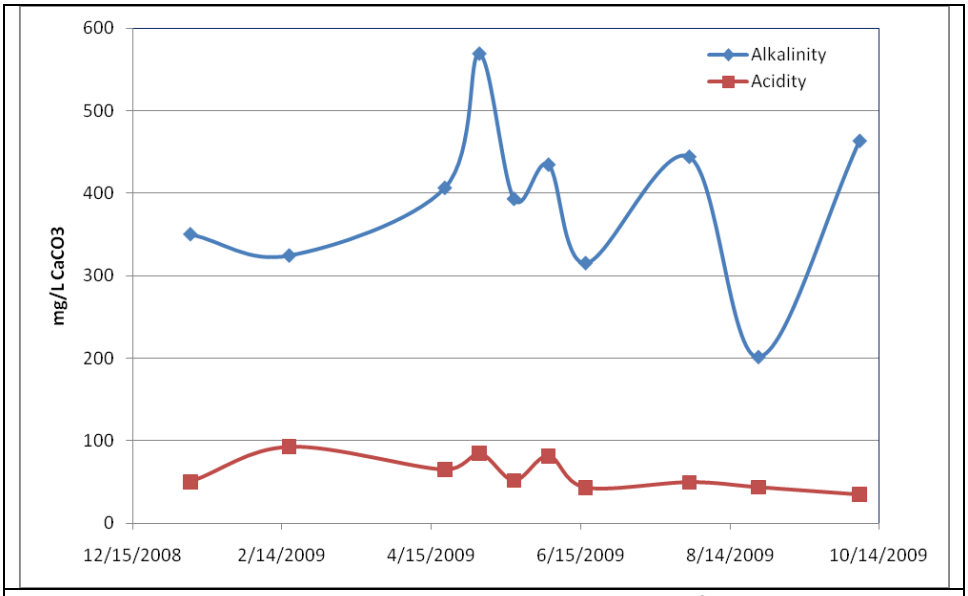

Figure 12. Graph showing alkalinity and acidity concentrations for the sampling port closest to the AMD inflow, port D11, showing no increase in acidity nor consistent decrease in alkalinity, which would be evidence for a depletion front developing in the bioreactor for acid-neutralization material.

It is possible that due to the size of this SRBC relative to the inflow rate of AMD, a defined pH boundary may not develop, but rather be more diffuse in nature. Another possibility can be attributed to the inundation of the LBOS within the cell that allows AMD to flow over the surface. The effect of this flow pattern is that a sharp boundary would not likely develop as the AMD is not concentrated in a small area of the cell but be rather extends across a broader area as it flows over and infiltrates into the LBOS at many points.

An unexpected result of installing the internal sampling ports within the SRBC is the observation of high concentrations of potassium and chloride in the most reduced pockets of the bioreactor cell. The highest concentrations for both potassium and chloride were obtained from the sampling ports within the thickest zone of LBOS closest to the AMD inflow (D series, Figure 6) as shown in Figure 13.

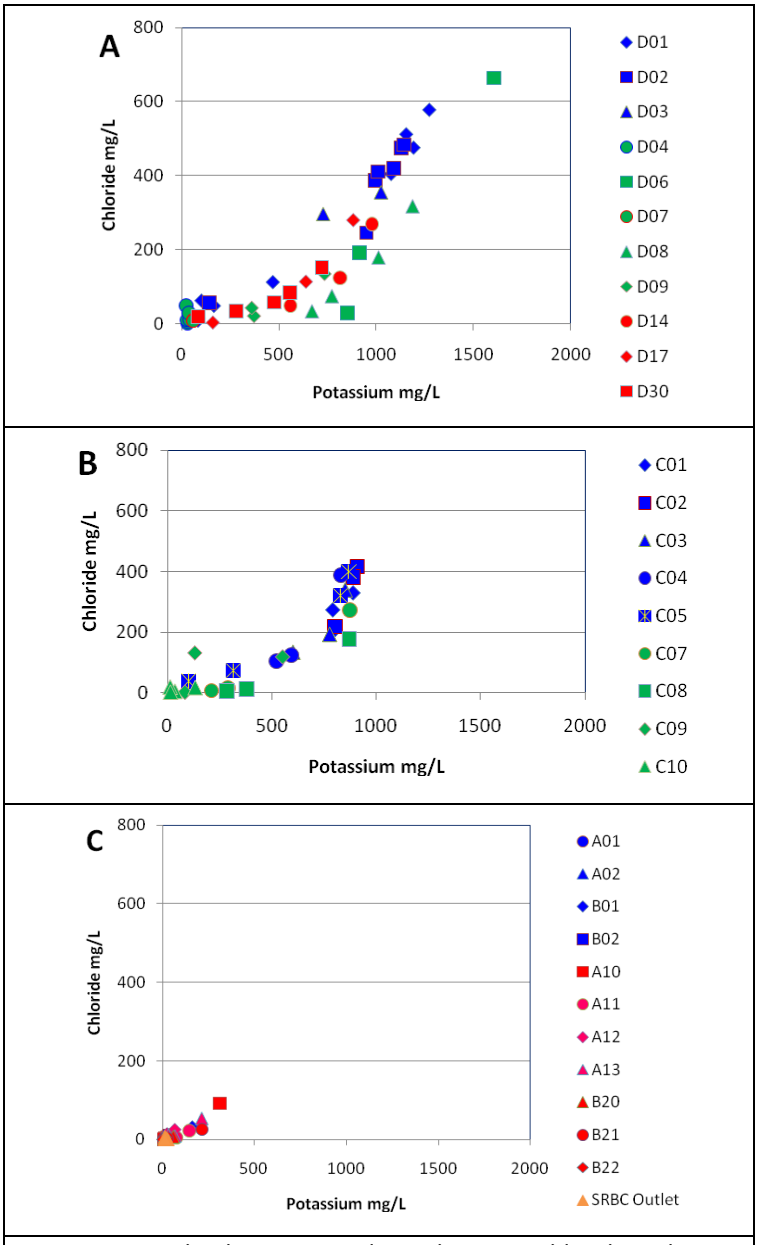

Figure 13. Graphs showing correlation between chloride and potassium for (A) the “D” series of samplers near the AMD inflow; (B) the “C” series of samplers further away from the AMD inflow; and (C) the "A" and "B" series of samplers in the shallowest part of the SRBC near the outflow.

The trend in the “D” and “C” series is towards more consistent higher concentrations in the pipe samplers at the base of the SRBC, indicated by blue in figures 13A-B, respectively, and more frequent lower concentrations obtained from the midlevel samplers (green) and shallow samplers (red). The overall trend is for the highest concentrations of potassium and chloride to occur in the thickest part of the LBOS in the bioreactor and much lower concentrations occurring in both pipe level and shallow samplers near the outflow. Samples from the SRBC outflow contain very little of either potassium or

chloride (Figure 13C). Because such high concentrations are found in the pipe network in the deepest part of the cell near the AMD inflow, and very low concentrations in the pipe near the outflow as well as at the outflow, the implication is that very little water flow is occurring in the pipe network. This then suggests that flow stagnation is prevalent in the deepest part of the cell. The source of chloride and potassium is unknown without conducting analyses of the materials comprising the LBOS, which is beyond the scope of this research project. The correlation of high potassium and chloride in general with the most reducing areas within the SRBC as indicated by sulfate concentrations (Figures 7-8), suggest that the source for these components may very well be the organic substrate that is decomposed through bacterial action. Should this prove to be true, then internally monitoring changes in the concentration of these components may indicate when the organic substrate is being decomposed by bacterial action and when substrate depletion occurrs.

Sulfur isotope studies

Bacterial sulfate reduction combines the oxidation of an available carbon source (CH_2O) with the reduction of sulfate (SO_4^{-2}) as an electron acceptor in a dissimilatory reaction (energy is generated but the sulfur is not incorporated into the cell):

$$2CH_2O + SO_4^{-2} \rightarrow 2HCO_3^- + H_2S \qquad (5)$$

In this reaction, sulfate containing "lighter" sulfur (^{32}S) will be converted to sulfide more readily compared to sulfate comprised of the "heavier" sulfur (^{34}S) due to the fact that the ^{32}S-oxygen bonds are easier to break apart. The result of this preferential use is that the residual sulfate (*i.e.* the sulfate not yet consumed in the reaction) will be enriched in ^{34}S and the sulfide that is generated will be depleted in ^{34}S relative to the isotopic composition of the original sulfate.

Sulfur isotope values are reported in delta (δ) notation relative to the Vienna Canyon Diablo Troilite (VCDT) international standard and have units of parts per thousand or permil (‰):

$$\delta^{34}S_{\text{sample}} = \left\{ \frac{\left(\frac{^{34}S}{^{32}S}\right)_{sample}}{\left(\frac{^{34}S}{^{32}S}\right)_{VCDT}} - 1 \right\} \times 1000‰$$

In order to determine what process is controlling observed decreases in sulfate concentrations during remediation efforts, the difference between $\delta^{34}S$ of sulfate in the untreated AMD compared to the $\delta^{34}S$ of sulfate present in a sample can be used:

$$\Delta^{34}S = \delta^{34}S_{sample} - \delta^{34}S_{AMD}$$

Both biotic (bacterial sulfate reduction) and abiotic (mineral precipitation) reactions are capable of lowering sulfate concentrations yet the effect on the sulfur isotopes are unique to each process. For example, the precipitation of gypsum ($CaSO_4 \bullet 2H_2O$), an abiotic process, imparts a very small depletion in the residual sulfate ($\Delta^{34}S$ = ~-4‰). In contrast, bacterial sulfate reduction results in a significant enrichment of the residual sulfate ($\Delta^{34}S$ = >+20‰) (Clark and Fritz, 1997). For the purposes of this study only $\delta^{34}S_{sulfate}$ were measured and positive $\Delta^{34}S$ values indicate a significant influence by bacterial sulfate reduction with the magnitude of the value directly proportional to the degree of reduction.

$\delta^{34}S$ of AMD sources

The AMD coming from the seep, as measured at the weir, has a very consistent $\delta^{34}S$ that averages to -6.5 (±0.3) ‰. The sulfate in the water entering the SRBC from the watershed, as described above, has a significantly more depleted $\delta^{34}S$ value of -9.8 (±0.2) ‰. These values reflect different environments and/or rates of formation for the sulfate in the two waters (Figure 14).

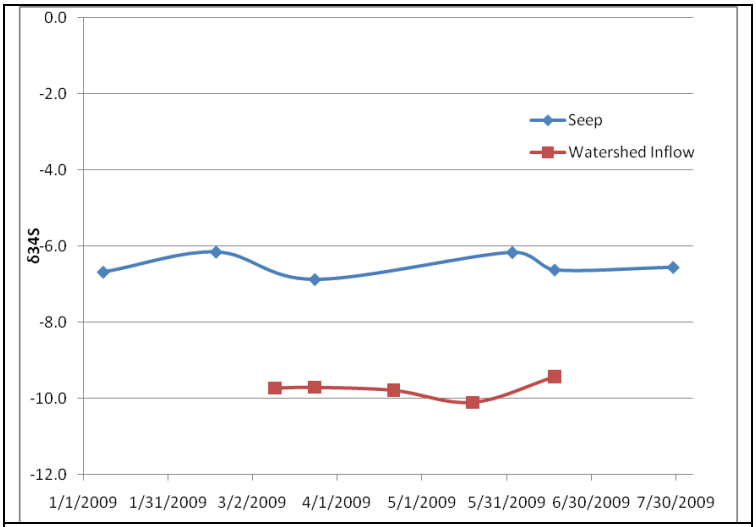

Figure 14. Graph showing isotope ratios of sulfate-sulfur for AMD seep and watershed drainage that flow into the SRBC cell.

$\delta^{34}S$ of SRBC outflow

In contrast to the consistency observed in the waters entering the SRBC, the outflow water has had a wide range of $\delta^{34}S_{sulfate}$ values, as shown in figure 15.

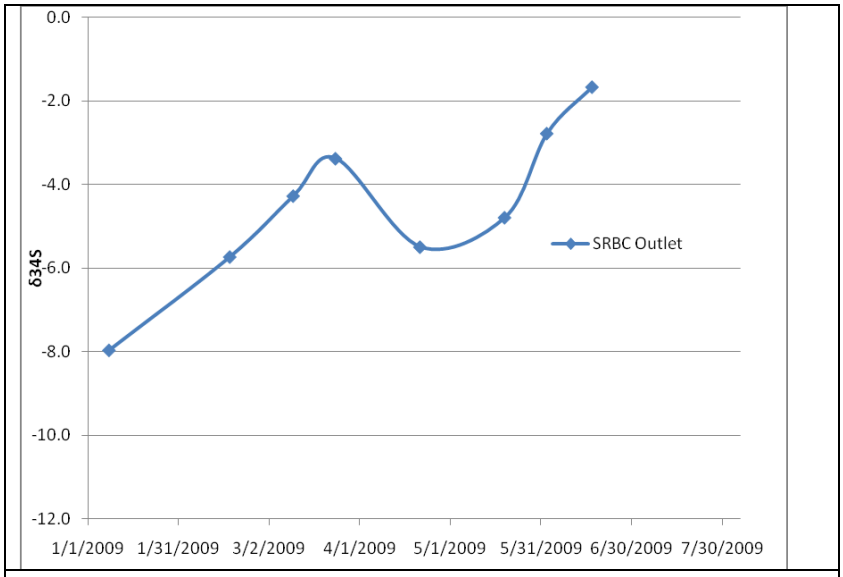

Figure 15. Graph showing isotope ratios of sulfate-sulfur for SRBC outflow.

The depleted values in the early stages of the SRBC indicate that the outflow water was dominated by flow coming from the watershed. Conversely, the most recent sample shows little or no influence from

the watershed. The trend from more depleted $\delta^{34}S_{sulfate}$ values (-8.0‰) to more enriched values (-2.0‰) corresponds well with the observed decrease in flow rate measured at the outlet, reflecting a diminished input of sulfate to the SRBC from the watershed and a probable increase in sulfate reduction bioactivity as the discharge rate decreases.

$\delta^{34}S$ inside the SRBC-Winter

Sulfur isotope data from the first sampling event after the SRBC filled (January 8th, 2009) show that bacterial sulfate reduction is occurring but not in a uniform manner throughout the system.
Areas near the AMD input at the eastern end of the cell have similar $\delta^{34}S$ values compared to the AMD. Port locations D11 and D12 (Figure 6), for example, have low $\Delta^{34}S$ values (0.2‰ and 0.7‰, respectively). These small differences in $\delta^{34}S$ coupled with a decrease in the sulfate concentrations (relative to the AMD source) indicate that bacterial sulfate reduction in combination with gypsum precipitation are controlling the sulfate concentration.

In contrast, samples collected from ports C10 and D15 (further from the AMD source, figure 6) have higher $\Delta^{34}S$ values (6.6‰ and 20.8‰, respectively) indicating bacterial sulfate reduction is primarily responsible for the lower sulfate concentrations in these areas.
Interestingly, the sample collected from the SRBC outlet provided a $\delta^{34}S$ value of -8.0‰ and a $\Delta^{34}S$ of -1.3‰ relative to the AMD input. In this case, the sample is likely comprised of water from the watershed input (with an average $\delta^{34}S$ value of -9.7‰) resulting in a much more reasonable $\Delta^{34}S$ of 1.7‰. Again, this low value represents a minimal influence of bacterial sulfate reduction.

$\delta^{34}S$ inside the SRBC-Spring

Samples were collected from the western part of the SRBC for the first time on March 10th, 2009. Monitoring ports in the vicinity of the watershed inflow have low $\delta^{34}S$ values, ranging from -8.4‰ at A10 to -2.9‰ at A12, suggesting a minimal amount of bacterial sulfate reduction. The sample collected at A11, on the other hand, is relatively enriched with a $\delta^{34}S$ of 13.5‰ ($\Delta^{34}S_{A11\text{-}WS}$ of 23.2‰) that indicates the observed decrease in sulfate concentration, from 1319 mg/L in the watershed inflow down to 605 mg/L in the sample, is likely a result of bacterial sulfate reduction.

Further to the East, samples were also collected from a transition zone between the shallow west side of the SRBC and the deeper east end. All but one of these samples are depleted with $\delta^{34}S$ values ranging from -5.0‰ at B22 to -1.0‰ at B20. Again, this represents a low level of bacterial sulfate reduction in these areas. The sample collected from B1 is enriched with a $\delta^{34}S$ of 6.1‰ ($\Delta^{34}S_{B1\text{-}WS}$ of 15.8‰) indicating bacterial sulfate reduction is likely the dominant sulfate removal process in that area.

Three samples were also collected from mid-level ports in the eastern end of the SRBC on March 24th 2009. Two of these samples (D15 and D13) show an influence of bacterial sulfate reduction given that they are enriched relative to the AMD source (3.1‰ and 16.0‰ compared to -6.9‰). The other sample, collected at a port (C10) on the western "edge" of the deep part of the SRBC, shows a moderate amount of enrichment (-0.7‰) as the result of a small degree of bacterial sulfate reduction.

Two additional samples collected on April 21st 2009 show an interesting contrast in reaction environments at the eastern end of the SRBC. One of the samples was collected from the deepest portion of the cell from port D1 (in the pipe network). This sample had a highly enriched $\delta^{34}S$ value of 35.7‰ and a resulting $\Delta^{34}S_{D1\text{-}AMD}$ of 42.2‰ again signifying a high degree of bacterial sulfate reduction. In contrast, a sample collected near the AMD input (D11) has a low $\delta^{34}S$ value (-5.2‰) and a small $\Delta^{34}S_{D11\text{-}AMD}$ of 1.3‰, similar to what was described for this location in the winter sampling events.

$\delta^{34}S$ inside the SRBC-Summer

Samples were collected from the SRBC, mainly from the eastern deep end, on June 2nd and 17th 2009. Similar to the observations noted for the winter and spring events, samples collected from monitoring ports D11 and D12, near the AMD input, have low $\delta^{34}S$ (-1.6‰ and -1.3‰, respectively) suggesting low bacterial activity in these areas. Further into the cell, however, numerous mid-level sampling locations showed very high levels of bacterial sulfate reduction as evidenced by enriched $\delta^{34}S$ values ranging from 8.2‰ at D8 to 51.8‰ at port D9 (the highest yet observed within the SRBC).

Six samples also were collected from the shallow western end of the cell. At this time, all of the shallow locations, 4 of the samples, show some degree of influence by bacterial sulfate reduction (3.3‰ at A13 to 17.4‰ at A10). The two sampling ports in the pipe network, A1 and A2, have lower $\delta^{34}S$ values (-1.8‰ and -0.8‰, respectively) indicating less influence by bacterial sulfate reduction.

Sulfate isotope summary

The general trend of sulfur isotope data collected from the inflows, outflows and internal monitoring ports indicates that when discharge occurs from the SRBC, bacterial sulfate reduction is most prevalent in deep sampling ports from the thickest LBOS layer such as observed in port D1, and in shallower ports that may very well lie outside of the main flow path of AMD across the surface and through the substrate such as occurs at D13, D15, and A11. When little or no discharge occurs from the cell, the reduction of sulfate appears to be more widespread. The lack of significant bacterial sulfate reduction at shallow collection ports near the AMD inflow suggests that even though an acid neutralization front has not been observed to be developing in the cell, there appears to be a bacterial activity boundary that can be seen near the AMD inflow. The continued monitoring of an expanding front for minimal bacterial sulfate reduction as well as the development of an acid-neutralization depletion front will be critical in determining the rate of sulfate-reducing substrate relative to acid-neutralizing substrate and ultimately predicting the lifespan of the SRBC.

CONCLUSIONS

The advantage of internally monitoring the chemical reactions of an SRBC provides some indication of where flow and stagnation are occurring, ultimately leading to better predictions of longevity for a SRBC. Sulfate concentrations and sulfate-sulfur isotope data are crucial to measuring the degree and extent of biological activity within a cell. Flow patterns are able to be delineated from this data as well which will be useful in determining how to design future SRBCs in order to maximize the full complement of LBOS emplaced in a cell. One lesson to be learned from data collected from this particular cell is that insufficient LBOS was used, allowing a flow path to develop over the top of the substrate, bypassing the thickest sequence of LBOS. Another useful observation is that the pipe network is oriented in the wrong direction, having to flow up dip from near the AMD source to the discharge point, which has led to extended periods of stagnation within the pipe network at the base of the thickest layer of LBOS near the AMD source. A longer period of monitoring may very well reveal whether the current flow pattern within the cell and the presence of a second sulfate source recharge point closer to the cell discharge will result in depletion of neutralization and reducing substrate in the shallow layer of LBOS near the discharge, causing early failure of the treatment system.

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APPENDIX A. Addressing unique water sample analyses issues

The effect of sample instability on sample collection and preparation

The methods used in this work are those in general use for ambient waters and were selected from *Standard Methods For the Examination of Water and Water,* (APHA, AWWA and WPCF, Editions 16 and 21) and USEPA's *Methods for the Analysis of Water and Wastes*. As noted in the introduction to the USEPA manual, the methods were developed for monitoring water supplies, waste discharges, and ambient waters. Hence the methods are intended for use on samples obtained from sources under atmospheric conditions. These conditions are not typical of the interior of a sulfate reducing bioreactor when it is functioning as intended. While some parameters could be measured in situ, most others could not, and the unusual physical and chemical instability of the samples under atmospheric conditions could adversely affect the accuracy of laboratory analyses.

Characterization of the water chemistry within the bioreactor presented a series of challenges. Initially biological activity within the structure was sufficiently vigorous to raise the water temperature as high as 30 degrees C. despite ambient temperatures that were much lower. During winter months bubbles could be observed collecting beneath the surface ice. However as the bioreactor aged, the temperature of water within the reactor fell due to a suspected decrease or qualitative change in substrate reactivity or microbial processes. The appearance of gas bubbles subsided concurrently.

The generation of gas within the closed bioreactor could be due in part to the chemical reaction between the lime incorporated in the substrate and the acidity of the mine drainage, which releases carbon dioxide. While this reaction may generate some of the gas, the elevated temperature of the water can only be due to microbial activity. The composition of the gases was not determined; however, anaerobic microbial activity typically generates carbon dioxide, methane, hydrogen sulfide, and nitrogen. The appearance of gaseous metabolic byproducts indicates a dynamic system in which these dissolved or trapped gases can be expected to exert a significant effect upon the water chemistry. The equilibration of the water with the atmosphere during sample handling not only allows rapid out-gassing, it also prompts rapid precipitation of dissolved components and the coagulation of colloidal substances. Observation of bioreactor water samples after they are brought into contact with the atmosphere reveals a rapid darkening in color and an increase in turbidity indicative of a precipitation reaction. The nature of this precipitation reaction has not been determined.

In order to assess water chemistry apart from the influence of solid phase matter within the reactor, the samples must be filtered. The presence of solid material can interfere with the reactivity of reagents used in lab analyses. Because solutions must exhibit net charge neutrality, the charge balance between the sum of dissolved equivalents of anions and the sum of dissolved equivalents of cations serves as an important check on the accuracy of analyses. The need to obtain this charge balance serves as a further reason to filter samples prior to analysis.

In order to force the samples through filtration membranes of the desired porosity, either pressure or vacuum is required. Initially, the feasibility of using a positive pressure system was evaluated. This consisted of a peristaltic pump, flexible tubing, and 142 mm. filters mounted in stainless steel filter holders. This system was deemed impractical because the carry-over of contaminants necessitated the

disassembly of the apparatus and replacement of the tubing between samples. Vacuum filtration was the only alternative.

During vacuum filtration, the filtered sample must drip from the filter into the collection vessel, causing aeration of the water. The receiving container was typically maintained under a vacuum between 300-400 mm of Hg. Many of the samples were subjected to this reduced pressure for an hour or more, during which time bubbling and off-gassing was visible from the filtered liquid. Passing the water through the solids trapped on the filter induced further agglomeration of organic material which clogged the filter. It is possible that the water interacted with the solids as it passed through them. The membrane filters had to be replaced repeatedly during filtration.

Although filtration was necessary, there was visible evidence that the vacuum filtration altered the composition of the samples. After filtration, the samples rapidly became turbid and colloidal phases and precipitates continued to form in those aliquots that were not immediately preserved with acid.

Analytical challenges

One important indicator of sulfate reduction is the sulfide ion concentration, which was measured as acid volatile sulfide, AVS, using distillation and Hach's adaptation of Standard Method 427C, the methylene blue method. The test was always performed within 24 hours of sample collection as recommended in EPA's Methods for the Analysis of Water and Wastes. Initially, the test was performed on sample aliquots that had been vacuum filtered.

Total dissolved sulfide consists of both ionized hydrogen sulfide and unionized hydrogen sulfide, which is readily released from solution as H_2S gas. At acidic and circum-neutral pH, a very large percentage of dissolved sulfide is present in the form of the dissolved gas which has limited solubility. Subjecting such samples to reduced pressure very likely causes the loss of H_2S prior to analysis. In subsequent sampling, separate aliquots were collected without vacuum filtration and preserved with NaOH for dissolved sulfide analysis. This approach appeared to yield consistent results, although the concentration of AVS often exceeded the linear range for this determination, necessitating dilution of the distillate and reanalysis.

The high organic content of the samples also presented problems for the analytical equipment used for metals analysis. The Inductively Coupled Plasma spectrophotometer used to analyze major cations was clogged and contaminated by the organic matter present in the samples despite the fact that the samples were filtered and acidified. Agglomeration of high molecular weight organic matter can take place in the constricted passageways within the instrument.

The issue was solved by digesting the samples using a modification of EPA Method 3050A. This procedure uses a hot plate digestion of the sample with 1:1 nitric acid and hydrogen peroxide to oxidize organics and a final dilution step to return the digestate to its original volume. The digestion procedure not only destroys interferences, it also dissolves organically bound metal ions allowing them to be more uniformly atomized during analysis.

Organic matter and dissolved sulfide in the samples interfered with the titration of ferrous iron. The effect was observed primarily on samples with low ferrous iron and high dissolved organic matter content. During these titrations, multiple inflection points were detected, which meant that the titration had to proceed at a slow rate, demanding more time. When compared to total iron analyses determined

by ICP, many of the ferrous iron titrations from highly reduced, organic-rich samples generated false high concentrations for ferrous iron. For these samples, the total iron determined by ICP spectroscopy was reported as the ferrous iron value when the pH of the sample was greater than 5.

The high content of organic matter may have created a positive bias in one or more of the gravimetric type tests. One such test is the total dissolved solids determination. Typically this test determines the mass of dissolved ionic species, but in samples with high organic content, dissolved organic matter may also contribute to the final weight of solids. Similarly, attempts to precipitate sulfur species for isotopic analysis may have been subject to a positive interference from organic compounds that may have bound with a portion of the reagents that would otherwise react to create insoluble sulfur compounds.

APPENDIX B. Chemical Data for inflow sources and SRBC discharge point

Red colored numbers are flags for potentially erroneous data. NA in data cells indicates no analyses were performed for that component. Blank spaces indicate component analyses not yet completed.

Sample ID	Date	Temp C	SpC uS/cm	DO mg/L	pH	Eh vs SHE mV	TSS mg/L	TDS mg/L	Acidity mg/L CaCO3	Alkalinity mg/L CaCO3
AMD Seep	6/13/2007	27.7	3438	6.1	2.8	670	NA	NA	585	0
AMD Seep	7/23/2007	28.2	3672	5.6	2.7	690	4	3820	612	0
AMD Seep	8/3/2007	28.6	3796	5.2	2.7	672	11	4300	730	0
AMD Seep	9/5/2007	20.5	3917	4.8	2.5	684	39	4240	684	0
AMD Seep	10/25/2007	11.4	3039	7.4	2.9	697	6	3110	440	0
AMD Seep	11/28/2007	2.53	3181	6.0	2.9	679	9	3220	510	0
AMD Seep	8/4/2008	23.3	3614	4.9	2.8	654	NA	NA	NA	NA
AMD Seep	9/3/2008	24.9	3721	4.9	2.6	685	NA	NA	NA	NA
AMD Seep	9/17/2008	16.9	3634	4.8	2.7	681	NA	NA	NA	NA
AMD Seep	10/1/2008	11.3	3531	5.3	2.9	681	NA	NA	NA	NA
AMD Seep	10/14/2008	17.4	3727	3.8	2.8	691	NA	NA	673	0
AMD Seep	12/17/2008	0.8	2643	11.4	3.5	662	NA	NA	NA	NA
AMD Seep	1/8/2009	0.0	3084	9.2	3.3	661	NA	3180	416	0
AMD Seep	1/22/2009	0.4	3653	10.8	3.0	621	26	4350	702	0
AMD Seep	2/13/2009	9.5	2472	10.3	3.0	651	NA	NA	343	0
AMD Seep	2/17/2009	1.0	3390	10.5	2.9	641	20	NA	481	0
AMD Seep	3/10/2009	18.9	3403	8.6	2.8	717	200	3820	479	0
AMD Seep	3/24/2009	10.6	3302	8.8	3.0	654	60	348	574	0
AMD Seep	4/21/2009	11.3	2603	9.6	3.0	639	10	158	357	0
AMD Seep	5/19/2009	23.6	3019	8.8	2.8	680	NA	3440	376	0
AMD Seep	6/2/2009	29.9	3107	7.5	2.9	682	80	3860	405	0
AMD Seep	6/17/2009	26.1	2857	7.4	3.0	555	40	2020	351	0
AMD Seep	7/29/2009	25.4	3418	3.9	2.9	677	NA	3380	473	0
AMD Seep	8/12/2009	27.3	3538	5.5	2.9	676	40	2900	512	0
AMD Seep	8/26/2009	26.1	3575	6.6	2.8	675	80	4050	599	0
Watershed inflow	2/13/2009	7.3	1203	10.5	5.6	288	NA	NA	72	12
Watershed inflow	3/10/2009	11.4	2076	7.8	6.1	314	NA	1420	34	161
Watershed inflow	3/24/2009	10.0	2007	8.6	6.4	244	NA	194	25	180
Watershed inflow	4/21/2009	10.3	1328	8.3	5.7	332	10	59	77	57
Watershed inflow	5/19/2009	14.9	1936	7.6	6.1	48	NA	1860	122	48
Watershed inflow	6/17/2009	20.2	1644	6.4	6.2	159	NA	1720	93	58
Watershed inflow	8/12/2009	20.5	2715	1.3	6.3	111	80	2240	63	84
SRBC Outlet	1/8/2009	4.4	1775	1.2	6.2	261	NA	1600	91	311
SRBC Outlet	2/13/2009	4.8	1055	3.0	6.7	152	NA	NA	14	116
SRBC Outlet	2/17/2009	5.5	1457	2.5	6.9	-9	40.0	1.3	74	406
SRBC Outlet	3/10/2009	9.1	1893	5.2	6.7	108	375	1910	23	441
SRBC Outlet	3/24/2009	10.5	2058	6.7	6.8	156	NA	201	40	423
SRBC Outlet	4/21/2009	13.5	1572	0.5	6.7	152	20	116	32	240
SRBC Outlet	5/19/2009	16.6	1580	0.5	6.5	-115	<10	1440	13	269
SRBC Outlet	6/2/2009	22.6	1601	1.2	6.5	-94	100	1700	17	320
SRBC Outlet	6/17/2009	22.5	1785	-0.3	6.5	4	60	1460	18	390
SRBC Outlet	7/29/2009	22.3	1923	1.1	6.5	-162	120	1730	27	611

Sample ID	Date	Cl mg/L	NO3 mg/L	PO4 mg/L	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Fe(tot) mg/L	Fe(II) mg/L	Mn mg/L
AMD Seep	6/13/2007	4	<1	<1	2530	520	150	17	9	180	80	12
AMD Seep	7/23/2007	6	<1	<1	2900	500	160	19	10	180	61	12
AMD Seep	8/3/2007	5	<1	<1	2840	500	160	18	11	215	100	13
AMD Seep	9/5/2007	6	<1	<1	2840	560	180	66	17	205	65	14
AMD Seep	10/25/2007	6	<1	<1	2470	420	160	15	8	115	24	11
AMD Seep	11/28/2007	5	<1	<1	2340	480	160	63	14	145	35	12
AMD Seep	8/4/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	110	NA
AMD Seep	9/3/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	9/17/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	10/1/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	10/14/2008	7	<1	<1	2960	520	165	15	11	205	31	14
AMD Seep	12/17/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	1/8/2009	3	<5	<1	2580	515	175	12	8	120	32	15
AMD Seep	1/22/2009	4	0	0	3210	550	180	21	10	280	195	14
AMD Seep	2/13/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	2/17/2009	3	0	0	2320	360	135	11	5	76	30	11
AMD Seep	3/10/2009	7	0	3	2740	550	170	18	9	115	4	14
AMD Seep	3/24/2009	2	0	0	3630	510	160	19	9	205	85	13
AMD Seep	4/21/2009	1	0	0	1760	330	110	13	6	99	68	9
AMD Seep	5/19/2009	2	0	3	2000	410	130	11	6	83	28	11
AMD Seep	6/2/2009	5	0	20	2320	490	140	14	8	96	14	12
AMD Seep	6/17/2009	3	0	0	2960	370	110	11	6	80	23	9
AMD Seep	7/29/2009	1	< 1	1	2150	450	120	13	6	135	54	10
AMD Seep	8/12/2009	1	< 1	< 1	2370						52	
AMD Seep	8/26/2009	5	0	1	2010						67	
Watershed inflow	2/13/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Watershed inflow	3/10/2009	1	0	0	1180	480	71	11	7	10	10	9
Watershed inflow	3/24/2009	2	0	0	1280	425	63	10	7	4	4	8
Watershed inflow	4/21/2009	5	0	0	735	220	36	8	4	32	33	5
Watershed inflow	5/19/2009	29	3	0	1370	330	52	7	6	68	72	13
Watershed inflow	6/17/2009	< 1	0	0	2450	290	42	5	5	53	53	10
Watershed inflow	8/12/2009	< 1	< 1	< 1	1390						35	
SRBC Outlet	1/8/2009	1	<5	12	890	385	70	6	29	0.5	0.5	6
SRBC Outlet	2/13/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SRBC Outlet	2/17/2009	4	0	0	625	170	34	4	23	<0.1	4	3
SRBC Outlet	3/10/2009	4	0	3	1020	340	74	11	19	<1	15	7
SRBC Outlet	3/24/2009	4	0	2	1170	425	96	12	19	2	20	9
SRBC Outlet	4/21/2009	1	0	0	745	260	63	9	15	1	4	6
SRBC Outlet	5/19/2009	8	1	0	840	270	64	6	13	<1	6	6
SRBC Outlet	6/2/2009	3	0	7	960	300	70	7	15	<1	5	7
SRBC Outlet	6/17/2009	3	0	0	**2420**	305	70	9	15	<1	9	7

SRBC Outlet	7/29/2009	3	<1	5	1030	320	78	8	13	37	37	8	

Sample ID	Date	Al mg/L	Sulfide mg/L	As µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Hg µg/L	Ni mg/L	Pb µg/L	Mo µg/L	Se µg/L	Sb µg/L
AMD Seep	6/13/2007	6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	7/23/2007	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	8/3/2007	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	9/5/2007	8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	10/25/2007	14	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	11/28/2007	12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	8/4/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	9/3/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	9/17/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	10/1/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	10/14/2008	7	NA	NA	NA	<0.01	<0.05	NA	0.4	<0.01	<0.01	<0.01	NA
AMD Seep	12/17/2008	NA	NA	2	12	<1	3	3	0.38	<1	<1	<1	2
AMD Seep	1/8/2009	15	0.061	3	14	<1	5	4	0.47	<1	<1	<1	3
AMD Seep	1/22/2009	9	0.004	<1	7.4	14	4	4	0.39	3	<1	<1	4
AMD Seep	2/13/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AMD Seep	2/17/2009	14	<0.001	<1	11	8	2	3	0.26	5	<1	<1	2
AMD Seep	3/10/2009	13	0.002	<1	12	9	5	4	0.42	2	<1	<1	3
AMD Seep	3/24/2009	11	0.007	<1	12	4	7	1	0.48	2	<1	<1	4
AMD Seep	4/21/2009	9	0.007	4	13	<1	18	1	0.44	4	1	<1	1
AMD Seep	5/19/2009	11	0.012	5	28	<1	21	<1	0.53	1	<1	<1	5
AMD Seep	6/2/2009	11	NA	6	14	<1	25	1	0.34	2	<1	2	2
AMD Seep	6/17/2009	7	NA	6	16	<1	18	<1	0.49	4	<1	7	5
AMD Seep	7/29/2009	5	NA	<1	11	<1	28	5	0.56	<1	<1	3	8
AMD Seep	8/12/2009		<0.001	<1	9.8	<1		5		1	<1	4	8
AMD Seep	8/26/2009		<0.001	1	11	<1		7		2	<1	4	9
Watershed inflow	2/13/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Watershed inflow	3/10/2009	<0.5	0.007	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Watershed inflow	3/24/2009	<0.5	0.009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Watershed inflow	4/21/2009	<0.5	0.005	2	4	NA	12	1	0.12	1	<1	NA	<1
Watershed inflow	5/19/2009	<0.5	0.010	4	11	<1	7	<1	0.36	5	<1	2	1
Watershed inflow	6/17/2009	<0.5	0.019	4	3	<1	24	1	0.25	11	<1	13	2
Watershed inflow	8/12/2009		0.07	<1	1	<1		4		<1	<1	3	6
SRBC Outlet	1/8/2009	<0.5	0.05	<1	<0.5	<1	1	1	0.06	<1	<1	5	2
SRBC Outlet	2/13/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SRBC Outlet	2/17/2009	<0.5	<0.001	<1	0.5	2	<1	2	0.08	7	<1	6	3
SRBC Outlet	3/10/2009	<0.5	<0.001	<1	<0.5	<1	1	2	0.12	3	<1	<1	3
SRBC Outlet	3/24/2009	<0.5	0.009	<1	<0.5	4	1	2	0.11	3	<1	<1	4
SRBC Outlet	4/21/2009	<0.5	0.010	4	<1	<1	2	1	0.06	1	<1	<1	2
SRBC Outlet	5/19/2009	<0.5	0.05	4	<1	<1	6	<1	0.02	<1	<1	<1	4
SRBC Outlet	6/2/2009	<0.5	2.39	5	<1	<1	14	1	0.06	2	<1	2	3
SRBC Outlet	6/17/2009	<0.5	5.07	8	1	<1	11	<1	0.10	8	<1	<1	4

SRBC Outlet	7/29/2009	<0.5	24.7	5	<0.5	<1	13	1	0.08	<1	<1	2	6

APPENDIX C. Chemical data for SRBC internal "D" sampling ports

See Figure 6 for locations. Red colored numbers are flags for potentially erroneous data. NA in data cells indicates no analyses were performed for that component. Blank spaces indicate component analyses not yet completed.

Sample ID	Date	Temp C	SpC uS/cm	DO mg/L	pH	Eh vs SHE mV	Acidity mg/L CaCO3	Alkalinity mg/L CaCO3	Cl mg/L	NO3 mg/L	PO4 mg/L
D01	8/4/2008	31.5	3350	-1.7	6.4	-134	NA	NA	NA	NA	NA
D01	8/19/2008	34.1	3565	-2.7	6.8	-103	NA	NA	NA	NA	NA
D01	9/3/2008	33.4	3640	0.9	6.5	-181	NA	NA	39	<1	NA
D01	9/17/2008	32.5	3489	0.3	6.5	-177	NA	NA	NA	NA	NA
D01	10/1/2008	31.6	3358	-0.4	6.5	-146	NA	NA	NA	NA	NA
D01	10/14/2008	31.0	3211	-5.6	6.6	-131	40	2210	8	<1	<1
D01	1/8/2009	11.1	6263	4.4	6.6	0	325	5700	511	<5	46
D01	1/22/2009	11.1	6670	8.5	6.7	178	688	6110	577	1	28
D01	2/17/2009	9.6	6140	4.5	6.6	342	156	5290	404	<1	36
D01	3/24/2009	12.8	6574	5.6	6.7	149	171	5730	475	25	12
D01	4/21/2009	11.1	3525	0.0	6.7	-109	102	3480	48	<1	36
D01	5/5/2009	13.8	3401	-3.7	6.7	-107	116	3820	62	39	3
D01	6/2/2009	18.3	3085	2.8	6.4	-67	377	3960	14	<1	33
D01	6/17/2009	18.5	2887	3.4	6.3	-118	458	3460	8	<1	40
D01	7/15/2009	19.4	6337	6.6	6.6	234	160	6140	412	5	<1
D01	7/29/2009	16.9	4706	1.5	6.4	124	231	4460	112	< 1	23
D01	8/26/2009	20.7	6065	3.7	6.7	101	229	2560	284	<1	1
D02	8/4/2008	30.9	3726	0.0	6.5	-120	NA	NA	NA	NA	NA
D02	8/19/2008	30.9	4061	-1.4	6.5	-160	NA	NA	NA	NA	NA
D02	9/3/2008	33.8	5485	-3.6	6.7	-171	NA	NA	149	<1	NA
D02	9/17/2008	33.5	4921	1.6	6.6	-178	NA	NA	112	NA	NA
D02	10/1/2008	33.0	3551	1.6	6.5	-183	NA	NA	NA	NA	NA
D02	10/14/2008	32.1	3535	-0.5	6.8	-147	42	2270	56	<1	<1
D02	1/8/2009	14.6	6314	6.1	6.7	62	293	5710	474	<5	36
D02	1/22/2009	14.8	6345	8.6	6.7	160	786	6080	483	<1	42
D02	2/17/2009	14.4	6234	4.8	6.6	123	242	4590	420	<1	36
D02	3/24/2009	15.7	6026	5.4	6.7	146	201	5560	387	25	30
D02	4/21/2009	12.9	6178	-0.2	6.6	-87	188	5860	411	<1	28
D02	6/2/2009	18.9	5676	3.2	6.6	6	126	5900	245	<1	36
D02	7/15/2009	20.8	6439	6.5	6.7	218	122	5950	11	< 1	26
D02	8/26/2009	20.3	6515	2.1	6.6	72	265	2810	400	<1	<1
D03	9/3/2008	35.3	5224	0.8	6.7	-171	NA	NA	NA	NA	NA
D03	2/17/2009	11.9	5262	5.0	6.6	181	343	5040	297	< 1	41
D03	6/2/2009	18.2	5999	2.1	6.7	50	137	6250	356	<1	35
D04	1/8/2009	6.4	2677	4.0	7.0	137	36	579	<5	<5	<5
D04	2/17/2009	6.7	3081	2.5	6.9	100	84	997	5	<5	8
D04	5/5/2009	14.4	3300	0.2	6.6	-102	96	2640	10	3	2
D04	6/2/2009	17.6	2998	2.3	6.5	-119	278	3550	11	<1	41
D04	6/17/2009	18.6	2560	3.0	6.3	-78	327	2970	49	<1	<1
D04	7/29/2009	20.3	2525	1.9	6.3	-70	274	2760	28	< 1	14
D04	8/26/2009	21.8	2595	4.9	6.3	-80	372	1470	NA	NA	NA

D05	2/17/2009	9.6	3587	3.2	6.7	25	187	3620	102	<1	38
D05	5/5/2009	14.3	3943	1.0	6.5	-4	410	4700	94	<1	2
D05	6/17/2009	18.4	3948	3.0	6.4	-7	619	4710	53	<1	<1
D05	7/29/2009	18.5	3990	1.3	6.5	18	368	4410	145	8	27
D06	2/17/2009	12.0	7128	4.4	6.6	12	172	5160	664	< 1	19
D06	6/17/2009	19.6	4636	3.3	6.6	60	132	4370	191	<1	<1
D06	7/29/2009	20.0	4608	2.5	6.5	48	85	4200	28	<1	2
D07	2/17/2009	7.5	3197	2.5	6.8	-79	93	1180	9	<1	<1
D07	6/2/2009	20.3	2915	4.5	6.8	-67	135	3520	10	<1	29
D07	7/29/2009	19.4	3042	-0.5	6.2	-62	701	3530	7	<1	6
D07	8/26/2009	20.4	3177	2.2	6.1	-63	1142	1840	7	<1	44
D08	2/17/2009	10.5	6680	4.7	6.7	34	NA	NA	NA	NA	NA
D08	3/24/2009	13.0	6093	7.2	6.7	369	194	5620	317	<1	15
D08	4/21/2009	13.1	5464	0.2	6.6	-34	200	5380	179	<1	26
D08	6/17/2009	19.6	4260	2.8	6.6	59	115	4470	75	<1	<1
D08	7/29/2009	20.0	4233	1.4	6.6	28	77	4190	34	<1	1
D09	2/17/2009	10.4	5166	4.8	6.6	-2	NA	NA	NA	NA	NA
D09	3/24/2009	13.0	4612	7.4	6.6	31	229	4480	135	<1	77
D09	6/17/2009	19.6	3078	2.3	6.6	-101	119	3410	21	<1	72
D09	7/29/2009	21.0	3306	2.7	6.5	-8	445	3450	43	<1	1
D11	1/8/2009	4.5	2697	1.1	6.9	148	50	350	1	<5	<5
D11	2/17/2009	6.2	2527	3.3	6.8	38	93	324	3	<5	5
D11	4/21/2009	11.9	2575	8.0	7.0	80	65	406	1	<1	<1
D11	5/5/2009	15.9	2560	1.2	6.9	183	85	569	5	<1	< 1
D11	5/19/2009	16.8	2151	3.0	6.6	112	52	393	2	<1	3
D11	6/2/2009	20.1	2088	2.0	6.8	18	82	435	2	<1	6
D11	6/17/2009	20.6	2164	1.3	6.6	2	43	315	2	<1	<1
D11	7/29/2009	23.4	2259	3.7	6.5	71	50	444	4	<1	2
D11	8/26/2009	22.7	2305	6.3	6.4	-8	44	201	3	<1	12
D12	1/8/2009	5.0	2726	1.0	7.1	119	73	490	7	<5	<5
D12	2/17/2009	6.7	3047	4.5	6.7	20	117	1070	5	<5	21
D12	6/2/2009	20.0	2079	3.5	6.9	43	69	396	2	<1	6
D12	8/26/2009	23.3	2330	7.1	6.5	12	NA	NA	NA	NA	NA
D13	2/17/2009	8.1	3344	3.3	6.7	-3	NA	NA	NA	NA	NA
D13	3/24/2009	12.1	3074	6.6	6.9	60	106	2760	21	29	38
D13	5/5/2009	14.5	3259	0.8	6.6	-8	225	4120	23	<1	1
D14	2/17/2009	10.6	5963	5.1	6.7	14	NA	NA	NA	NA	NA
D14	3/24/2009	13.8	5166	5.9	6.6	68	141	4760	269	<1	12
D14	4/21/2009	12.9	4631	0.5	6.6	61	126	4570	124	<1	3
D14	6/17/2009	19.1	3919	2.6	6.5	44	73	4160	49	<1	<1
D15	1/8/2009	8.9	3250	3.6	6.6	41	51	2720	67	<5	74
D15	2/17/2009	8.6	3443	5.0	6.6	-18	NA	NA	NA	NA	NA
D15	3/24/2009	14.4	2889	7.0	6.9	107	84	1530	8	<1	35
D15	6/17/2009	19.3	2705	2.1	6.5	60	275	3220	39	<1	<1
D16	6/2/2009	19.1	3536	1.9	6.6	79	97	4010	41	<1	37

D16	7/29/2009	21.0	3421	0.4	6.5	24	62	3630	35	<1	1
D17	1/22/2009	10.9	5436	12.7	6.7	145	877	5400	280	<1	43
D17	3/24/2009	13.7	5390	4.8	6.7	132	148	4060	113	<1	68
D17	7/29/2009	21.5	2917	0.5	6.4	12	272	3160	2	2	5
D17	8/26/2009	22.8	2970	5.4	6.5	1	193	1670	3	<1	29
D30	1/22/2009	6.8	4006	11.7	6.6	175	360	3910	151	<1	19
D30	2/17/2009	7.6	3661	5.8	6.6	73	123	3340	83	<1	12
D30	4/21/2009	13.2	3581	5.3	6.7	98	314	3640	57	<1	<1
D30	6/2/2009	21.4	2956	1.8	6.5	82	87	2940	34	<1	15
D30	7/29/2009	22.9	2688	0.1	6.3	-70	51	2550	19	<1	13
D30	8/26/2009	22.2	2678	5.4	6.5	4	70	1250	18	1	9

Sample ID	Date	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Fe(tot) mg/L	Fe(II) mg/L	Mn mg/L	Al mg/L	Sulfide mg/L	COD mg/L
D01	8/4/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D01	8/19/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D01	9/3/2008	135	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D01	9/17/2008	190	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D01	10/1/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D01	10/14/2008	986	580	140	13	30	<1	<1	11	<0.5	NA	NA
D01	1/8/2009	12	460	165	42	1160	3	3	8	<0.5	0.03	1860
D01	1/22/2009	205	570	190	58	1280	3	3	11	<0.5	0.007	1450
D01	2/17/2009	152	530	195	50	1080	<1	<1	8	<0.5	0.004	1740
D01	3/24/2009	6	550	195	54	1190	<1	<1	10	<0.5	0.02	1170
D01	4/21/2009	352	570	145	19	165	<1	<1	6	<0.5	3.40	512
D01	5/5/2009	456	580	145	17	100	<1	<1	6	<0.5	0.184	384
D01	6/2/2009	461	570	135	16	85	<1	<1	6	<0.5	0.76	850
D01	6/17/2009	70	500	125	15	83	<1	<1	7	<0.5	0.93	1260
D01	7/15/2009	112	580	190	46	970	14	14	11	<0.5	0.02	1010
D01	7/29/2009	38	550	160	26	470	2	2	9	<0.5	0.05	NA
D01	8/26/2009	51						<1			<0.001	797
D02	8/4/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D02	8/19/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D02	9/3/2008	47	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D02	9/17/2008	93	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D02	10/1/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D02	10/14/2008	983	580	145	15	144	<1	<1	11	<0.5	NA	NA
D02	1/8/2009	<5	490	165	43	1130	3	3	9	<0.5	0.04	1930
D02	1/22/2009	201	590	195	50	1140	3	3	9	<0.5	0.007	1590
D02	2/17/2009	200	540	190	45	1090	<1	<1	7	<0.5	0.011	1330
D02	3/24/2009	32	590	195	47	1000	<1	<1	11	<0.5	0.005	1010
D02	4/21/2009	202	580	195	47	1010	4	4	10	<0.5	0.012	1190
D02	6/2/2009	502	550	185	45	950	<1	<1	10	<0.5	0.12	1000
D02	7/15/2009	101	530	210	47	1080	<1	<1	9	<0.5	0.017	1010
D02	8/26/2009	25						<1			<0.001	848
D03	9/3/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D03	2/17/2009	205	670	195	39	730	<1	<1	10	<0.5	0.009	1320
D03	6/2/2009	307	580	205	45	1020	<1	<1	11	<0.5	0.09	1780
D04	1/8/2009	1530	520	110	10	31	13	9	7	<0.5	0.038	68
D04	2/17/2009	1610	610	150	15	30	<1	5	20	<0.5	0.007	140
D04	5/5/2009	853	740	147	15	27	<1	<1	11	<0.5	27.9	160
D04	6/2/2009	285	600	105	14	40	<1	<1	8	<0.5	19.8	400
D04	6/17/2009	255	230	53	6	24	<1	<1	13	<0.5	2.32	810
D04	7/29/2009	23	460	100	12	37	1	1	8	<0.5	7.40	NA
D04	8/26/2009	NA						<1			8.44	889
D05	2/17/2009	241	590	165	23	300	<1	<1	6	<0.5	0.03	549
D05	5/5/2009	220	540	175	26	360	<1	<1	9	<0.5	0.67	852
D05	6/17/2009	368	620	180	20	350	<1	<1	11	<0.5	0.06	1690
D05	7/29/2009	<5	570	170	20	350	<1	<1	10	<0.5	0.20	NA
D06	2/17/2009	0	430	145	62	1610	6	6	6	<0.5	0.015	1520

D06	6/17/2009	80	350	120	28	920	7	7	7	<0.5	0.06	810
D06	7/29/2009	5	370	115	25	850	10	6	7	<0.5	0.04	NA
D07	2/17/2009	1580	580	150	15	60	<1	<1	6	<0.5	NA	215
D07	6/2/2009	896	570	140	17	62	<1	<1	8	<0.5	9.91	290
D07	7/29/2009	7	540	140	14	59	1	1	8	<0.5	9.69	NA
D07	8/26/2009	72						<1			29.5	479
D08	2/17/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D08	3/24/2009	5	520	165	43	1190	<1	<1	7	<0.5	0.004	1020
D08	4/21/2009	136	450	145	36	1010	2	2	6	<0.5	0.012	872
D08	6/17/2009	116	420	130	24	770	15	15	7	<0.5	0.05	520
D08	7/29/2009	2	400	130	20	670	1	1	6	<0.5	0.28	NA
D09	2/17/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D09	3/24/2009	112	480	155	32	740	<1	<1	5	<0.5	0.03	686
D09	6/17/2009	1600	400	125	15	370	<1	<1	4	<0.5	1.41	500
D09	7/29/2009	7	410	125	15	360	<1	<1	5	<0.5	0.49	NA
D11	1/8/2009	1950	510	115	9	19	22	19	17	<0.5	0.04	62
D11	2/17/2009	1390	450	105	10	12	20	19	14	<0.5	0.007	5
D11	4/21/2009	1390	460	110	11	16	31	31	12	<0.5	0.002	30
D11	5/5/2009	1280	450	115	13	10	53	55	11	<0.5	0.84	16
D11	5/19/2009	1120	400	94	8	7	30	32	8	<0.5	0.012	41
D11	6/2/2009	1880	390	91	8	7	39	39	8	<0.5	0.010	30
D11	6/17/2009	2570	400	190	9	7	58	58	9	<0.5	0.03	10
D11	7/29/2009	1180	440	105	11	8	43	43	8	<0.5	0.08	NA
D11	8/26/2009	1060						21			0.03	48
D12	1/8/2009	1580	470	115	10	48	<1	<1	30	<0.5	0.05	187
D12	2/17/2009	1450	610	145	14	36	<1	<1	23	<0.5	0.007	215
D12	6/2/2009	1340	380	92	8	7	31	33	8	<0.5	<0.001	30
D12	8/26/2009	NA	NA	NA	NA	NA	NA	NA			NA	NA
D13	2/17/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D13	3/24/2009	515	550	140	189	150	1	1	5	<0.5	0.011	270
D13	5/5/2009	214	550	150	18	160	<1	<1	7	<0.5	0.02	680
D14	2/17/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D14	3/24/2009	10	450	135	38	980	<1	<1	9	<0.5	0.007	870
D14	4/21/2009	115	440	120	27	810	9	9	9	<0.5	0.004	327
D14	6/17/2009	403	420	120	20	560	32	32	10	<0.5	0.10	320
D15	1/8/2009	414	300	105	18	560	<1	<1	5	<0.5	0.05	552
D15	2/17/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D15	3/24/2009	1150	520	135	17	140	<1	<1	6	<0.5	0.011	90
D15	6/17/2009	232	470	125	13	95	1	1	7	<0.5	0.12	600
D16	6/2/2009	139	410	130	18	570	<1	<1	7	<0.5	0.02	370
D16	7/29/2009	71	390	120	13	330	5	5	7	<0.5	0.08	NA
D17	1/22/2009	294	590	190	39	880	2	2	6	2	0.004	1110
D17	3/24/2009	269	520	140	24	640	<1	<1	5	<0.5	0.013	554
D17	7/29/2009	20	500	110	11	160	<1	<1	7	<0.5	0.13	NA
D17	8/26/2009	210						<1			<0.001	480

D30	1/22/2009	324	390	105	25	720	2	2	9	<0.5	0.007	590
D30	2/17/2009	286	280	98	20	560	<1	<1	2	<0.5	0.009	439
D30	4/21/2009	205	430	98	18	480	5	5	11	<0.5	0.002	900
D30	6/2/2009	1150	400	91	14	280	32	<1	10	<0.5	0.06	970
D30	7/29/2009	194	210	49	6	85	<1	<1	4	<0.5	0.17	NA
D30	8/26/2009	182						<1			0.09	257

APPENDIX D. Chemical data for SRBC internal "A" and "B" sampling ports, and surface water samples

See figure 6 for locations. Red colored numbers are flags for potentially erroneous data. NA in data cells indicates no analyses were performed for that component. Blank spaces indicate component analyses not yet completed.

Sample ID	Date	Temp C	SpC uS/cm	DO mg/L	pH	Eh vs SHE mV	Acidity mg/L CaCO3	Alkalinity mg/L CaCO3	Cl mg/L	NO3 mg/L	PO4 mg/L
A01	1/8/2009	4.0	1827	3.2	6.5	285	NA	NA	NA	NA	NA
A01	3/10/2009	12.1	2085	4.0	6.7	88	47	722	10	< 1	22
A01	5/19/2009	19.3	1662	4.8	6.8	-53	18	332	8	7	30
A01	6/17/2009	23.2	1816	1.7	6.5	-34	26	359	6	5	13
A01	7/15/2009	22.6	2194	2.6	6.5	-65	53	1050	33	16	19
A01	8/12/2009	24.0	1436	2.1	6.6	-6	28	360	2	< 1	2
A01	8/26/2009	21.5	1828	1.8	6.6	-87	60	402	4	< 1	5
A02	3/10/2009	11.7	1997	2.6	6.7	20	48	578	10	< 1	6
A02	5/19/2009	18.5	1663	3.6	6.6	-52	33	397	5	1	11
A02	6/17/2009	23.1	1875	1.0	6.4	-126	36	531	5	< 1	10
A02	7/15/2009	22.4	2234	1.7	6.5	-46	67	1150	4	< 1	5
A02	8/12/2009	24.1	1303	2.2	6.5	-9	39	291	2	< 1	5
A02	8/26/2009	21.9	1610	1.8	6.6	-87	93	413	3	< 1	3
A10	1/8/2009	3.7	2495	4.2	7.0	220	82	1220	92	<5	<5
A10	3/10/2009	14.7	2219	7.2	6.7	173	48	456	3	< 1	5
A10	5/19/2009	17.4	1719	4.8	6.5	-22	50	784	3	< 1	8
A10	6/17/2009	22.3	1676	0.9	6.3	-204	38	962	< 1	< 1	< 1
A10	8/12/2009	24.2	1873	0.8	6.4	-16	34	408	1	< 1	< 1
A10	8/26/2009	21.0	2054	3.8	6.3	-101	187	468	3	< 1	2
A11	3/10/2009	13.3	2559	4.5	6.8	90	100	1880	23	< 1	27
A11	5/19/2009	17.3	2349	2.2	6.5	-53	268	3030	5	< 1	6
A11	6/17/2009	22.5	1931	0.3	6.4	-116	129	1800	12	< 1	17
A11	8/12/2009	24.3	2484	2.3	6.7	25	56	758	4	< 1	8
A11	8/26/2009	21.2	2578	6.7	6.3	-34	165	374	30	< 1	< 1
A12	3/10/2009	12.7	2568	3.3	6.6	139	68	559	26	< 1	11
A12	5/19/2009	16.9	2070	2.6	6.6	-63	35	882	14	< 1	6
A12	6/17/2009	22.6	2100	-1.4	6.6	-118	64	1700	15	< 1	4
A12	8/12/2009	23.1	2166	-0.3	6.5	-65	62	1010	52	< 1	1
A12	8/26/2009	20.7	2672	3.4	6.4	-97	73	465	14	1	1
A13	3/10/2009	11.5	2412	3.3	7.0	81	97	2060	53	< 1	21
A13	5/19/2009	17.5	1810	1.8	6.7	-70	96	1780	8	< 1	15
A13	6/17/2009	23.0	1786	-0.6	6.5	-116	77	1210	11	< 1	11
A13	8/12/2009	23.7	2042	2.0	6.4	-13	75	979	5	< 1	9
A13	8/26/2009	20.9	1939	1.0	6.5	-103	75	991	12	< 1	8
B01	1/8/2009	6.1	1952	2.4	7.0	175	48	570	11	<5	<5

B01	3/10/2009	11.6	2524	4.2	6.6	23	88	1560	32	< 1	31
B01	5/19/2009	20.2	1905	1.8	6.7	-77	36	653	4	2	8
B01	8/12/2009	23.4	1708	0.5	6.6	-23	32	486	2	1	1
B02	1/8/2009	3.1	1711	8.1	7.0	209	NA	NA	NA	NA	NA
B02	3/10/2009	11.4	2059	3.0	6.7	-45	41	557	10	< 1	12
B02	5/19/2009	24.5	2010	2.5	7.0	-60	27	798	9	< 1	10
B02	8/12/2009	23.9	1366	2.1	6.7	-2	58	327	14	< 1	< 1
B20	3/10/2009	12.0	2086	3.1	6.7	-27	65	738	7	< 1	4
B20	5/19/2009	19.0	1811	3.7	6.6	1	24	239	2	< 1	< 1
B20	8/12/2009	24.5	1552	0.6	6.6	-1	26	216	11	1	< 1
B20 Dup	8/12/2009						40	232	15	2	1
B21	1/8/2009	4.8	2195	4.1	6.8	149	158	908	26	<5	34
B21	3/10/2009	11.3	2011	4.2	6.8	-50	72	552	4	< 1	13
B21	5/19/2009	20.2	1716	6.2	7.0	-65	24	479	2	< 1	4
B21	8/12/2009	23.9	1566	-0.6	6.7	-50	42	409	14	2	3
B22	3/10/2009	11.9	1977	3.0	6.9	-1	56	372	6	< 1	2
B22	5/19/2009	18.5	1485	1.0	6.6	-28	18	198	1	< 1	4
B22	8/12/2009	23.9	1541	0.5	6.7	3	26	241	3	< 1	3
Surface 1 (W)	3/10/2009	13.9	1802	9.9	5.4	336	18	13	3	< 1	3
Surface 1 (W)	3/24/2009	16.1	2062	6.2	5.8	263	23	33	3	< 1	< 1
Surface 1 (W)	5/19/2009	17.0	1369	4.5	4.5	54	66	0	0	< 1	< 1
Surface1 (W)	6/17/2009	24.4	1746	5.2	3.5	538	56	0	2	< 1	< 1
Surface 1 (W)	7/29/2009	24.0	1792	3.5	6.7	19	14	32	2	2	<1
Surface 1 (W)	8/26/2009	19.8	2157	1.8	6.7	-20	NA	NA	NA	NA	NA
Surface 2 (E)	3/24/2009	13.2	2163	7.0	3.6	374	53	0	3	< 1	< 1
Surface 2 (E)	6/2/2009	27.7	1453	9.8	3.5	420	273	0	1	< 1	5
Surface 2 (E)	6/17/2009	27.3	1714	10.9	3.4	581	90	0	2	< 1	< 1
Surface 2 (E)	7/29/2009	26.4	1918	4.9	4.5	513	31	11	2	<1	1
Surface 2 (E)	8/26/2009	23.0	2004	3.3	6.9	-5	NA	NA	NA	NA	NA

Sample ID	Date	SO4	Ca	Mg	Na	K	Fe(tot)	Fe(II)	Mn	Al	Sulfide	COD
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
A01	1/8/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
A01	3/10/2009	890	390	86	10	50	<1	<1	9	<0.5	0.01	95
A01	5/19/2009	859	290	66	6	8	<1	<1	7	<0.5	0.06	57
A01	6/17/2009	2410	340	75	8	7	3	7	8	<0.5	3.47	10
A01	7/15/2009	1000	400	93	11	13	<1	<1	12	<0.5	19.8	85
A01	8/12/2009	513						20			13.5	10
A01	8/26/2009	682						37			17.4	150
A02	3/10/2009	919	390	87	9	38	4	10	7	<0.5	<0.001	80
A02	5/19/2009	784	290	68	7	26	1	6	6	<0.5	0.06	91
A02	6/17/2009	2370	330	75	7	25	<1	17	7	<0.5	5.31	10
A02	7/15/2009	1160	420	97	11	16	<1	<1	9	<0.5	23.3	115
A02	8/12/2009	586						10			14.4	10
A02	8/26/2009	520						34			41.9	115
A10	1/8/2009	658	280	73	13	310	3	3	4	<0.5	0.005	487
A10	3/10/2009	1120	400	72	12	16	24	41	19	<0.5	<0.001	65
A10	5/19/2009	676	330	58	7	11	25	27	12	<0.5	0.014	97
A10	6/17/2009	2180	310	54	7	9	<1	<1	10	<0.5	1.55	100
A10	8/12/2009	597						9			12.6	425
A10	8/26/2009	808						16			10.4	132
A11	3/10/2009	521	350	140	28	145	1	<1	21	<0.5	<0.001	220
A11	5/19/2009	172	400	125	19	78	11	11	21	<0.5	0.033	228
A11	6/17/2009	2030	310	80	10	42	<1	<1	11	<0.5	13.9	270
A11	8/12/2009	654						<1			16.4	220
A11	8/26/2009	1350						11			0.41	185
A12	3/10/2009	1270	470	100	16	68	22	21	17	<0.5	<0.001	190
A12	5/19/2009	753	380	89	13	24	<1	<1	19	<0.5	0.145	133
A12	6/17/2009	2110	370	80	13	27	<1	<1	19	<0.5	27.3	190
A12	8/12/2009	517						29			14.6	300
A12	8/26/2009	1160						8			3.66	135
A13	3/10/2009	284	340	75	16	215	<1	<1	6	<0.5	0.022	330
A13	5/19/2009	221	300	66	9	69	<1	<1	8	<0.5	0.171	328
A13	6/17/2009	2150	320	67	9	33	<1	<1	8	<0.5	16.9	390
A13	8/12/2009	260						24			14.6	250
A13	8/26/2009	365						55			51.0	485
B01	1/8/2009	989	340	72	7	52	1	1	9	<0.5	0.016	168
B01	3/10/2009	688	420	105	16	165	<1	<1	12	<0.5	0.018	235
B01	5/19/2009	747	360	82	8	21	<1	18	7	<0.5	0.25	82
B01	8/12/2009	402						44			12.3	125
B02	1/8/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
B02	3/10/2009	961	370	90	12	35	<1	<1	7	<0.5	0.037	3260
B02	5/19/2009	848	340	81	8	54	<1	11	7	<0.5	0.18	142
B02	8/12/2009	44						22			13.1	20
B20	3/10/2009	880	370	84	12	59	3	8	7	<0.5	0.004	76
B20	5/19/2009	1000	330	79	7	6	5	8	7	<0.5	0.012	53

B20	8/12/2009	624						8			7.75	70
B21	1/8/2009	713	250	88	9	215	2	2	4	<0.5	0.022	589
B21	3/10/2009	966	360	87	11	24	<1	<1	8	<0.5	0.10	120
B21	5/19/2009	853	330	77	7	7	<1	11	6	<0.5	0.30	69
B21	8/12/2009	597						52			6.53	1125
B22	3/10/2009	1020	370	83	11	17	<1	2	7	<0.5	0.002	44
B22	5/19/2009	784	250	62	6	5	3	5	5	<0.5	0.018	52
B22	8/12/2009	572						9			5.31	190
Surface 1 (W)	3/10/2009	1120	310	80	11	11	<1	2	8	1	0.004	22
Surface 1 (W)	3/24/2009	1350	380	94	12	12	1	1	9	<0.5	0.009	16
Surface 1 (W)	5/19/2009	862	210	55	6	4	2	4	6	2	0.012	75
Surface1 (W)	6/17/2009	2440	280	69	7	5	4	4	7	2	0.29	10
Surface 1 (W)	7/29/2009	1190	310	79	5	7	<1	<1	9	<0.5	0.005	NA
Surface 1 (W)	8/26/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Surface 2 (E)	3/24/2009	1790	360	99	13	13	4	4	9	4	0.007	9
Surface 2 (E)	6/2/2009	906	200	53	5	4	4	4	5	2	NA	2
Surface 2 (E)	6/17/2009	2450	260	68	7	5	5	5	6	3	NA	14
Surface 2 (E)	7/29/2009	1340	325	86	9	6	<1	<1	8	<0.5	0.03	NA
Surface 2 (E)	8/26/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

APPENDIX E. Chemical data for SRBC internal "C" sampling ports

See figure 6 for locations. NA in data cells indicates no analyses were performed for that component.

Sample ID	Date	Temp C	SpC uS/cm	DO mg/L	pH	Eh vs SHE mV	Acidity mg/L CaCO3	Alkalinity mg/L CaCO3	Cl mg/L	NO3 mg/L	PO4 mg/L
C01	9/3/2008	34.9	4215	1.1	6.5	-171	NA	NA	48	<1	NA
C01	2/17/2009	12.3	5527	5.0	6.6	-35	373	5210	330	<1	31
C01	6/2/2009	18.4	5430	4.2	6.7	-25	133	5550	274	21	46
C01	7/29/2009	20.6	5123	3.8	6.6	27	99	4810	210	3	25
C02	1/8/2009	14.7	5549	5.0	6.6	-2	455	5520	416	<5	46
C02	2/17/2009	12.6	5686	5.1	6.6	-29	228	5000	382	< 1	37
C02	7/29/2009	20.1	5132	4.0	6.7	38	100	4910	219	<1	5
C03	8/4/2008	32.5	3372	1.0	6.4	-133	NA	NA	NA	NA	NA
C03	2/17/2009	11.1	5440	4.6	6.6	-31	353	5050	340	<1	50
C03	6/2/2009	17.4	4925	2.3	6.6	-74	146	5040	194	< 1	31
C03	7/29/2009	20.6	4321	3.8	6.7	38	92	4310	135	<1	25
C04	2/17/2009	11.5	5442	5.4	6.6	-24	278	4920	388	<1	<1
C04	6/2/2009	17.5	4359	3.6	6.7	-58	164	4470	124	<1	34
C04	7/29/2009	20.4	4027	3.1	6.6	15	89	4010	105	<1	25
C05	1/8/2009	10.2	5516	4.7	6.6	77	324	5130	400	<5	42
C05	2/17/2009	10.9	5543	4.7	6.6	-27	385	5100	321	<1	<1
C05	6/2/2009	20.1	3281	4.3	6.8	-71	119	2910	74	< 1	38
C05	7/29/2009	21.3	2864	1.6	6.5	-39	84	2540	38	<1	25
C07	2/17/2009	10.5	5230	4.6	6.5	-14	622	4960	272	<1	59
C07	6/2/2009	18.3	2780	4.2	6.6	-63	157	2970	16	<1	70
C07	7/29/2009	22.1	2664	3.5	6.5	4	113	2880	8	<1	26
C08	1/8/2009	9.6	5674	4.7	6.6	31	NA	NA	NA	NA	NA
C08	2/17/2009	8.3	5761	6.3	6.7	42	NA	NA	NA	NA	NA
C08	3/24/2009	15.0	5186	4.8	6.6	174	249	5040	178	<1	7
C08	6/2/2009	18.8	3262	3.2	6.5	5	104	3760	13	<1	37
C08	7/29/2009	21.9	3064	2.6	6.5	32	71	3290	6	<1	25
C09	2/17/2009	9.0	4408	4.4	6.6	21	NA	NA	NA	NA	NA
C09	3/24/2009	14.6	4156	4.8	6.5	149	310	4190	120	<1	20
C09	6/2/2009	19.3	2469	3.5	6.6	-74	95	2160	133	2	48
C09	7/29/2009	22.8	2459	1.5	6.5	-89	109	2570	3	9	25
C10	1/8/2009	7.5	1966	2.5	6.8	74	101	960	17	<5	<5
C10	2/17/2009	7.7	2144	4.1	6.6	15	NA	NA	NA	NA	NA
C10	3/24/2009	14.2	2429	5.2	6.6	181	56	571	5	<1	10
C10	6/2/2009	20.7	2166	4.4	6.6	-51	45	966	19	<1	26
C10	7/29/2009	23.2	2140	2.3	6.6	-84	44	1510	2	<1	11

Sample ID	Date	SO4 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Fe(tot) mg/L	Fe(II) mg/L	Mn mg/L	Al mg/L	Sulfide mg/L	COD mg/L
C01	9/3/2008	170	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
C01	2/17/2009	252	600	190	42	890	2	2	11	<0.5	0.002	1192
C01	6/2/2009	286	510	190	36	790	<1	<1	10	<0.5	0.045	848
C01	7/29/2009	8	470	160	34	810	<1	<1	9	<0.5	0.04	NA
C02	1/8/2009	<5	570	175	35	910	1	1	9	<0.5	0.044	1875
C02	2/17/2009	40	640	195	45	890	1	1	10	<0.5	<0.001	1606
C02	7/29/2009	3	470	165	36	800	<1	<1	8	<0.5	0.11	NA
C03	8/4/2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
C03	2/17/2009	58	620	190	40	850	1	1	10	<0.5	0.013	1248
C03	6/2/2009	16	530	175	33	780	<1	<1	9	<0.5	0.13	740
C03	7/29/2009	2	430	145	26	600	<1	<1	8	<0.5	0.05	NA
C04	2/17/2009	205	610	185	41	830	1	1	10	<0.5	0.015	1258
C04	6/2/2009	18	510	160	27	590	<1	<1	8	<0.5	0.21	580
C04	7/29/2009	4	500	150	23	520	1	1	9	<0.5	NA	NA
C05	1/8/2009	<5	520	155	33	870	1	1	8	<0.5	0.027	1870
C05	2/17/2009	206	580	180	42	830	2	2	10	<0.5	0.007	1218
C05	6/2/2009	413	460	125	19	320	<1	<1	8	<0.5	1.24	380
C05	7/29/2009	249	440	110	15	100	<1	<1	8	<0.5	20.0	NA
C07	2/17/2009	195	570	185	37	870	<1	<1	7	<0.5	0.011	1540
C07	6/2/2009	67	380	100	13	290	<1	<1	4	<0.5	7.04	358
C07	7/29/2009	34	395	105	11	210	<1	<1	4	<0.5	8.56	NA
C08	1/8/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
C08	2/17/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
C08	3/24/2009	18	480	175	34	870	2	2	9	<0.5	0.022	1036
C08	6/2/2009	8	380	130	14	380	<1	<1	7	<0.5	0.029	410
C08	7/29/2009	3	415	130	12	290	4	4	8	<0.5	0.014	NA
C09	2/17/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
C09	3/24/2009	14	480	140	25	550	6	6	7	<0.5	<0.001	1048
C09	6/2/2009	411	430	105	12	130	<1	<1	5	<0.5	19.8	158
C09	7/29/2009	75	410	99	10	84	<1	<1	5	<0.5	22.6	NA
C10	1/8/2009	612	270	59	9	130	2	2	5	<0.5	0.044	247
C10	2/17/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
C10	3/24/2009	1220	420	103	12	36	3	6	8	<0.5	<0.001	38
C10	6/2/2009	883	400	96	10	14	<1	<1	7	<0.5	29.1	20
C10	7/29/2009	508	410	97	11	15	<1	<1	7	<0.5	22.0	NA