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CHROMIUM SPECIATION AND MOBILITY IN
CONTAMINATED SOILS, SAULT STE. MARIE, MI

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**CHROMIUM SPECIATION AND MOBILITY IN CONTAMINATED SOILS,
SAULT STE. MARIE, MI**

By

Gary Allen Icopini

A DISSERTATION

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ABSTRACT

CHROMIUM SPECIATION AND MOBILITY IN CONTAMINATED SOILS, SAULT STE. MARIE, MI

By

Gary Allen Icopini

The fate and mobility of chromium in a wetland area was studied using both field and laboratory techniques. Wetlands have been used as sinks for chromium because in reducing wetland environments chromium will exist as Cr(III) which is a less toxic form of chromium and inorganic Cr(III) solids are very insoluble. However, there is very little information concerning the mobility of chromium in organic rich environments like wetlands. Chromium speciation in the soils was investigated using sequential chemical extractions. Chromium speciation in the aqueous samples was investigated using solid phase extraction resins that removed the cationic, anionic, and hydrophobic organic species from solution. The mobility of chromium in these soils was assessed using intact soil core microcosms. The microcosms were treated with solutions to simulate acid rain deposition and the influx of nitrate and potassium.

The speciation work indicated that chromium was associated with both inorganic and organic components of the system. The results from the soil speciation studies showed that the solid phase chromium was primarily extracted by the acidic moderately reducible (MR) and basic oxidizable extractions. These results indicate that the solid forms of chromium in these environments will be either a chromium hydroxide or associated with the soil organic matter, with chromium hydroxide becoming more

dominant at higher total concentrations of chromium in the soils. The aqueous phase chromium concentrations in the surface and pore waters at this site are higher than would be predicted by inorganic thermodynamic calculations. No Cr(VI) was observed in these samples. The aqueous chromium in the field samples was found to be slightly correlated with dissolved organic carbon ($R^2=0.66$). The results of the solid phase extraction performed on the aqueous field samples show that aqueous chromium in field samples exists primarily as an anion in these waters (96%). It is concluded that the solubility and mobility of chromium is controlled, at least in part, by complexation with dissolved organic carbon and that this may be a thermodynamically driven process.

Intact soil core microcosms were used to investigate the mobility of chromium in laboratory studies. The data from the microcosm experiments also indicated that the aqueous chromium existed as an organically complexed anion. The results of the microcosm experiments indicate that the solubility of chromium may also be increased if the soils experience periods of cyclic saturation and unsaturation. There also may be an increased solubility of chromium if the degradation of soil organic matter is increased.

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I. INTRODUCTION

1.1 The Problem

The purpose of this study was to investigate the fate and mobility of chromium in a wetland area contaminated with tannery waste. This study was part of a larger project that was designed to address two primary goals. The first goal was to define the current state of chromium in the soil and aqueous phases of the site. The second goal was to evaluate the stability of the chromium in the soil and assess the potential for mobilization of chromium from these soils. This project was the result of a collaboration between personnel with the Center for Microbial Ecology and the Geological Sciences Department at Michigan State University. The focus of the study presented here is the geochemical aspects of the project.

The biogeochemistry of chromium is complicated by its redox chemistry; in the environment chromium can exist as Cr(III) or Cr(VI) (Rai et al., 1989). Chromium (VI) is known to be toxic, mutagenic, and carcinogenic (Palmer and Puls, 1994) and Cr(VI) is also highly mobile in many soil environments (Rai et al., 1989). However, almost any naturally occurring reductant can reduce Cr(VI) to Cr(III) (Rai et al., 1989; Palmer and Puls, 1994) and chromium in tannery effluent is likely to be in the Cr(III) form (Walsh and O'Halloran, 1996a; Kotas and Stasicka, 2000). Chromium (III), in comparison to Cr(VI), is relatively immobile within a pH range of 5 to 12 (Sass and Rai 1987) and has a relatively low toxicity (Palmer and Puls, 1994). Chromium (III) also bonds with organic compounds (James and Barlett, 1983a and b; Walsh and O'Halloran, 1996a and b; Kotas

and Stasicka, 2000). The nature of chromium speciation in soil and groundwater environments is complex. Processes that control chromium speciation include redox transformations, precipitation/dissolution reactions, and adsorption/desorption reactions.

The environmental chemistry of chromium has received much attention, especially in the last twenty years (Rai et al., 1989; Richard and Bourg 1994; Losi et al., 1994a; Fendorf, 1995; Kotas and Stasicka 2000). This research includes laboratory investigations of the reactivity and mobility of chromium in simple systems with limited components (Rai et al., 1987; Eary and Rai, 1987; Fendorf et al., 1993; Wittebrodt and Palmer, 1996a and b; Buerge and Hug, 1998; Zhang and Bartlett, 1999) and complex systems involving natural materials, such as soils and aquifer material (Bartlett and Kimble, 1976a and b; Bartlett and James, 1979; Bartlett and James, 1983a, b, and c; Zachara et al., 1989; Saleh et al., 1989; Milacic and Stupar, 1995; and Cifuentes et al., 1996). There have also been a number of field-based studies dealing with chromium mobility and reactivity (Davis et al., 1994; Kent et al., 1994; Armienta and Quere, 1995; Walsh and O'Halloran, 1996). The majority of the field studies deal with the development of remedial options for Cr(VI) in ground-water environments (Davis and Olsen, 1995; Palmer and Puls, 1994). Common remedial approaches to Cr(VI) contamination involve reducing the chromium to Cr(III) *in situ* (Hanson et al., 1993; Powell et al., 1995; and Blowes et al., 1997). The rationale for this approach is based on the assumption that inorganic Cr(III) solids are very insoluble and Cr(III) is not considered to be toxic (Palmer and Puls, 1994). However, there is very little information concerning the speciation or mobility of chromium in organic rich environments like wetlands.

Natural and constructed wetlands have been proposed as treatment options for heavy-metal (including chromium) contaminated water because wetlands have been demonstrated to act as sinks for metals (Makos and Hrncir, 1995; Polprasert et al., 1996; Scholes et al., 1998; Barbosa and Hvitved-Jacobsen, 1999). However, natural wetlands are often host to complex webs of physical and biogeochemical cycles that may influence metal mobility. An example of one such cycle is the oxidation of Cr(III) to Cr(VI) by manganese oxides in water-surface films as described by Masscheleyn et al. (1992). In laboratory experiments, they observed the formation of Cr(VI) in stagnant water above wetland sediment. It was suggested that dissolved Cr(III) interacts with manganese in iron and manganese oxide films at the water surface and is oxidized to Cr(VI). The films were assumed to be primarily organic material upon which iron and manganese oxides precipitate as reduced dissolved iron and manganese interacts with oxygen from the atmosphere. The reduced iron and manganese came from the reduction of iron and manganese oxides in the sediment, which subsequently diffuses into the water column. This study demonstrates the need to examine the biogeochemistry of chromium in wetland environments.

Mattuck and Nikolaidis (1996) studied the mobility of chromium in a wetland using both field and laboratory methods. This study was similar to the work presented here. Dialysis membrane samplers were used to sample pore water. They reported aqueous chromium concentrations of 0 to 406 $\mu\text{g/L}$ in the pore waters but no Cr(VI). Although they reported relatively high aqueous chromium concentrations, they gave no explanation for these elevated chromium concentrations. Sequential chemical extractions performed on the sediments indicated that 60 to 90% of the chromium was bound in the

Fe/Mn-oxide and residual fractions, which was interpreted as sediment bound chromium. However, sodium pyrophosphate, which is not very aggressive (Chao, 1984), was used as the organic matter extractant. According to Chao (1984) sodium pyrophosphate extracts the organic matter by chelating and stripping the metals that bind the organic matter together. A combination of nitric acid and hydrogen peroxide, which oxidizes organic carbon and are often used as organic matter extractants (Chao, 1984; Tessier et al., 1979; Belzile et al., 1989; Schulmeister 1993; and Fielder et al., 1994), was used as the residual extraction. It is possible that much of the chromium that Mattuck and Nikolaidis (1996) have assigned as sediment bound may actually be organically bound chromium released by the residual extraction. Mattuck and Nikolaidis (1996) also performed stirred, batch, leaching experiments to simulate acid rain deposition or acidic groundwater influx. The leaching experiments were conducted at pH 3, 4, and 5. The most chromium was released increased as the pH of the slurry decreased, with the highest chromium concentrations of approximately 20 $\mu\text{g/g}$ at pH 3. They suggest that the mobility of chromium in wetlands is controlled by the formation of relatively insoluble chromium hydroxide solids. This study will add to the understanding of the fate and mobility of chromium in wetland environments.

1.2 Approach

The first goal was to define the current state of chromium in the soil and aqueous phases. In order to understand how chromium may become mobile at this site, it was necessary to determine the state of chromium in the soil and aqueous phases that developed over the past fifty years. The primary hypothesis was that chromium is associated with soil organic matter as Cr(III) and that dissolved chromium will be

associated with dissolved organic matter. The most likely alternative to this hypothesis is that the chromium sequestered by these soils is in the form of a $(\text{Cr}_x, \text{Fe}_{1-x})(\text{OH})_3$ solid, which has a very low solubility (Rai et al., 1989). To test this hypothesis, soil samples were collected from three depths at 80 locations, which spanned the range of chromium concentrations and vegetative types. Selective chemical extractions were used to determine the partitioning of chromium in different environmentally reactive phases of the soil or sediment sample. Selective chemical extractions are designed to target specific solid phases within the sediment (Tessier et al., 1979; Belzile et al., 1989; Yong et al., 1993). Organic carbon, iron and manganese-oxides appear to be the major controls on chromium redox chemistry and mobility, therefore the selective extractions targeted these phases.

Along with the selective chemical extractions, pore water samples were collected and a new field sampling procedure was established to further investigate the biogeochemistry of chromium. Solid phase extraction media were used in the field in order to remove anion, cations, and hydrophobic organic compounds from aqueous samples in separate reactions. Solid-phase extractions (SPEs) were developed as separation media for liquid chromatography. Solid-phase extractions have also been used to investigate various aspects of aqueous geochemistry. SPEs have also been used for isolating dissolved organic matter (DOM) (Leenheer, 1981; Mills and Quinn, 1981; Mills et al., 1987) and metal-organic complexes from natural waters (Mills et al., 1982; Mills and Quinn, 1984; Mills et al., 1987; Mills et al., 1989; Paulson et al., 1994; Elbaz-Poulichet et al., 1994; Martin et al., 1994; Donat et al., 1997). The majority of these workers used Sep-Pak columns (Waters Associates) which are selective for the

hydrophobic fraction of DOM. This study also used Sep-Pak columns to perform this separation. SPEs have also been used to remove cations from aqueous environmental samples (Pai and Fang, 1990; Davis et al., 1994; Kaplan et al., 1994). Chelex-100 resin in the sodium form (BIORAD Inc.) was used in this study to remove cations from solution and replace them with sodium. Relatively fewer investigators report the use of anion exchange resins to investigate speciation in environmental samples (Leenheer, 1981; Kaplan et al., 1994). AG anion exchange resins in the fluoride form (BIORAD Inc.) were used in this study to separate anions, in particular organic anions, from the bulk sample.

The second goal of the project was to evaluate the stability of the chromium in the soil and assess to the potential for mobilization of chromium from these soils. A secondary hypothesis is that the mobility of chromium in these soils is controlled by the stability of the organic matter to which it is bound. Experiments were conducted in the laboratory using intact soil microcosms to assess mobility. The design and data collection involved in the microcosm experiments were the result of collaboration with the microbiologists working on the project. During these experiments treatment fluids were pumped through a soil core and allowed to react for a period of at least one week. The objective of these experiments was to determine the biogeochemical conditions in which chromium may become mobile. Conditions that were tested included: addition of nutrients (nitrate, phosphate, and potassium), the addition of an alternate terminal electron acceptor (nitrate), and changes in pH. The biogeochemical conditions were monitored during the experiments and total extractions were performed on the soils before the experimentation.

The criteria for the selection of treatments was limited to simulating possible events that could occur at this site that may change the mobility of chromium. If the chromium is predominantly present as a $(\text{Cr}_x\text{Fe}_{1-x})(\text{OH})_3$ species the concentration of chromium in solution will be controlled by the solubility of this solid. The first treatment chosen for the microcosm experiments was the simulation of the acidification of the pore water at the site due to acid rain. An acid rain treatment was chosen because it was thought to be the most likely acidification event at this site. An amount of fluid equivalent to approximately five years of acidic precipitation was pumped through the microcosms during the experiment.

Other treatments were developed to further test the hypothesis that the mobility of chromium in these soils is controlled by the stability of the organic matter to which it is bound. If chromium is associated with soil organic matter, the degradation of the organic matter may release chromium to solution as an organically complexed species.

Therefore, the amount of chromium in solution would be proportional to the amount of organic matter degraded. The treatments for the second round of microcosm experiments were designed to determine if chromium could be mobilized from the soils by changes in microbial processes. The treatments for the second set of microcosm experiments were designed to simulate the possible addition of nutrients. One of these treatments attempted to maximize the efficiency of the microbial community by altering the redox state to a higher level. In this treatment 90 mg/L nitrate was added to a simulated rain solution. Another treatment attempted to simulate an overall increase in the nutrient level of the pore water. The objective of this treatment was to add nutrients to the system that were lacking and thereby potentially increasing the microbial degradation of organic matter.

In this treatment nitrate and phosphate were both added in concentrations of 25 mg/L and 2 mg/L respectively to a simulated rain solution.

II. BACKGROUND

2.1 Study Site

The study site was in Sault Ste. Marie, MI and borders the St. Mary's River (Figure 1-site map). The site supports abundant plant life and much of the site is considered to be a wetland. The soils and subsurface geology are complex and heterogeneous across the site. The dark, near-surface soils contain abundant organic matter and in some areas the soils have been characterized as peat (Cannelton, 1992). Almost all parts of the site are covered by fill. The fill consists of materials such as scrap leather, hair, bricks, concrete, scrap wood, scrap metal, glass, and cans. The fill was

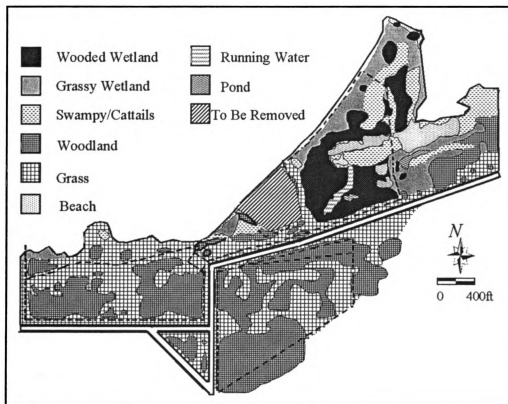


Figure 1. A map of the study site, showing type of vegetative surface coverings.

deposited on discontinuous layers of sands and gravels, with the predominant texture of a silty sand (Cannelton, 1992). Depth to bedrock, which is reported to be Jacobsville Sandstone, ranges from 30 to 60 feet (Cannelton, 1992).

This research was initiated as the result a practical need for scientific information concerning the mobility of chromium at the site. The study site is a wetland that received tannery waste discharge from the late 1890's until approximately 1958. During the tanning process an acidic Cr(III) solution is used to bind collagen fibers of the skin and make the leather resistant to degradation (O'Flaherty et al., 1958; Walsh and O'Halloran, 1996b). This solution is provided in excess and there is a large amount of waste fluid produced. Today tannery waste is regulated but during the time when the tannery at the site operated there were few regulations and liquid waste was disposed of through pipes and ditches that drained toward the river. As a result of this activity, there are areas at this site which have concentrations of chromium in the soil which exceed 200,000 mg/kg. The primary discharge areas that have the highest concentrations of chromium will be removed.

2.2 Geochemistry of Chromium

In aqueous environments Cr(III) forms strong complexes with OH^- and exhibits amphoteric behavior (Baes and Mesmer, 1976). In the pH range of most natural waters (pH 6-8) it exists primarily as a $\text{Cr}(\text{OH})_3$ solid (Rai et al., 1989). The solubility of the $\text{Cr}(\text{OH})_3$ solid is very low (Baes and Mesmer, 1976) and if Fe^{3+} is present Cr(III) preferentially forms $(\text{Cr}_x\text{Fe}_{1-x})(\text{OH})_3$ (Sass and Rai, 1987). The $(\text{Cr}_x\text{Fe}_{1-x})(\text{OH})_3$ solid is highly insoluble and since iron is present in geologic environments the solubility of Cr(III) in most natural systems is very low (Rai et al., 1989). Chromium (III) is also

known to bind to soil organic matter (Bartlett and Kimble, 1976b; Palmer and Puls, 1994). Likewise, Cr(III) can be complexed by dissolved organic matter, thereby increasing the solubility of Cr(III) in soil environments (James and Bartlett, 1983a,b; Davis et al., 1994; Walsh and O'Halloran, 1994 a and b). Davis et al. (1994) studied the mobility of chromium and arsenic in an aquifer at a site contaminated by tannery operations similar to the study site. They found aqueous Cr(III) concentrations much higher than expected from equilibrium with solid phases. The increase in solubility was attributed to complexation with dissolved organic matter. Walsh and O'Halloran (1994b) in studying chromium speciation in an estuary receiving tannery effluent also found high Cr(III) concentrations and attributed these concentrations to complexation with dissolved organic matter. Overall however, the solubility of Cr(III) in most natural systems is very low.

The redox potential of the Cr(VI)/Cr(III) couple is very high and because of this there are few oxidants present in natural systems that are capable of oxidizing Cr(III) to Cr(VI) (Rai et al., 1989). Dissolved oxygen and manganese oxides (MnO_2) are the only two oxidants in the environment that are known to oxidize Cr(III) to Cr(VI) in the pH range of most natural waters (Palmer and Puls, 1994). The oxidation of Cr(III) by dissolved oxygen has been shown to be a very slow reaction (Schroeder and Lee, 1975) and in some studies no oxidation was observed (Eary and Rai, 1987; Bartlett and Kimble, 1976a). Oxidation of Cr(III) to Cr(VI) by Mn-oxides has been demonstrated in a number of studies (Schroeder and Lee, 1975; Bartlett and James, 1979; Takacs, 1988; Eary and Rai, 1987). This reaction is much more rapid than the oxidation Cr(III) by dissolved oxygen and is likely to be more important in groundwater and soil systems.

Chromium (VI) exists in aqueous solutions as monomeric ions H_2CrO_4^0 , HCrO_4^- , and CrO_4^{2-} , or as the dimeric ion $\text{Cr}_2\text{O}_7^{2-}$ (Palmer and Puls, 1994). Chromium (VI) is relatively more mobile than Cr(III) in subsurface environments. The solubility of Cr(VI) is controlled by the formation of the $\text{Ba}(\text{Cr,S})\text{O}_4$ solid solution in environments that contain BaSO_4 (Rai et al., 1989). When BaSO_4 solids are not present in the system, Cr(VI) solubility will be controlled by adsorption/desorption reactions under acidic to slightly basic conditions (Rai et al., 1989). It has been shown that Cr(VI) is adsorbed by iron oxides, aluminum oxides, and kaolinite (Davis and Leckie, 1980; Zachara et al., 1989; Rai et al., 1989). Adsorption to these solid phases is inversely proportional to pH, adsorption decreases with increasing pH. Under acidic to slightly basic conditions iron oxides are the dominant adsorbents in the environment (Zachara et al., 1989; Rai et al., 1989).

Since Cr(VI) is a strong oxidant it can be reduced by many reducing agents found in natural systems. Ferrous iron as aqueous Fe^{2+} (Eary and Rai, 1988) or derived from oxide or silicate minerals (Eary and Rai, 1989; White and Hochella, 1989) has been shown to rapidly reduce Cr(VI) to Cr(III), which can lead to the formation of a $(\text{Cr}_x\text{Fe}_{1-x})(\text{OH})_3$ precipitate. Microbial reduction of Cr(VI) to Cr(III) has also been documented (Llovera et al., 1993; Shen and Wang, 1994). Reduction of Cr(VI) by soil organic matter has also been documented (Schroeder and Lee, 1975; Bartlett and Kimble, 1976b). The Cr(III) may hydrolyze and precipitate as a chromium -hydroxide or it may bind to the remaining soil organic matter (Palmer and Puls, 1994). Reduced sulfur is another naturally occurring reducing agent that has been found to reduce Cr(VI) (Smilie et al., 1981; Palmer and Puls, 1994). Rai et al. (1989) conclude that since ferrous iron and

organic matter are ubiquitous in soil and groundwater, Cr(VI) will be reduced to Cr(III) in many natural systems.

III. METHODS

This chapter is divided into three sections. The first section describes the methods used for collection and analysis of solid samples, which includes soils and sediments. The second section describes the methods used for collection and analysis of liquid samples. The third section describes the experimental design and sampling for the microcosm experiments. Images presented in this dissertation are presented in color.

3.1 Solid samples

3.1.1 – Sample Grid Development, Surveying, and Site Locations

The first step in the sampling program was to develop an unbiased sampling grid that covered the entire site. A basic GIS analysis was performed on a preexisting data set (Cannelton, 1992; Cannelton, 1995) to identify possible trends in chromium concentrations across the site, identify areas of data need, and determine the spacing between sampling locations. This analysis led to the development of the sampling grid used in this study. There were several factors considered in the grid development including, sampling from areas that represented the full range of concentrations, and equally spaced sampling locations to reduce sampling bias.

An existing local datum was used as the starting point for the grid. The sampling locations were then established by measuring distances with surveying equipment and a 200-ft. steel tape from known positions. Each sampling location was marked with a wooden stake, which could then be used to site other locations. The grid showing labeled sampling locations is illustrated in Figure 2.

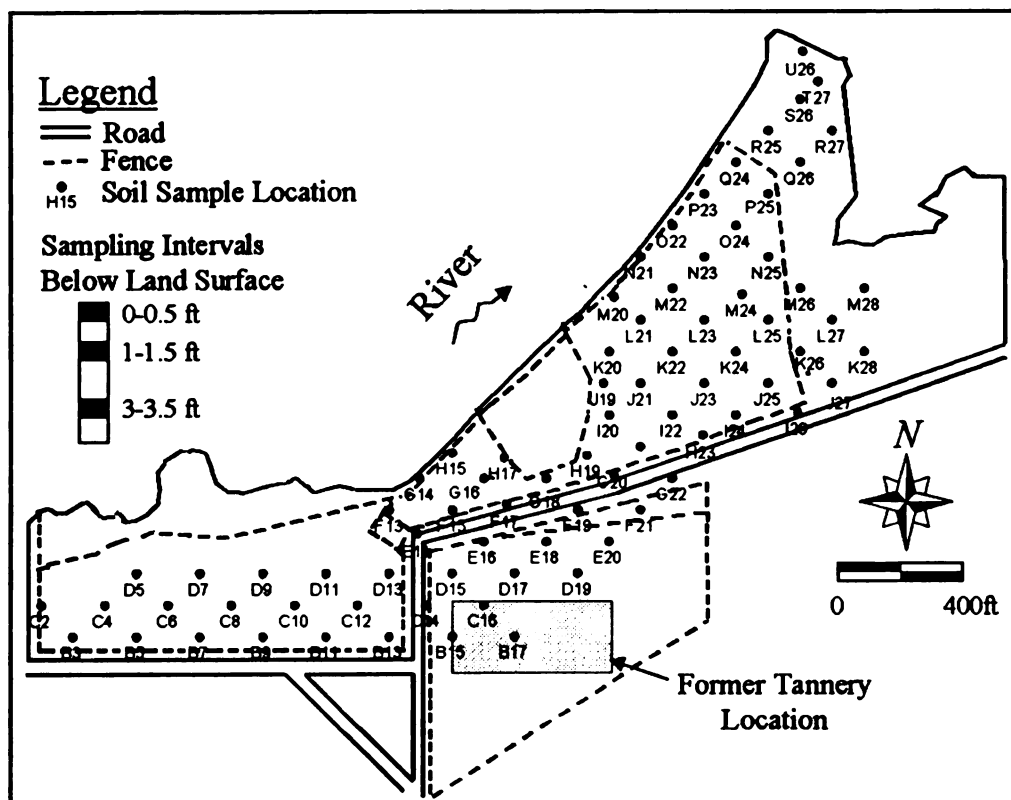


Figure 2. A map of the study site, showing the locations of the sampling sites.

3.1.2 – Sample Collection

Soil cores were collected with an AMSTM stainless steel, split spoon, coring device, with two-inch diameter, plastic core liners to contain the sample. Initially, samples were collected from three depths at each site. Sampling intervals below land surface were 0 to 0.5 feet, 1.0 to 1.5 feet, and 3.0 to 3.5 feet. An AMSTM hand auger was used to remove intervening material between the sampling depths. Some sampling difficulties arose when rocks, wood, or other impenetrable objects were encountered at depth. Thus it was not always possible to obtain three samples at every location. Samples were collected in acid-washed plastic core liners, the ends were capped and taped to eliminate further exposure to the atmosphere, and stored on ice in the field. The

sample location and core descriptions are presented in Appendix A. Samples were frozen within 8 hours after collection and stored at approximately -20°C .

3.1.3 – Sequential Chemical Extractions

Selective chemical extractions were used to determine the partitioning of chromium in different environmentally reactive phases or hydromorphic phases of the soil or sediment sample. Selective chemical extractions are designed to target specific solid phases within the sediment. Organic carbon, iron and manganese-oxides appear to be the major controls on chromium redox chemistry and mobility, therefore the selective extractions targeted these phases. The use of these methods has been questioned because of the non-specific nature of the extractions and possible post-extraction readsorption occurring between extractions (Gruebel et al., 1988; Rapin et al., 1986; Rauret et al., 1989; and Tipping et al., 1985). However, there appears to be a consensus that these methods can be used to gain useful information concerning metal partitioning within sediments as long as the limitations are recognized (Gephart, 1982, Chao, 1984, Martin et al., 1987, Belzile et al., 1989, Schulmeister, 1993, and Fielder et al., 1994).

One approach to the use of selective chemical extractions is to use them in sequence. The chemical extractants are applied to a soil sample in sequence starting with the least aggressive extractant. Upon completion of each reaction, solutions are centrifuged and the supernatants extracted for analysis. A summary of selected sequential extraction procedures is presented in Table 1. The hydromorphic fractions generally targeted include exchangeable (metals bound to exchange sites on clays), easily acid soluble (metals associated with carbonates), easily reducible (metals associated with Mn-oxides), moderately reducible (metals associated with Fe-oxides), oxidizable (metals

Table 1. A summary of selected sequential extraction procedures.

Authors	Exchange able	Weakly acid soluble	Easily reduced	Moderately reduced	Oxidizable	Residual	Other phases
Tessier et al. 1979	1. 1 M MgCl ₂	2. 1 M NaOAc in HOAc, pH 5		3. 0.04 M NH ₂ OH·HCl in 25% HOAc	4. 30% H ₂ O ₂ and HNO ₃ to pH 2; and 3.2 M NH ₄ OAc in 20% HNO ₃	5. HF-HClO ₄	
Hoffman and Fletcher 1979			2. 0.1 M NH ₂ OH·HCl, pH 2.5	3. 0.175 M (NH ₄) ₂ C ₂ O ₄ - 0.1 M H ₂ C ₂ O ₄ , pH 3.5	1. NaOCl, pH 9.5	5. HClO ₄ and HNO ₃	4. Crystalline Fe-oxides - Na-DCB*, pH 7
Emmerich et al. 1982	1. 0.5 M KNO ₃	4. 0.05 M Na ₂ -EDTA			3. 0.5 M NaOH	5. HNO ₃	2. Adsorbed - X-H ₂ O**
Mahan et al. 1987 microwave technique	1. 1 M MgCl ₂	2. 1 M NaOAc in HOAc, pH 5		3. 0.04 M NH ₂ OH·HCl in 25% HOAc	4. 30% H ₂ O ₂ and HNO ₃ to pH 2; and 3.2 M NH ₄ OAc in 20% HNO ₃	6. Aqua regia and HF and Boric acid	
Belzile et al. 1989	1. 1 M MgCl ₂	2. 1 M NaOAc in HOAc, pH 5	3. 0.1 M NH ₂ OH·HCl in 0.1 N HNO ₃	4. 0.04 M NH ₂ OH·HCl in 25% HOAc	5. 30% H ₂ O ₂ and HNO ₃ to pH 2; and 3.2 M NH ₄ OAc in 20% HNO ₃		
Ure et al. 1993		1. 0.11 M HOAc		2. 0.1 M NH ₂ OH·HCl with HNO ₃ pH 2	3. 30% H ₂ O ₂ and HNO ₃ to pH 2; and 1 M NH ₄ OAc with HNO ₃ pH 2		

* Na-DCB -- Na dithionite-sitrate-bicarbonate. ** X-H₂O -- Ion exchange water, extracted three times.

associated with organic matter and sulfides), and residual (metals associated with chemically resistant mineral phases).

The procedure used in this study is a modification of the procedure used by Belzile et al. (1989) with additions to better characterize the organic and possible sulfide mineral phases. The modification consisted of inserting a 5% NaOCl (pH 9.5) extraction between the 0.04M hydroxylamine HCl extraction and the 30% H₂O₂ (pH 2) extraction. The NaOCl should dissolve organic carbon and liberate metals associated with it, while having little impact on the sulfide phases present (Papp et al., 1991). The procedure used is listed in Table 2 and a detailed description of the procedure is outlined in Appendix B.

Table 2. Summary of the sequential extraction procedure used in this study (modified after Bezile et al., 1989).

Target Substrate	Extraction Phase	Extraction Solution*	Extraction Conditions
Exchange Sites	Exchangeable (EX)	1.0M MgCl ₂ , pH 7 10 mL	20°C, 1 hour
Carbonates	Weakly Acid Soluble (WAS)	1.0M NaOAc, pH 5 10 mL	20° C, 5 hours
Reactive Fe-Oxides and Mn- Oxides	Easily Reducible (ER)	0.1M NH ₂ OH·HCl in 0.1M HNO ₃ 25 mL	25° C, 5 hours
Crystalline Fe-Oxides	Moderately Reducible (MR)	0.04M NH ₂ OH·HCl v/v 25%HOAc20 mL	96° C, 6 hours
Organic Matter	Basic Oxidizable (OX1)	NaOCl, pH 9.5 3 times, 6 mL each then 3.2M NH ₄ OAc5 mL	96° C, 15 min. 25° C, 1 hour
Sulfides	Acid Oxidizable (OX2)	0.02M HNO ₃ , 3 mL 30% H ₂ O ₂ , pH 2, 8mL then 3.2M NH ₄ OAc, 5mL then add DDW to 25mL	85° C, 5 hours 25° C, 1 hour

3.1.4 – Total Extractions

Total extractions were performed on samples taken from the top and bottom of cores used in the microcosm experiments. The total extraction method used in this study

was based on that of Hewitt and Reynolds (1990). The extraction was conducted in CEMTM PTFE, microwave digestion vessels. The extraction consisted of placing approximately 0.5 g of dry soil in a digestion vessel, adding 10 mL of trace-metal grade nitric acid, and then sealing the vessel before heating in a microwave. The digestion vessels were then allowed to depressurize and then the sample was diluted to 100 mL with distilled-deionized water.

3.1.5 – Solid Phase Organic Carbon Content

Organic carbon content of soils was determined by a loss on ignition method. Organic matter content was determined using sub-splits of homogenized soil taken prior to the sequential chemical extractions. The method was modified after a procedure developed by researchers from the Department of Soil Science at the University of Wisconsin, Madison, WI (Shulte et al., 1991). Analyses were done in the Plant and Soil Testing Lab at Michigan State University.

3.2 Aqueous Samples

3.2.1 – Sample Collection

This section provides a brief description of the sample collection approach. A more detailed description of the sampling collection procedures can be found in Appendix C. Sampling of the pore waters was accomplished with two types of dialysis membrane samplers. The first type (Figure 3) is a solid block of acrylic (3' x 24" x 4 or 6"), called a peeper, in which hollow ports have been drilled. Peepers with two different sizes of ports were used during the sampling. Each port contained approximately 15 or 40 mL of water. The ports on the peeper were filled with de-aerated distilled, deionized water (DDDW). A semi-permeable membrane (0.2 μ m pore diameter Biodyne B™

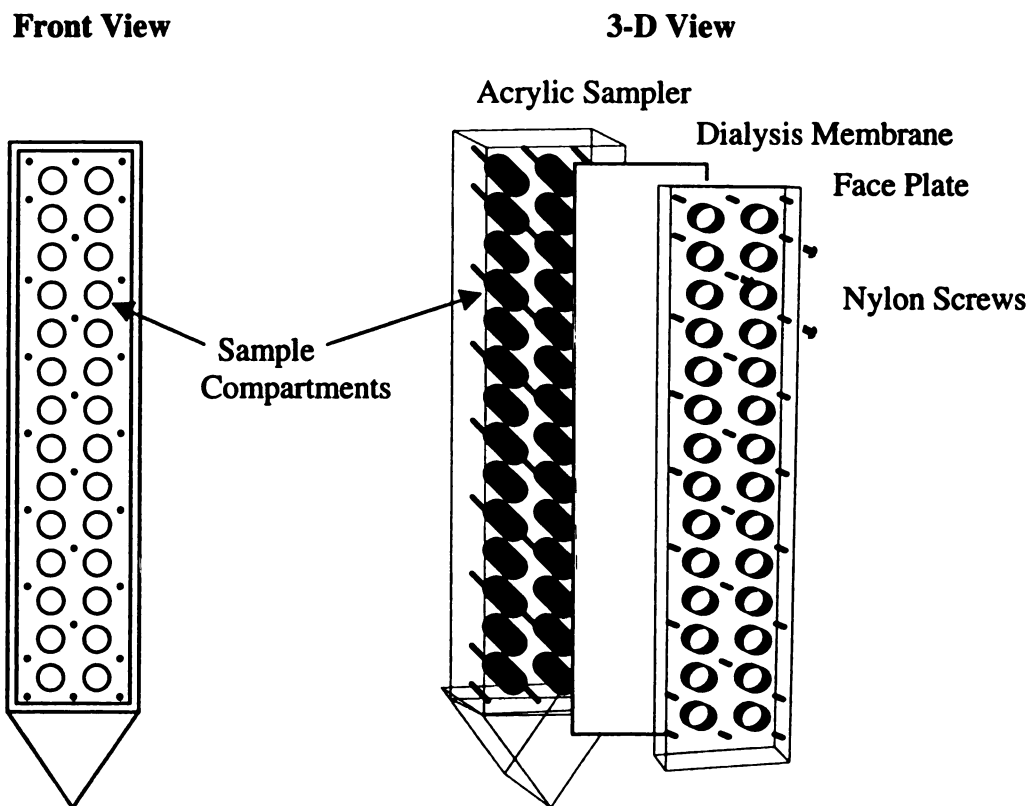


Figure 3. Schematic diagram of a “peeper” sampler used to collect pore-water samples.

nylon membrane, Pall Corp.) was placed across the filled peeper ports (while expelling all gas bubbles) and held in place by an acrylic face plate which was secured with nylon screws.

The second type of dialysis membrane sampler ('barrel' sampler; Figure 4) was originally designed as a component of a multi-level sampling apparatus for water wells (U.S. Filter/Johnson Screens Corp.). A barrel consists of a polyethylene tube (1" diameter x 3" long) with caps that screw onto each end of the tube. Each barrel contained approximately 45 mL of water. The barrel samplers are designed with disposable, nylon, dialysis membranes (0.2 μm), which were fitted in to screw cap ends of the barrel. The barrels were filled with de-aerated distilled, deionized water and capped with the membrane screw caps such that no gas bubbles were present inside the barrel.

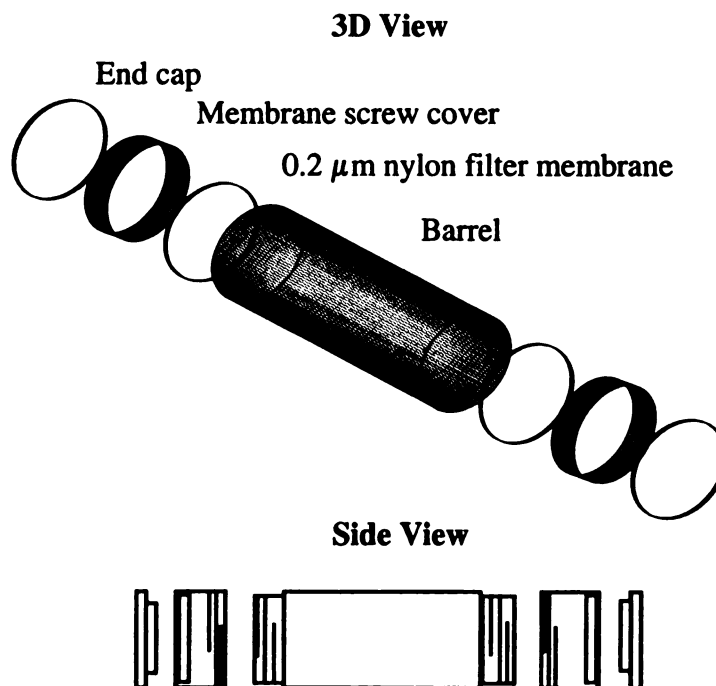


Figure 4. Schematic diagram of a "barrel" sampler used to collect pore-water samples.

The membrane allows exchange of solutes between the distilled water and the surrounding pore waters of a saturated porous medium (Hesslein, 1976; Carignan et al., 1985; and Tessier et al., 1996). The peepers and barrels were installed below the land surface in saturated areas. The samplers were left in place for at least two weeks to allow biogeochemical equilibration to occur between the sampler and the pore water (Hesslein, 1976; Carignan et al., 1985; Tessier et al., 1996). In order to obtain sufficient fluid for analysis, four to six adjacent peeper ports were sampled to make up one sample. Three barrels bound together constituted one sample when using barrel samplers.

Aqueous field sampling was conducted during the summer and fall of 1997 and 1998. During the latest field-sampling season, samples were also taken from the surface waters at the site. The surface water sampled was primarily shallow, standing water less than six inches deep but samples of springs and deeper water were also obtained. The sampling of surface waters was accomplished with a battery operated peristaltic pump, which was used to pump water through a 0.45 μm filter. The filtered water was collected in a 1 L, acid-washed, polypropylene bottle and filled to allow minimal or no headspace. Splits were then taken from the 1 L bottle for the various analyses that were performed, as described in the following section.

3.2.2 – Analytical Measurements

Field measurements that were made included temperature, pH, Eh, S^{2-} , Cr(VI), Fe^{2+} , and alkalinity. Laboratory measurements included dissolved organic carbon (DOC), NH_4^+ , CH_4 , anions (Cl^- , Br^- , NO_3^- , NO_2^- , SO_4^{2-}), and metals (Cr, Fe, Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Mn). Eh and pH were determined with electrodes. Sulfide was determined using sulfide vacu-vials (Chemetrics Inc.). Cr(VI) was determined using a

diphenylcarbazide colorimetric method (Fishman and Friedman, 1989). Fe(II) was determined using a phenanthroline colorimetric method (APHA, 1992). Alkalinity was determined by titration with sulfuric acid (APHA, 1992). Anions were analyzed by capillary electrophoresis (APHA, 1998) using an Applied Biosystems model 270HT capillary electrophoresis instrument. Cations were acidified to below pH 2 with Optima™ nitric acid and refrigerated until analysis. Cation concentrations in the field samples and the fluids from the total extractions were quantified using inductively coupled plasma mass spectroscopy (ICP-MS; VG-Elemental Plasma Quad1 or Micromass Platform). Cation concentrations that were in the high mg/L range and the fluids from the sequential extractions were quantified using atomic absorption spectroscopy (AAS; Perkin-Elmer model 5100PC), depending on concentration and the matrix of the samples. Multiple measurements were taken for each cation analysis (for both AAS and ICP-MS) and all the data satisfied the precision requirement of being within 10% RSD. Methane samples were analyzed by headspace extraction and quantified on a gas chromatograph. DOC samples were frozen immediately on dry ice and analyzed with a TOC 5000 Shimadzu carbon analyzer.

3.2.3 – Solid Phase Extraction Media

Chromium speciation was estimated by utilizing three different solid phase extraction resins in the field. Aqueous samples were brought into contact with these resins which removed different dissolved species in the sample. Chelex-100 resin in the sodium form (BIORAD Inc.) was used to remove cations from solution and replace them with sodium. The reaction was conducted as a batch reaction. Approximately one gram of resin was allowed to react with 8 to 10 mL of sample for at least one hour, as described

in the product literature (BIORAD Inc.). The sample was then filtered through an acid-washed, poly-carbonate, 0.4 μm nucleopore filter and acidified to a pH less than 2 with Optima™ nitric acid. The chromium remaining in solution after the reaction should have a negative or neutral charge.

One of the main goals for this research was to explore the role organic complexes has on chromium mobility. The anionic exchange resins were selected with the separation of organic molecules in mind, as they are among the suspected complexing agents of chromium. In the pH range of these waters, most of the functional groups on dissolved organic matter will be negatively charged (McBride, 1994). The AG 1 and AG MP resins (BIORAD Inc.) are strong anion exchange resins. AG-1 and AG MP are essentially the same resin except that AG-1 is for small molecules (molecular weights less than 2700) and AG MP is for large molecules (molecular weights up to 100,000 and higher). The AG MP resin was deemed necessary because the size of organic molecules could not be determined but was assumed to vary greatly with some being quite large. The resins were loaded into 10 cm glass columns with a 1 cm inner diameter. The lower half (outlet) of the column was filled with the AG-1 resin and the upper half (inlet) was filled with the AG MP resin. This insured that all sizes of anions could be removed.

The AG resins were purchased in the chloride form. The form (indicating the exchange ion that is liberated from a resin upon reaction with sample fluids) can be changed depending on the needs of the application (BIORAD Inc.). Different ions have different affinities for a particular resin. A resin with the most easily replaced ion attached is said to be in the most reactive form. The most reactive form for these resins is the hydroxide form and the most reactive form of the resin was desirable for this study.

However, the hydroxide form was undesirable because chromium is a pH sensitive element. The fluoride form is the next most reactive form of the resin. Since fluoride should not influence the pH of the water or the chemistry of chromium, these resins were used in the fluoride form.

The form of the resin was changed in two steps (as described in the product literature, BIORAD Inc.). First, the resins were converted from the Cl form to the hydroxide form by slowly (approximately 3 mL/min.) pumping 200 mL of 1.0 M NaOH through the column. Second, the resins were converted to the fluoride form by slowly (approximately 3 mL/min.) pumping 200 mL of 0.85 M NaF through the column. The conversion to the fluoride form was monitored by measuring the pH of the effluent during the process to insure that the pH returned to a neutral value. The volumes of NaOH and NaF solutions used to perform the conversions exceeded the recommended maximum volumes suggested for the conversion of these resins (BIORAD Inc.). Finally, 150 mL of deionized, distilled water (DDW) was passed through the column as rinse and to replace the pore water in the column with DDW. The columns were sealed with parafilmTM and stored upright until their use. The conversion was performed 2-5 days prior to use.

Along with being negatively charged, natural DOC may also exist as an uncharged hydrophobic species, which may also be complexed with metals such as chromium (McBride, 1994; Mills et al., 1987; Paulson et al., 1994; Elbaz-Poulichet et al., 1994; Martin et al., 1994; Donat et al., 1997). Sep-PakTM (Waters Associates) columns were used to remove the organic-hydrophobic species from solution, along with the metals bound to them, from the samples. The Sep-Pak columns were conditioned prior to

sample processing using the method of Mills et al. (1987). Conditioning consisted of successively rinsing with 10 mL methanol, 10 mL 0.3 mM HCl, 10 mL methanol and then 20 mL of DDW. The columns were then stored in plastic bags until use. The conditioning was performed 2-5 days prior to use.

Field sampling using these columns consisted of filling a 60 mL syringe with approximately 70 mL of filtered sample from which split samples were taken for the various treatments. One split was taken as the control (approximately 10 mL), which was bottled and acidified with OptimaTM nitric acid immediately. One split was taken for DOC analysis (approximately 10 mL) and was frozen immediately. One split was added to the Chelex-100 resin (approximately 10 mL) in a batch reaction and allowed to react for at least one hour prior to being refiltered and acidified. The graduated syringe was then used to inject 20 mL of sample into the column containing the AG resin. After the sample was injected into the AG column another 50 mL of DDW was passed through the column as a rinse. Fluid coming from the column was contained in a 100 mL volumetric flask, which was diluted to 100 mL with DDW when the rinse was completed (total dilution of 1:5). The sample was then transferred to a bottle and acidified. The syringe was then used to inject 20 mL of sample into the Sep-Pak column. The sample was then passed through the Sep-Pak resin and diluted by the same procedure as that described above for the AG resin split.

3.3 Microcosm Design and Sampling

Intact soil-core microcosms have been effectively used in the laboratory to assess the potential for *in situ* bioremediation (Dolan and McCarty, 1995; EPA, 1989) and are the approved testing procedure of the EPA for the determination of the potential fate and ecological effects of contaminants in terrestrial ecosystems (EPA, 1996). Intact-core microcosms have an advantage over other designs as the sediment core undergoes minimal disruption and does not require the sample to be sieved, repacked or rewetted (EPA, 1996). The complex physical, geochemical, and ecological structure of the soil matrix and associated microbial communities are therefore better preserved for laboratory study. Although the results of microcosm studies are influenced by the nature of the geological material studied and microcosm design, the ability to replicate in the laboratory the geochemical and physical properties of the site coupled with a defined sampling strategy afford many advantages over other methods (Wiedemeier et al., 1995).

The design of and data collection involved with the microcosm experiments was the result of a collaborative effort with personnel in the Center for Microbial Ecology at Michigan State University. The design of the intact core microcosm is presented in Figure 5. The intact core was recapped at each end with PVC fittings with o-rings that fit snugly to the interior walls of the core tube and accommodate HDPE -NPT male pipe adapters suitable for connecting Tygon tubing on the outer ends. Sediment removed to make space for the PVC fittings was analyzed for total chromium. The bottoms of the microcosms were fitted with a mesh (polypropylene SpectraMesh, mesh size 1mm) on the interior between the PVC bushing and the soil to retain the soil core. The soil core

was held vertically with fluid flow entering the bottom of the microcosm. Treatment solutions were supplied to the microcosm by pumping solution with a peristaltic pump. The effluent was collected from the top for analyses. The microcosm was fitted with a 0.22 μm nylon filter at the inflow to isolate the microbial community within the microcosm; the filter was used to prevent non-native microorganisms from entering the microcosms system; and possibly affecting the experimentation. An inlet purge system was used to flush the inlet tubing of stagnant fluid prior to pumping fluid through the microcosm. Both the treatment solution and the effluent samples were kept under argon to limit the amount of dissolved oxygen in the treatment fluid and reduce the possibility of oxidation reactions occurring in the sample fluid. All microcosm components were acid washed (10% HCl) prior to assembly to remove trace metals.

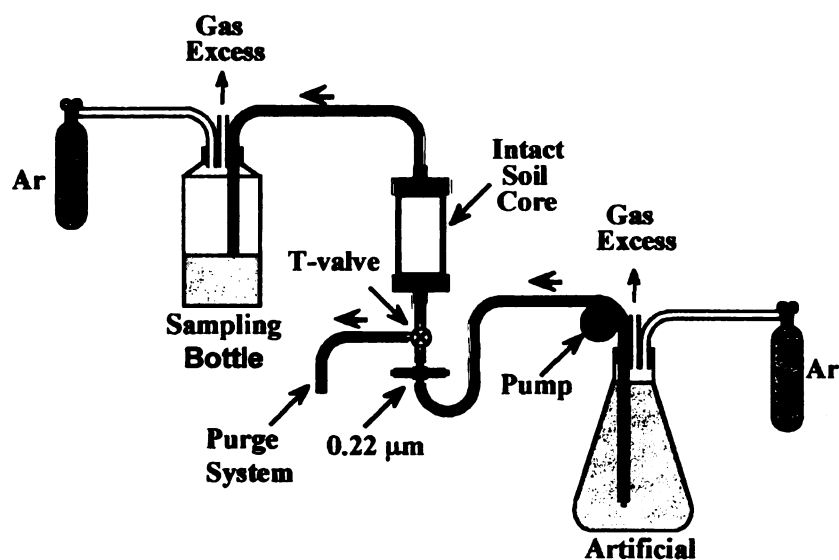


Figure 5. This diagram shows the design of the intact core microcosms. The red arrows show the flow direction of the water. The entire apparatus was maintained at 14°C in an incubation chamber. All fittings were non-metallic, all caps were Teflon[®] and the tubing was Tygon[®].

A sampling and treatment scheme of non-continuous pumping was devised. A non-continuous pumping scheme was employed because a continuous pumping scheme has the potential of stripping the microbial community from the soil. The physical act of pumping treatment fluids through a microcosm was termed an exchange. The amount of water pumped through a soil core for each exchange was in part determined by the volume of water that an empty core tube could contain (i.e., 250 mL). Since the porosity of the sediments in a core is significantly less than 100%, 250 mL clearly should exceed the amount of water necessary to completely replace the pore waters in the core. However, even with this amount of water, it is well known that because of heterogeneity within soils it is difficult to get complete replacement of water with just a single pore-water exchange. Therefore, the approximate amount of water necessary for pore-water replacement was estimated from a breakthrough curve study.

For this study, a bromide tracer (added as KBr) was continuously pumped through a fully assembled microcosm and the effluent was collected in 30 mL aliquots. The Br concentration in the aliquots was determined by specific ion electrode. The concentration of bromide in the treatment fluid was 11.4 mg/L. The data are presented in Figure 6 and show that Br begins to reach a steady state concentration after

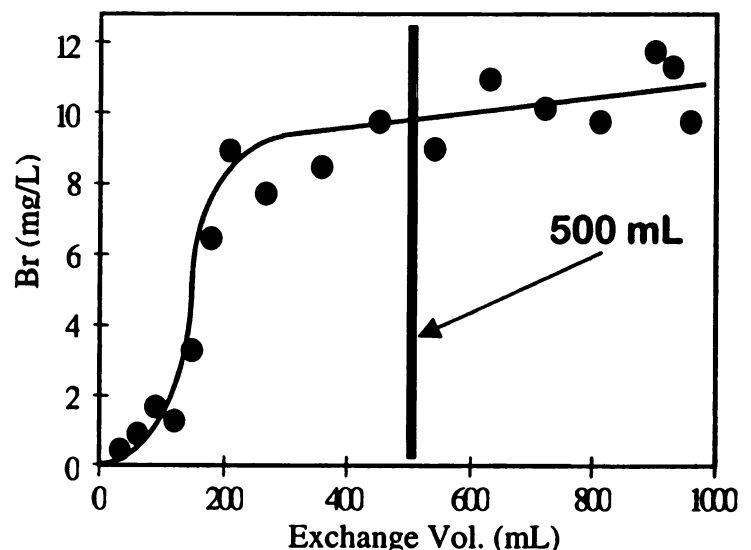


Figure 6. Breakthrough curve for Br tracer test in a soil core from site P25.

approximately 250 mL of solution had been pumped through the soil and is nearly at steady state by 500 mL (double the empty core volume). Thus, 500 mL was chosen as the treatment volume for subsequent microcosm studies.

As previously stated, the physical act of pumping treatment fluids through a microcosm is termed an exchange. During an exchange, the fluid obtained for the geochemical and microbial analysis was the first 120 mL of effluent from the microcosm. These samples represent the fluid that remained in the cores for the incubation period. The next 130 mL aliquot was saved in order to get enough material to be able to standardize and/or optimize the protocols used for microbial community analysis. The remaining 250 mL of exchange solution was discarded. At this point the addition of the input treatment solution was halted and the microcosm incubated at 13°C for one week or one month.

The duration of the incubation periods was determined by logistical and microbial concerns. An exchange could not be conducted every day because that would not allow enough time to prepare for the next exchange. The solution also needed enough time to react with the soil and the microbial community. A one week incubation time was established, because it was thought that this was sufficient time to allow the microbial community to adjust to the treatment and also allow for preparation for the next microcosm exchange. Toward the end of each experiment the incubation time was extended to determine if the duration of the incubation time was influencing the evolution of chromium from the microcosm.

IV. SPECIATION OF CHROMIUM IN THE SOILS

4.1 General Observations

The distributions of chromium and organic carbon in the soil samples are shown in Figure 7. The log concentrations of total leachable chromium and organic carbon concentrations are presented to allow for a full representation of the entire data sets. Total leachable metal concentrations reported in this section represent a summation of the concentrations from the sequential extraction procedure. The sequential extraction data for chromium are presented in Appendix D. The soil organic carbon concentrations are presented in Appendix E.

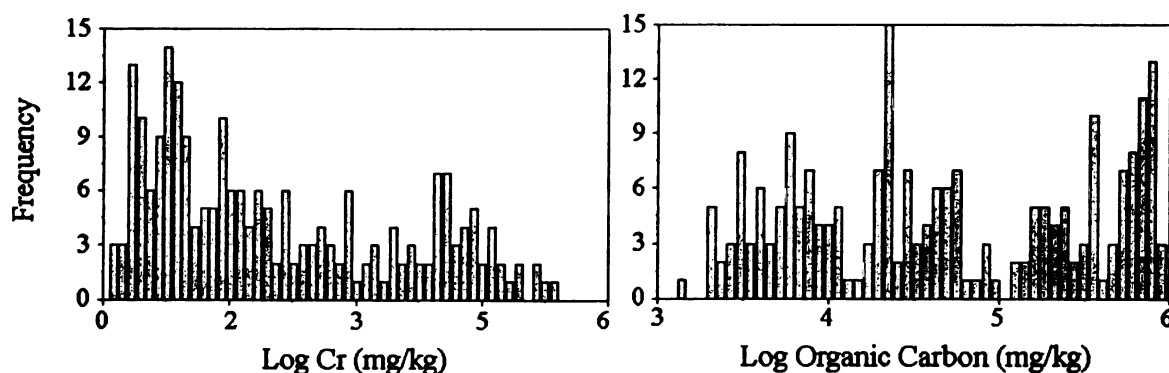


Figure 7. Frequency histograms of the \log_{10} concentrations of total chromium and organic carbon in the soil. Total chromium concentrations were determined by summing the concentrations of the sequential extractions.

The concentrations of chromium ranged from 1 to 260,000 mg/kg. The distribution of chromium concentrations indicates that there may be several populations. Jeong (1994) found pre-industrial age chromium concentrations in Lake Superior sediments to range from 50-80 mg/kg. Based on this information, the population of chromium concentrations from 0 to 100 mg/kg was considered to represent background

values for chromium in this area. Therefore, concentrations greater than 100 mg/kg are considered to be the result of human activity.

The distribution of soil organic carbon concentrations shows three separate populations. These populations represent different locations or depths from which the samples were collected. Samples from upland areas of the site and deeper samples that consisted primarily of silty sand dominate the population with the lowest concentrations. Samples from upper soil horizons of the upland areas and some samples from the wetland areas define the population between 10,000 and 100,000 mg/kg organic carbon. Those samples with greater than 100,000 mg/kg organic carbon were from the wetland areas.

The relationship between organic carbon and chromium in the sediments is shown in Figure 8. There is a positive correlation demonstrating the association of chromium with organic carbon, as might be expected at a former tannery site. The R^2 values for the correlation between log organic carbon and log chromium for soils comprising the entire database is 0.65. The R^2 for soils that are considered to have background concentrations of chromium is 0.32, while for soils with chromium > 100 mg/L it is 0.71. The

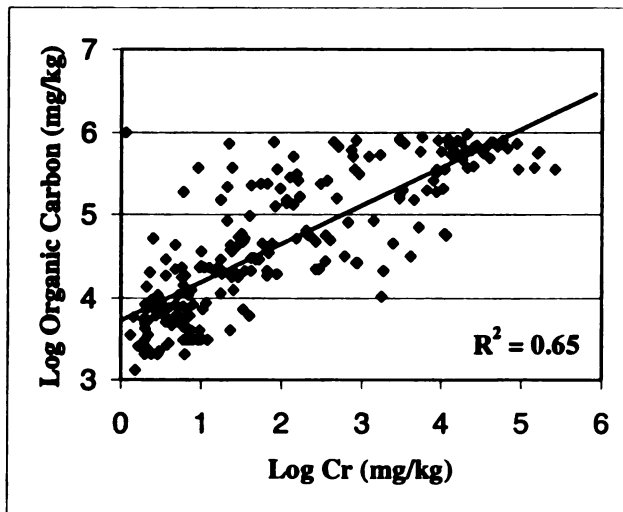


Figure 8. Correlation of the Log_{10} concentrations of Cr vs organic carbon in the soil samples.

correlation for the latter is relatively high which indicates that chromium may be associated with organic matter to a certain extent. However, the scatter in the plot demonstrates that other factors may be influencing chromium speciation in the soils.

4.2 Results of the Sequential Extractions

A summary of chromium partitioning or speciation among the various operationally defined sediment phases (see Section 3.1.3) is shown in Figure 9. Very little chromium was found to be associated with the exchangeable (EX) and acid oxidizable (OX2) phases. In terms of the entire data set (Figure 9a), chromium is slightly more associated with the moderately reducible (MR) phase (49.03%) than the basic oxidizable (OX1) phase (41.12%). To a much lesser extent chromium is associated with the easily reducible (ER) and weakly acid soluble (WAS) phases, 6.47% and 3.21%, respectively.

The relative amounts of chromium in both the MR and OX1 phases are almost equal ($\approx 44\%$) in samples with chromium concentrations less than 100 mg/kg (Figure 9b). Again, to a much lesser extent chromium is associated with the ER and WAS phases, 7.89% and 4.65%, respectively. For samples with chromium concentrations greater than 100 mg/kg (Figure 9c), the MR phase (56.42%) is the most dominant in sequestering chromium. The OX1 phase accounts for 37.48% of chromium concentrations while the ER and WAS phases only account for only a minor portion ($< 6\%$ combined).

The samples with chromium concentrations greater than 1000 mg/kg show an increased dominance of the MR extraction, with 65.45% of total leachable chromium coming from this extraction. The amount of chromium associated with the OX1

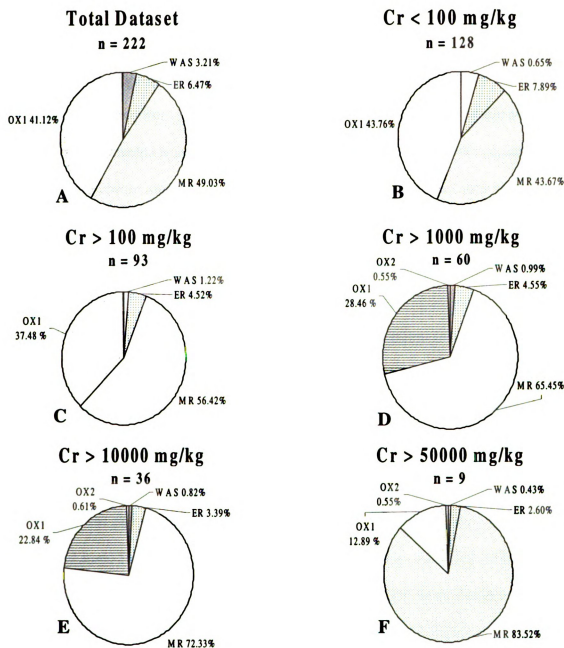


Figure 9. A summary of the sequential extraction data represented as average percent of Cr extracted in each extraction. The EX and OX2 extraction percentages are too small to appear on most of the pie diagrams.

and ER extractions were 28.46% and 4.55%, respectively. The WAS and OX2 extractions accounted for approximately 1.5% of the total leachable chromium.

The trend of increasing percentages of chromium leached from MR extraction continues with the subset of samples with concentrations greater than 10,000 mg/kg and greater than 50,000 mg/kg total chromium. The MR extraction accounted for 72.33% of chromium extracted from samples with greater than 10,000 mg/kg chromium and 83.52% of chromium extracted from samples with greater than 50,000 mg/kg chromium. The percentage of chromium leached from OX1 extraction also decreased with increasing chromium content to 22.84% for samples greater than 10,000 and 12.89% for samples greater than 50,000 mg/kg. The WAS, ER, and OX2 extractions accounted for less than 5% collectively in both cases.

The MR and OX1 extractions remove the most chromium from the samples in all cases. The MR extraction removed increasingly more of the total leachable chromium from the samples than the other extractions as the total concentration of chromium increased. The EX, WAS, ER, and OX2 extractions contribute only minor amounts of chromium. The association of chromium with the moderately reducible and oxidizable extractions was expected and has been found in river sediments (Gephart, 1982; Rauret et al., 1989; Lopez-Sanchez et al., 1993; Rezabek, 1988), aquifer material (Asikainen and Nikolaidis, 1994), and black shales (Schulmeister, 1993). Chromium has been shown to strongly associate with organic matter (Krajnc et al., 1995) (the OX1 extraction) and iron oxy-hydroxides (the MR extraction). Past work could not be found which demonstrates that chromium forms sulfide minerals (the OX2 extraction) as a result of environmental contamination. Chromium (III) can be adsorbed to Mn oxides (the ER extraction), but is

rapidly oxidized to Cr(VI) and desorbed (Takacs, 1988; Rai et al., 1989). Chromium also does not commonly occupy exchange sites on clay minerals (McBride, 1994). Thus, the sequential extraction data indicate that the two most important phases sequestering chromium in the soils are iron oxides and organic material.

Although this interpretation of the results appears to be straight forward, understanding the association of chromium with the MR (and ER) phases is not. The problem is in the nature of the selective chemical extractions. These extractions were designed for oxic systems i.e., systems exposed to oxygen (Tessier, 1979). In these systems, redox sensitive elements such as iron and manganese exist in their oxidized forms and precipitate out from solution as oxy-hydroxides (Baes and Mesmer, 1976). However, under anoxic conditions (lack of oxygen), iron and manganese oxy-hydroxides are thermodynamically unstable. There is debate as to the role of abiotic and biotic processes in the reduction of the oxy-hydroxides, but it is assumed that Fe/Mn oxy-hydroxides do not exist under anoxic conditions. Thus, it is unclear what phase of the sediment the ER and MR extractions are leaching.

The geochemical behavior of chromium in aqueous systems affords some insight into this problem and perhaps also to the nature of chromium speciation patterns in the soils at this site. In systems such as those that exist at this site, the abundance of organic matter and lack of manganese oxy-hydroxides [one of the few naturally occurring oxidants that can oxidize Cr(III) to Cr(VI)], are likely to create a biogeochemical environment in which the most common form of chromium will be in the Cr(III) state (Palmer and Puls, 1994). In the pH range of the most natural waters Cr(III) is not very soluble and may precipitate out of solution as $\text{Cr}(\text{OH})_3$ and if Fe(III) is present it will

preferentially form $(\text{Cr}_x\text{Fe}_{1-x})(\text{OH})_3$ (Bartlett and Kimble, 1976; Palmer and Puls, 1994; Rai et al., 1989). The solubility of these minerals or amorphous compounds increases with decreasing pH and at very low pHs they are very soluble. The pH of the MR extraction solution is less than one. Therefore the chromium that the MR extraction removes from the soil is most likely chromium hydroxide. The presence of these Cr mineral phases was investigated with X-ray diffraction analysis (Ellis, 1999), but no identifiable Cr mineral phases were present, which indicates an amorphous phase.

The results of the speciation study indicate that chromium is mainly associated with the operationally defined MR and OX1 phases in the soils. The association of chromium with the OX1 phase is consistent with the correlation of chromium with soil organic carbon (Figure 8). The increasing dominance of chromium in the MR extraction with increasing chromium concentrations may indicate that there is a limitation to the amount of chromium that can associate with natural organic matter. Considering the results of the sequential extraction data for chromium, the chemistry of the solutions used in the selective chemical attacks, and knowledge of the biogeochemistry of chromium; it is concluded that the dominant forms of particle-bound chromium in these soils are a $\text{Cr}(\text{OH})_3$ mineral/amorphous solid and chromium associated with organic matter. This hypothesis is consistent with observations of chromium in various aquatic (e.g., rivers, lakes) systems (Gephart, 1982; Rezabek, 1988; McKee et al., 1989).

V. AQUEOUS PHASE SPECIATION OF CHROMIUM

5.1 Pore-Water Data and Thermodynamic Modeling

The geochemical modeling code PHREEQC (Parkhurst, 1995) with the MINTEQ database (Allison et al., 1991) was used to assess the thermodynamic state of the surface-water and pore-water chemistry at the study site (aqueous field data is presented in Appendix F). The thermodynamic data for chromium in the MINTEQ database were updated using recent values from Ball and Nordstrom (1999). Geochemical modeling was used to determine if the solutions were in equilibrium, under saturated, or super saturated with respect to chromium solid (amorphous or mineral) phase(s). The geochemical modeling also computed the aqueous speciation based on the inorganic thermodynamic data.

Chromium hydroxides are the most likely inorganic solids that would be present in this environment (Rai et al., 1989; Richard and Bourg, 1991; Palmer and Puls, 1994). The most soluble of these hydroxide forms is $\text{Cr(OH)}_{\text{am}}$ (Rai et al., 1989). The solubility of chromium in the pore waters was compared to the solubility of $\text{Cr(OH)}_{\text{am}}$ to determine if the concentration of chromium in solution is controlled by the inorganic chemistry of chromium. The solubility of $\text{Cr(OH)}_{\text{am}}$ was determined using PHREEQC by simulating an equilibrium experiment at different pH values in pure water. The data presented here are the results of a simulation with a temperature of 25°C. Simulations were also conducted at lower temperatures (down to 10°C), which resulted in slightly lower

predicted equilibrium concentrations, but the differences in concentrations did not exceed 2 percent.

The results of the comparison between the pore waters and surface waters chromium concentrations and the solubility of $\text{Cr}(\text{OH})_{3\text{am}}$ are illustrated in Figure 10. The figure shows that most of the samples plot above the solubility curve for $\text{Cr}(\text{OH})_{3\text{am}}$, which indicates that the dissolved chromium is in excess of equilibrium concentrations with $\text{Cr}(\text{OH})_{3\text{am}}$. Surface-water samples were collected to assess the possibility of Cr(III) oxidation to Cr(VI) in surface waters as described by Masscheleyn et al. (1992). Although the surface samples had the highest concentrations of chromium, Cr(VI) was not detected in any of the field samples. This means that either the solutions are out of thermodynamic equilibrium with respect to $\text{Cr}(\text{OH})_{3\text{am}}$ or there are forms of dissolved chromium species in solution that were not accounted for in the geochemical modeling. The possibility of the solutions being out of equilibrium was initially investigated by examining the aqueous speciation as predicted by PHREEQC.

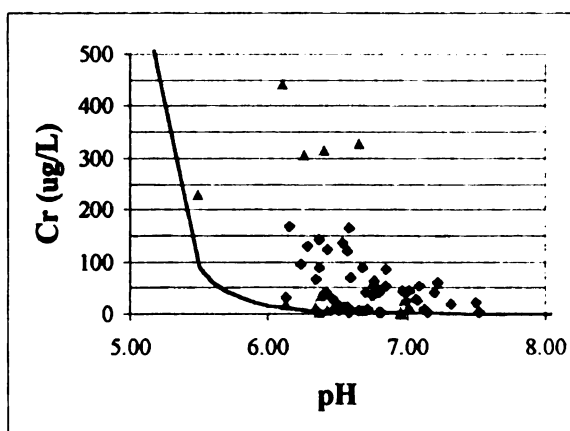


Figure 10. Concentration of dissolved chromium versus pH in pore waters (blue) and surface waters (brown triangles) at this site. The curve is the theoretical concentration of dissolved chromium in equilibrium with $\text{Cr}(\text{OH})_{3\text{ am}}$.

The dominant inorganic aqueous chromium species as computed by PHREEQC are presented in graphical form in Figure 11 for selected samples. The samples in the figure were chosen because they represent a range of chromium concentrations and pH

values observed at the site. The dominant species is pH dependent. At near neutral pH values, $\text{Cr}(\text{OH})_3$ is the dominant form of chromium in solution, while at the lower pHs $\text{Cr}(\text{OH})^{+2}$ is the dominant form of chromium. In the pH range of these waters, the thermodynamic models suggest that the dominant inorganic form of chromium will be either positively or neutrally charged.

5.2 Chromium and DOC

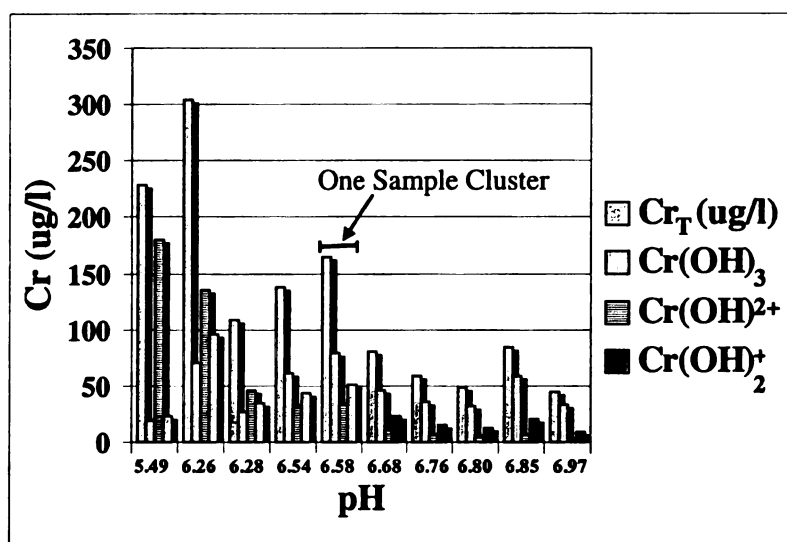


Figure 11. Graphical representation of the species computed by PHREEQC for selected water samples that represent the range of pH and chromium concentrations observed at the site. Each cluster represents the aqueous speciation for one sample.

There appears to be a relationship between aqueous chromium concentrations and dissolved organic carbon (DOC) in the field samples. Figure 12a shows a plot of all the aqueous chromium concentrations versus DOC in the field samples. It is not surprising the relationship is not highly correlated when the entire data set is plotted, because of the organic rich nature of the environment from which the samples were taken. It is conceivable that a sample could have high DOC and yet have very little chromium.

However a trend seems apparent for the samples with higher chromium concentrations. The samples with chromium concentrations greater than 30 µg/L are shown in Figure 12b. This subset of the data shows a slight correlation between aqueous chromium and DOC with a R^2 of 0.66. Although this is not a strong correlation, there does appear to be a correlation between chromium and DOC at higher chromium concentrations. This indicates that DOC may influence the concentrations of chromium in these waters. This relationship was further investigated by using solid phase extraction media to identify aqueous chromium species.

5.3 Solid Phase Extraction Data

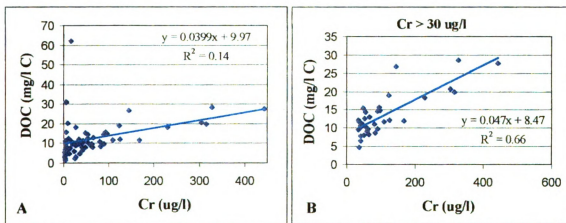


Figure 12a and 12b. Correlation of chromium vs DOC in the surface and pore water at this site. Figure 12b is a subset of the entire data set shown in Figure 12a consisting of those samples with chromium concentrations greater than 30 µg/L.

The first solid-phase-extraction media used was the Chelex-100 resin, which removes the cations from solution. The chromium remaining in solution after reaction should have a negative or neutral charge. Positively charged chromium species, such as those presented in Figure 11, should be removed with this extraction. The results of the solid phase extraction with the Chelex-100 resin are shown in Figure 13 (data for this and the other solid phase extractions is in Appendix G). Cr_{Chelex} is the concentration of

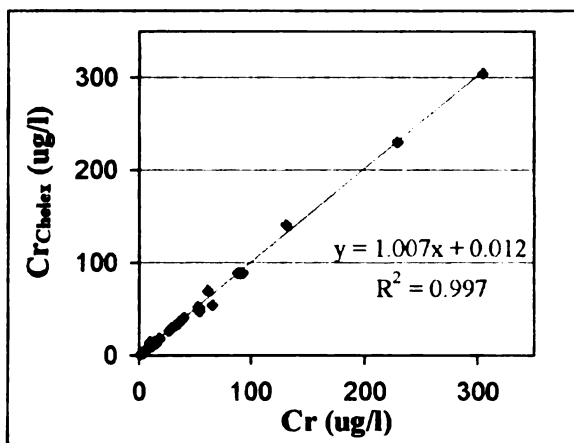


Figure 13. Correlation of total dissolved chromium versus Cr_{Chalex} (negatively charged or neutral chromium) in surface water and pore water at the study site.

chromium in solution after the reaction with the Chelex resin and therefore represents negatively charged or neutral aqueous chromium. Figure 13 clearly shows a one to one relationship (slope of 1.007 with a R^2 of 0.997). This indicates that the aqueous chromium in these samples exists as either a negatively charged or neutral species, with little or no cationic chromium.

The results of the solid phase extraction with the Sep-Pak resin are shown in Figure 14. This resin removes the hydrophobic fraction of the DOC and metals bound to this fraction. The non-hydrophobic fraction is the concentration of chromium in the effluent from the Sep-Pak column. There is strong relationship (R^2 of 0.995) between

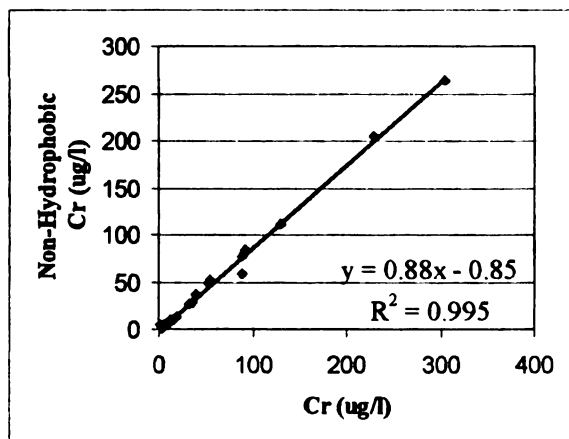


Figure 14. Correlation of total dissolved chromium versus non-hydrophobic chromium in surface water and pore water at the study site.

total aqueous chromium concentrations and the non-hydrophobic form of chromium. The slope of the line is 0.88, which indicates that approximately 12 percent of the aqueous chromium is associated with the hydrophobic fraction of the DOC.

The results of the solid phase extraction with the AG resins are shown in Figure 15. This resin removes the negatively charged species from solution and replaces them with fluoride. The concentration of chromium in the anionic form was estimated by subtracting the concentration of chromium in the column effluent from the concentration of chromium in the control split. There is a strong relationship between chromium and anionic chromium (R^2 of 0.995). The slope of the line is 0.96, which indicates that 96 percent of the aqueous chromium exists as an anion. Inorganic anion species of chromium that have been reported in environmental samples include only Cr(VI) species (Rai et al., 1989; Richard and Bourg, 1991; Kotas and Stasicka, 2000), however Cr(VI) was not detected in any of these samples. This indicates that chromium that is behaving as an anion in these waters is not an inorganic species, which suggests that this chromium exists as an anionic Cr(III)-DOC complex.

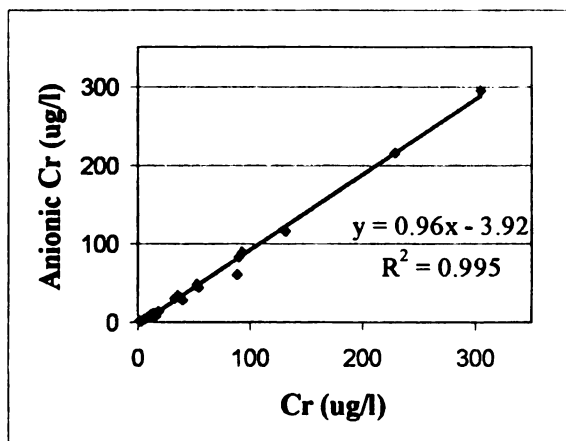


Figure 15. Correlation of total dissolved chromium versus anionic chromium in surface water and pore water at the study site.

The possibility of a Cr(III)-DOC complex was further examined by plotting the concentration of chromium remaining in solution after reaction with the AG resins on the same concentration of chromium versus pH as previously shown in Figure 10. This comparison is shown in Figure 16. The surface-water and pore-water data cluster around the solubility curve for $\text{Cr}(\text{OH})_3$. This indicates that the non-negatively charged chromium species in solution are very near or below the solubility of $\text{Cr}(\text{OH})_{3\text{am}}$, which suggests that these species are in near equilibrium with chromium hydroxides.

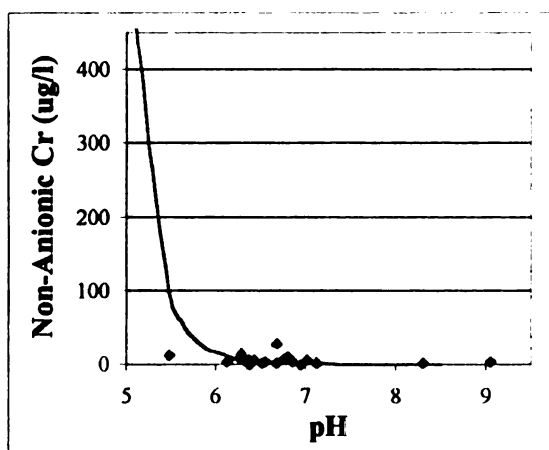


Figure 16. Concentration of non-anionic chromium versus pH in pore waters and surface waters at the study site. The curve is the theoretical concentration of dissolved chromium in equilibrium with $\text{Cr}(\text{OH})_{3\text{am}}$.

The results of the solid phase extractions indicate that aqueous chromium exists primarily as an anion in the pore waters and surface waters of this wetland. Since no Cr(VI) was observed in these samples, this anion is most probably a complex of Cr(III) with some form of DOC, which is consistent with the findings of other researchers (Davis et al., 1994; Walsh and O'Halloran, 1996). In the pH range of these waters (near neutral) most of the functional groups on natural dissolved organic matter will have a negative charge (McBride, 1994). This characteristic is consistent with the assumption that the chromium exists as a Cr(III)-DOC complex. Further, the linear relationships of the SPE data and the non-anionic data plotting near the solubility of chromium hydroxide suggests

that there may be a thermodynamic control on the solubility of dissolved chromium involving both the dissolution of chromium hydroxide and complexation with dissolved organic carbon.

There is an apparent contradiction in the interpretation of the results from the anion extraction and the hydrophobic extraction. The anion extraction indicates that 96 percent of the chromium is associated with an anionic species, however the hydrophobic extraction indicates that 12 percent of the chromium is associated with hydrophobic compounds. The contradiction arises from the fact that these two extractions combined exceed 100 percent, but if one takes into account the nature and complexity of natural organic matter the significance of this contradiction is diminished. It is completely plausible for organic compound to have both a hydrophobic component and a hydrophilic component (anionic). Soap is an example of such a compound (Cram and Cram, 1978). It is likely that all or most of the hydrophobic fraction is also part of the fraction removed by the anionic extraction. Another possibility is that the remaining 4 percent of the anionic extraction may be composed of neutral chromium species not associated with DOC, such as $\text{Cr}(\text{OH})_3$. However, the majority of the aqueous chromium exists as an anion, which is most likely a Cr(III)-DOC complex.

VI. SELECTION OF MICROCOSM SITES

6.1 Rational

The goal of the study was to investigate the fate and mobility of chromium in a complex wetland environment. The nature of the microcosm experiments required that a small subset of sites were used for these experiments and so the variability of the study site had to be reduced to a small group of samples which represent the range of conditions at the site. This chapter describes the process by which sampling sites were chosen for the collection of soil used in the microcosm experiments. At the study site there exists a diverse assemblage of chemical and physical conditions. The sites were chosen primarily because they were representative of the range of biogeochemical and physical conditions present at the study site. The criteria used to select these sites were based on statistical analysis of the sequential extraction data; the sequential extraction data; preliminary pore water data; and physical observations of the sites.

6.2 Statistical Analysis

6.2.1 – Factor Analysis

The selection of sites from which microcosm samples were collected was largely based on statistical analysis of the sequential chemical extraction data. Two types of factor analysis were used to identify differences in the sample population. Factor analysis is a multivariate statistical technique that is designed to reduce the number of variables describing the variance of a system. This analysis not only reduces the number of variables that can be used to describe the variance, but combines variables that behave

similarly into “factors”. The analysis provides insight to physical, chemical, or biological parameters that control a system. The two types of factor analyses were done for this study were Q-mode and R-mode. The analyses were done using Statistical Analysis System (SAS™) on the IBM (3090200J vm/cms) main frame computer at Michigan State University. The techniques follow those outlined by Davis (1986) and are similar to those that we have used previously (Long et al., 1992).

6.2.2 – Q-Mode Factor Analysis

The purpose of Q-mode factor analysis is to analyze a data set by dividing samples into groups that are similar in terms of their variables. The samples in this study are the individual soil samples from the entire database. The nine variables considered were Corg, Cr_{WAS}, Cr_{ER}, Cr_{MR}, Cr_{BOX}, Fe_T, Mn_T, Cu_T, and Zn_T. The subscript T indicates the total soil concentration, which is the summation of the sequential extraction data for iron, copper, zinc, and manganese (these data are presented in Appendices H through K respectively). The variables were logarithmically transformed prior to analysis to account for their log-normality. The data matrix used for the Q-mode factor analysis had the samples as columns and variables as rows. The matrix was row normalized prior to factor analysis using the methodology given in Davis (1986). Factor scores, which are used to estimate the relative importance of the variables in defining the populations, were calculated via a FORTRAN program (Davis, 1986). The number of factors that can be used to define the data set are interpreted from the relative importance of the eigenvalues describing the data set. Each eigenvalue describes a certain portion of the variance found in the data. The first eigenvalue is the most important in describing the variance. Each successive eigenvalue describes decreasingly less of the variance. One then chooses how

many eigenvalues are needed to describe a certain percentage of the variance of the data set. As an example, if the data set had ten variables, then there would be ten eigenvalues describing the variance. Perhaps the first three eigenvalues describe 95% of the data while the remaining seven only 5%. A choice can be made then that of the ten variables, only three are needed to describe the data. These first three eigenvalues become the three new factors describing the data. So the number of variables describing the data set is reduced from ten to three. The choice of the cut off percentage (95%), as in the example, is the decision of the investigator.

The Q-mode factor analysis revealed five factors that described the data set (>97%). Factors 1 and 2 account for 75% and 17% of the variability. The remaining three factors account for 4%, 2%, and 1%, respectively. The factor scores (Table 3) allow for insight into the variables influencing the individual factors. The relative importance of a variable on a factor was subjectively determined by examining the values of a variable along a row and choosing its highest value(s). Variables that are interpreted to be important in controlling the factors are shown in italics, and a negative sign denotes there is an inverse relationship between the variable and the factor. Thus, the five factors can be described by the variables listed after the factor at the bottom of Table 3.

These five factors can now be thought of as sub-populations or end members of the entire data set. The most important population is essentially the one dominated by chromium with an association with iron (factor 1). The other factors show Fe_T , Mn_T , and Corg to be important to varying degrees. The association in factor 5 of chromium and Corg is consistent with what we know about the biogeochemistry of chromium and its association with Corg at the site (Figure 8).

Table 3. Factor scores for the Q-mode factor analysis on the entire soil data base. The italicized scores indicate the variables important in controlling the five factors. The important variables for each factor are also listed at the bottom of the table.

Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Variable
0.17830	0.05847	-0.06442	<i>0.21115</i>	<i>0.46783</i>	Cr _{ORG}
<i>0.23424</i>	-0.19757	-0.21821	-0.02355	-0.14185	Cr _{WAS}
<i>0.31321</i>	-0.15900	-0.17377	-0.19729	-0.18841	Cr _{ER}
<i>0.47056</i>	0.08799	0.00280	0.06028	-0.21961	Cr _{MR}
<i>0.41989</i>	0.02340	0.02932	0.14259	<i>0.28045</i>	Cr _{OX1}
<i>0.48944</i>	<i>0.85147</i>	<i>0.59985</i>	0.10901	0.24556	Fe _T
0.22847	<i>0.37017</i>	0.16065	-0.92477	<i>0.46903</i>	Mn _T
0.21122	0.07678	0.06728	0.09316	<i>0.49842</i>	Cu _T
<i>0.28486</i>	<i>0.23681</i>	-0.72595	0.12734	<i>0.26448</i>	Zn _T
Factor 1 -- Fe _T , Cr _{MR} , Cr _{OX1} , Cr _{ER} , Zn _T , Cr _{WAS} Factor 2 -- Fe _T , Mn _T , Zn _T Factor 3 -- -Zn _T , Fe _T Factor 4 -- -Mn _T , Cr _{ORG} , Factor 5 -- Cu _T , Mn _T , Cr _{ORG} , Cr _{OX1} , Zn _T					

We also experimented with describing the data set with only three factors (>95%) and found similar grouping (i.e., chromium factor, Fe/Mn factor, and Corg factor). These associations were also found for the R-mode analysis as will be discussed in the next section. Five factors for the Q-mode analysis are presented here instead of the three factor model only because the results show slightly more detail in the nature of the data set. The relative importance of a factor in describing a sample (loadings) were calculated using SAS.

6.2.3 – R-Mode Factor Analysis

The purpose of R-mode factor analysis is to analyze a data set to divide variables rather than samples into groups that are similar. The samples used for the R-mode analysis were the soil samples that had chromium concentrations greater than 100 mg/L.

R-mode analysis was only done on this sub set of the entire database because a) the histogram of total leachable chromium (Figure 7) in the soils indicated that potentially more than one population of data exist, b), R-mode factor analysis is most robust when it is done on single populations, and c) these samples are those of greatest concern from an environmental risk perspective.

The eleven variables considered were Corg, Cr_{WAS}, Cr_{ER}, Cr_{MR}, Cr_{BOX}, Cr_T, Fe_T, Mn_T, Fe_{WAS}, Fe_{ER}, and Fe_{MR}. The variables were logarithmically transformed prior to analysis to account for their log-normality. The data matrix used for the R-mode factor analysis had the samples as rows and variables as columns. Eigenvalues are used to determine the number of factors that can be used to describe the data set.

The results of the R-mode analysis are shown on Table 4. Only four factors were needed to define 100% of the variance of the data. The relative amounts of data variance that are explained by the factors are shown in the Table 4. The relative importance of the variables in characterizing a factor are also shown in Table 4. Using the same method as for the Q-mode analysis, variable associations for a factor were chosen and are shown in italics. The resulting factors are shown at the bottom of the table.

6.2.4 -- Summary of Factor Analyses

Both the Q- and R-mode factor analyses give similar associations among the variables. Thus, both types of analyses give similar information that lends internal consistency to this analysis. Both show that factors accounting for a) chromium, b) chromium associations with iron, c) chromium associations with Corg, and d) Fe/Mn associations needed to be considered in the selection of the samples for microcosm work.

Table 4. Results of R-mode factor analysis on soils from the site with chromium concentrations greater than 100 mg/kg. At the top of the table are the eigenvalues and proportion of the variance explained by each factor. The center of the table shows the loadings of the variables on the factors. The variables that comprise each factor are listed at the bottom of the table.

Eigenvalue	5.2032	2.3071	0.9609	0.6729
Proportion	0.5712	0.2533	0.1055	0.0739
Cumulative	0.5712	0.8244	0.9299	1.0038
	Factor 1	Factor 2	Factor 3	Factor 4
C _{ORG}	0.11020	0.09804	0.01048	0.80894
Cr _{WAS}	0.92122	0.01296	-0.03864	0.05836
Cr _{ER}	0.90999	0.06141	0.16508	-0.13067
Cr _{MR}	0.96324	-0.03619	0.06896	-0.01967
Cr _{OX1}	0.70413	0.07705	-0.13267	0.42263
Cr _T	0.93055	-0.00410	0.03029	0.09736
Fe _{WAS}	0.21911	-0.15359	0.87103	-0.14426
Fe _{ER}	-0.13122	0.27324	0.71044	0.23827
Fe _{MR}	0.12011	0.95872	-0.18235	0.01573
Fe _T	-0.05622	0.67127	0.35798	0.20560
Mn _T	-0.02807	0.73363	0.00737	-0.49265
Variance explained by each factor eliminating other factors Factor 1 Factor 2 Factor 3 Factor 4 3.071545 1.522758 1.199903 0.821770				
Factor 1 -- Cr _{WAS} , Cr _{ER} , Cr _{MR} , Cr _{OX1} , Cr _T Factor 2 -- Fe _{MR} , Fe _T , Mn _T Factor 3 -- Fe _{WAS} , Fe _{ER} Factor 4 -- C _{ORG} , Cr _{OX1} ,				

6.3 Criteria Used for Selection of Soil Samples

Initially, a preliminary list of criteria for site selection was developed based on the speciation studies and general observations presented in Chapter 4 and factor analysis.

The criteria, rationale and proposed sites for the preliminary list are summarized in Table

5. The speciation studies show that the MR phase and OX1 phase are most important in

sequestering chromium. Therefore sites were selected that exhibited a dominance in either phase. The general observations indicated that there was an association of chromium and organic matter and therefore sites were chosen that had both high and low organic matter concentrations. Sites were also chosen based on the grouping of samples by the factor analysis.

Table 5. A listing of the initially proposed microcosm sites and the rationale and criteria associated with their selection.

#	Criteria	Rationale	Sites
1	Speciation Cr: MR > BOX	The speciation studies show that the MR phase and BOX phase are most important in sequestering Cr. This criterion examines the case in which the MR phase is dominant.	J23 0-0.5 or J23 1-15
2.	Speciation Cr: BOX > MR	Opposite of 1.	P25 0-0.5 or L27: 0-0.5
3.	General low Cr _T and high Corg	This examines the effect of high amounts of Corg on low concentrations of Cr. This case would be of lower priority for this study	K28: 0-0.5
4.	General high Cr _T and low Corg	Opposite of 3.	O22: 3-3.5
5.	Factor analysis high R loadings on factors 1, 2, 3, 4	This is the most common association of factors for the sub data set that comprises soils with Cr > 100 mg/L.	K22: 0-0.5
6.	Factor analysis high R loadings on factors 1,2,4 only	This is a common association.	S26: 0-0.5 or J19: 0-0.5
7.	Factor analysis high R loadings on factor 3 only	This is a common association.	O22: 3-3.5 or Q26: 0-0.5
8.	Factor analysis high R loadings on factors 2, 3, 4 only	This is a common association.	K22: 1-1.5

Once this preliminary list was developed, field sampling of the pore waters was conducted at these sites, along with more detailed field observations. The additional data

gained from the field work included an estimation of oxidation-reduction state (redox) and possible terminal electron acceptor processes (TEAP) as indicated by various biogeochemical indicators such as Fe^{+2} , S_2^- , and CH_4 (Lovely and Goodwin, 1988). Also the additional field work provided for a distinction between sites based on the physical conditions at the site such as the saturation history and basic soil characteristics.

The results from the pore water analysis (Appendix F) showed that, as expected, various degrees of anoxia exist throughout the study area. All major TEAP variables could be measured to some degree. Some sites had very high amounts of dissolved CH_4 , Fe^{2+} , or S^{2-} . This is suggestive of various types of microbial activity such as methanogenesis, iron reduction, and sulfate reduction. Most sites had negative to very negative Eh measurements, which indicates reducing conditions and is consistent with the anoxia indicated by the TEAP variables.

The saturation history became an important observation as a result of the pore water sampling. When a peeper was installed at P25 in June 1997, there was approximately 5 inches of standing water at the surface. However, when the peeper was retrieved from this site three weeks later, there was no longer any surface water and the top ports were partially exposed to air. This caused the oxic conditions in several inches of soil near the surface, as evidenced by red iron oxide coatings on the peeper upon retrieval. Similar changes in saturation were also observed at N23. The history of changing saturation states at these sites created a new criterion for selection.

The sites selected for the microcosm studies are listed Table 6, with the criteria used to select them. Only sites with high chromium were chosen for the microcosm experiment because those samples are of the highest environmental concern. Based on

logistical constraints, only six sites could be chosen to represent the diversity of the site.

Each of the chosen sites represents a group of sites defined by their physical nature or biogeochemistry, which spans the range of possible conditions at the site.

Table 6. A summary of the physical and chemical characteristics of the sample sites selected for the microcosm work.

Site: Depth (ft)	Sequential Extraction (% of MR and OX1)	Factor Analysis	Redox/ TEAP	Saturation State	Soil Organic Matter (% OM)	Soils
J23: 0-0.5	MR – 85.8 OX1 – 13.0	R loading on factors 1 and 4; Q loading on factor 1	highly anoxic high CH ₄ , high S ²⁻	running water at the surface	74.4	dark brown organic rich
P25: 0-0.5	MR – 36.7 OX1 – 62.5	R loadings on factors 3 and 4; Q loading on factor 1	oxic to anoxic high NH ₄ ⁺ , high CH ₄	variable saturation conditions	62.1	dark brown organic rich
K22: 0-0.5	MR – 60.4 OX1 – 37.6	R loadings on factors 1, 2, 3 and 4; Q loading on factor 1	weakly anoxic low CH ₄ , high SO ₄ ²⁻	standing water	76.5	dark brown organic rich
J19: 0-0.5	MR – 79.3 OX1 – 19.7	R loadings on factors 1, 2 and 4; Q loading on factor 1	No data	usually dry	65.3	dark brown organic rich silty sand
N23: 0-0.5	MR – 51.5 OX1 – 45.6	R loadings on factors 3 and 4; Q loading on factor 1	anoxic very high CH ₄ , very high Fe ²⁺ , high Mn _T , high Cr _T	variable saturation conditions	77.3	dark brown organic rich
O22: 3-3.5	MR – 84.8 OX1 – 14.5	R loading on factor 3; Q loadings on factors 1 and 2; high Cr _T and low C _{org}	anoxic high NH ₄ ⁺ , high SO ₄ ²⁻	dry at surface, wet at depth	69.9	grey silty sand

VII. ACID RAIN MICROCOSMS

7.1 Rational

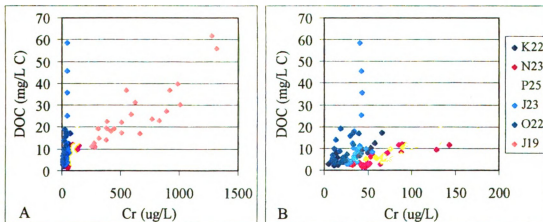
The first treatment chosen for the microcosm experiments was the simulation of the acidification of the pore water at the site due to acid rain. One likely source for acid input to the soils at this site is atmospheric precipitation. Acidic conditions may cause the dissolution of chromium hydroxide solids resulting in the possible liberation of chromium to the environment (Rai et al., 1989; Mattuck and Nikolaidis, 1996). The solubility of chromium hydroxide reaches a minimum at pHs between 6 and 11 (Rai et al., 1989). In this pH range, the dominant form of chromium in solution is as the neutrally-charged species, $\text{Cr}(\text{OH})_3^0$ (Figure 11). At pHs below 6 Cr(III) solubility increases rapidly with decreasing pH (Figure 10). Thus, lowering of the pH should liberate chromium from these soils.

Soil cores from the six microcosm sites were treated with a synthetic acid rain solution. The composition for the synthetic acid-rain water is listed in Appendix L and was based on published data for acid rain in the northeastern United States (Galloway et al., 1976). The resultant pH of this acid water was 3.86. Duplicate samples from the six microcosm sites were treated with a non-acidic control solution. The control solution was prepared by substituting sodium salts for the acids used in making the artificial-rain solution. Sodium salts with the same counter anion as the acid were used to make the simulated control-rain solution. Both solutions were autoclaved prior to use in an

exchange. This chapter presents the results of these microcosm experiments. The data for the microcosm experiments is presented in Appendix M.

7.2 Dissolved Chromium versus DOC Results

Similar to the results from the field data, there appears to be a relationship between aqueous chromium concentrations in some of the microcosm samples and dissolved organic carbon (DOC) (Figures 17a and 17b). Figure 17b is an expanded view showing the lower concentration data in Figure 17a. These figures show all of the chromium versus DOC data collected during the six-month experimental period. The data is presented by the site from which the cores were collected and includes data from both the acid rain and the control microcosms. Samples from microcosms J19, P25, N23, and K22 showed strong positive correlations between dissolved chromium and DOC. Samples from microcosms J23 and O22 show very weak correlations between dissolved chromium and DOC. The correlation for the J23 data is strongly influenced by the J23 control microcosm, which had very high concentrations of DOC in the initial samples



Figures 17a and 17b. Correlation of chromium versus DOC in the acid-rain and control microcosm effluent (R^2 values for the groups are; K22 = 0.68, N23 = 0.71, P23 = 0.71, J23 = 0.19, O22 = 0.26, J19 = 0.78). The samples are grouped by site and include both the acid rain treated and the control samples from each site.

from the microcosm (shown in light blue on Figure 17b). The chromium data from O22 microcosms were not highly correlated with DOC. The O22 microcosms consisted primarily of gray, silty sand with very little organic carbon (Table 6; Appendix A) and was significantly different in this respect to the rest of microcosms. The majority of the data indicates that there is an association between chromium and DOC.

7.3 Solid Phase Extraction Results

There was not enough fluid in the microcosm samples to use the three resins that were used in the field samples, but the chelex 100 resin was used with the microcosm samples to aid in identifying the aqueous speciation of chromium. The data from the chelex 100 reaction are plotted in Figure 18. Similar to the previous graphs showing chelex data, Cr_{Chelex} represents that concentration of chromium remaining in solution after the reaction with chelex resin, which should represent negatively charged or neutral chromium. There is a strong relationship (R^2 of 0.98) between total aqueous chromium concentrations and Cr_{Chelex} . These results indicate that dissolved chromium exists as a negatively charged or neutral species. Since both the chelex and DOC data are similar to

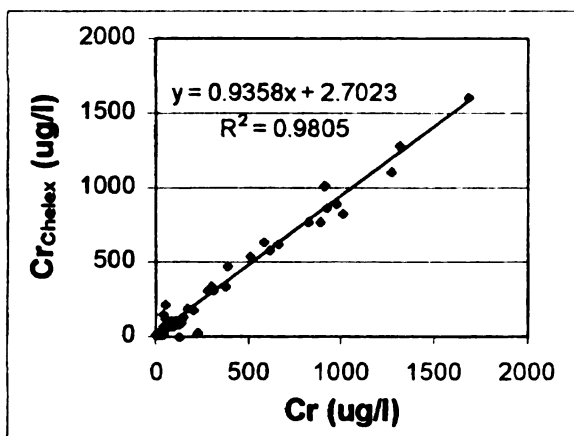


Figure 18. Correlation of total dissolved chromium versus Cr_{Chelex} (negatively charged or neutral chromium) in the acid rain microcosm effluent water.

the field data, it can be assumed that the aqueous chromium probably exists as an anionic, chromium-organic complex.

7.4 Changes in pH Over Time

Over the duration of the experiment the pH values approached the pH ranges that were observed in the field samples (Figure 19). The range of pH values in the field samples associated with the sites where cores were taken for the microcosms are also shown as vertical lines to the right of the plot. The first samples were collected differently than the method outlined in section 3.3 and were collected at the end of the initial 500 mL exchange of fluid, which replaced the pore water that was in the core originally. All other samples consisted of the first 120 mL of effluent water coming from the microcosm during an exchange as described in section 3.3.

The pHs of the first several exchange solutions are generally higher for each microcosm than they are in the pore water at their respective field sites. The initial high

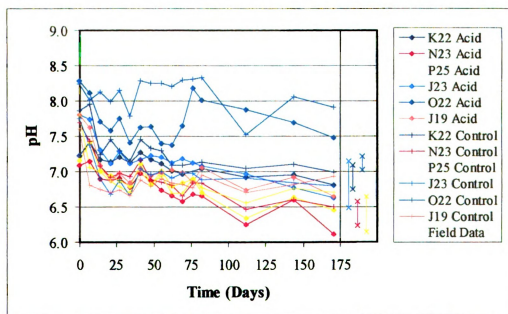


Figure 19. Changes in the pH of fluids in the microcosms as function of time. The range of pH values observed in the pore-waters at these sites are represented by the vertical lines to the right of the concentration profiles.

pH values may reflect conditions that developed within each microcosm during the holding period between soil collection and the initiation of the experimentation. Also, there is very little difference in the pHs of the microcosm effluent between the acid and control microcosms from the same site. After the second or third week most of the pHs in the pore waters of the microcosms decrease and appear to stabilize at levels near the field measurements. The one exception to these general observations are the O22 microcosms, in which the pH values remain much higher than the field data through the experiment. The cause of the pH behavior in the O22 sample is not clear, but may be related to the composition of the soil (e.g., sandy, low organic matter).

The mobilization of chromium from these microcosms is not likely to be the result of acid-driven dissolution. The fact that the acid-rain microcosm pH values were similar to control microcosm pH values indicates the buffering capacity of the soil neutralized the effects of acid rain during the course of the experiment. This was apparent even though the amount of treatment water pumped through the microcosms was the equivalent of approximately 5 years of rain, assuming an average rain fall of 31.5 inches (NOAA, 1993). This calculation was based on the amount of water that would pass the surface of the cylinder and also assumes that all the rain infiltrates flows through soil. It is unlikely that in an actual rain event all of the rain will pass vertically through the soil, for this reason the calculation should be considered as a maximum exposure. If the acid rain simulation had a significant effect on the pore water of the microcosms a much greater decrease of the pH in the exchange water would be expected. Therefore the buffering capacity of the soil exceeds the amount of acid that was applied to the microcosm.

7.5 Changes in Chromium Concentrations Over Time

In general, chromium concentrations in the microcosm effluent tended to decrease over time as shown in Figure 20 for all the microcosms and in Figure 21 showing those microcosms with lower concentrations of chromium. The range of chromium concentrations in the field samples associated with the sites where cores were taken for the microcosms are also shown in Figure 21 as vertical lines to the right of the plot. Hexavalent chromium was not detected in any of microcosms exchange solutions. The first samples taken for analysis from the microcosm were at the end of the initial exchange of 500 mL. These samples would represent the mostly new fluid in the microcosm, as most of the original fluid would have been flushed out. These data are plotted at time zero on Figures 20 and 21. Each subsequent sample was taken at the beginning of the exchange, as described in the methods section and represents fluid in the microcosm for the previous week or month depending on the incubation period.

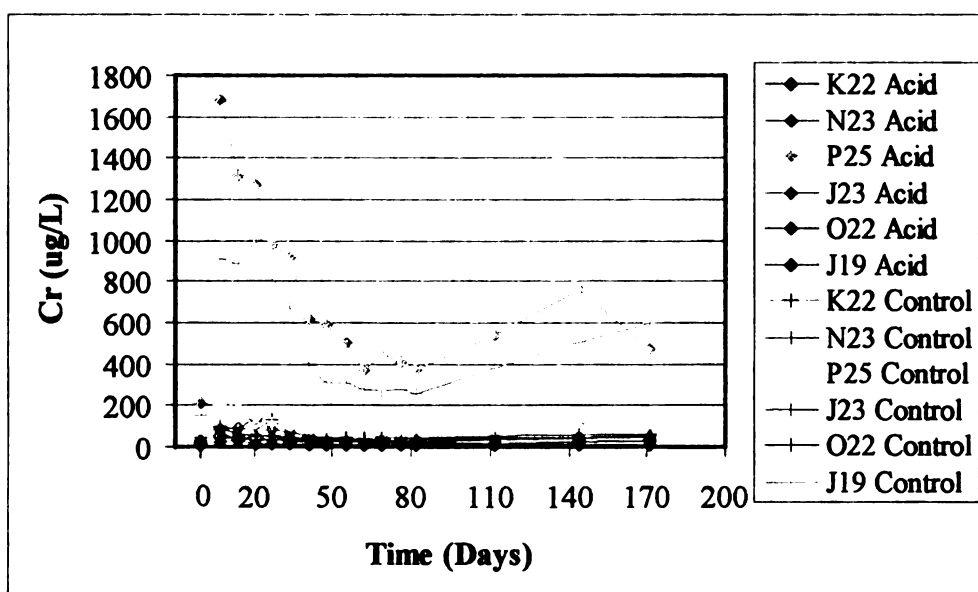


Figure 20. Chromium concentrations in the exchange solutions.

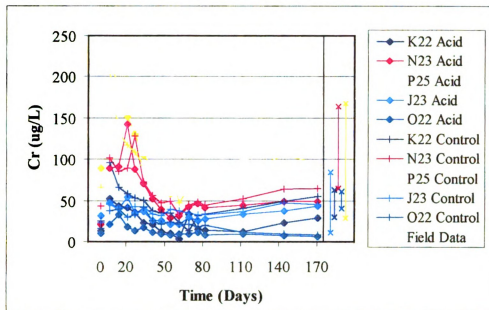


Figure 21. This figure is similar to Figure 20, although sample J19 was not included. Also, the vertical lines, to the right of the concentration profiles, represent the ranges of chromium concentrations observed in the pore-waters at these sites.

In general, chromium concentration trends in the exchange water are similar for both the acid and control microcosms from a given site. Chromium concentrations in the exchange water of all the microcosms decreased over the time during the initial one week incubation periods. When the incubation period was extended to one month the concentration of chromium increased in all microcosms except the O22 microcosms. This implies that the mechanism causing the release of chromium was allowed to develop more fully during a month incubation period. The incubation period appears to have a significant influence on the release behavior of chromium.

The dissolved chromium concentrations in the microcosm effluents are similar to the measured concentrations in the field pore-water samples (Figure 21). The majority of the chromium concentrations fall within the range of concentrations for the corresponding field pore waters for all sites except O22, which were generally lower than

the field concentrations. The site at J19 was usually unsaturated and therefore pore water was not available for comparison. The acid and control exchange solutions do not appear to mobilize the chromium to dissolved concentrations that are higher than what are normally found in the pore water at the site (Figure 21). This indicates that the simulated acid-rain treatment did not mobilize chromium to a greater extent than the conditions currently at the site and also demonstrates that the microcosms were successful in replicating the conditions observed in the field.

Dissolved chromium concentrations in the exchange water from microcosms J19, P25, and N23 are higher than the rest of the microcosms. Sites J19, P25, and N23 are all sites that experience unsaturated field conditions at least part of the year. Site J19 is in a small upland area that is usually unsaturated. The water table is more than 3 feet below the surface at this site. Site P25, and to a lesser extent site N23, are in areas that have an observed history of periods of saturation and unsaturation. The rest of the sites are in areas that are continually saturated with water. Considering only the sites that experience unsaturated field conditions, concentrations in the exchange water are highest in J19 and lowest in N23. J19 site is also experiences unsaturated conditions more than the N23 site, which may suggest that the duration that a site is saturated or unsaturated may have an effect on the mobility of chromium.

The amount of chromium released from the microcosms did not appear to be related to the total concentration of chromium in the soil (Table 7). Chromium concentrations were determined on soil removed from the ends of the cores during construction of the microcosms. The totals were determined using the method described in section 3.1.4. The data are arranged on Table 7 in order of decreasing amounts of

chromium in the microcosm effluent. In many of the cores there was a large difference in the solid phase chromium concentrations between the top and the bottom. The highest soil concentrations were observed in the microcosms from J19, which also had the highest concentration of chromium in the exchange water. The microcosms from P25 released the second most chromium in the microcosm experiments, but the soils had relatively low chromium concentrations. The microcosms from the K22 sites contain the second highest concentrations of chromium in the soil, but very little chromium was eluted from these microcosms (Figure 21). There appears to be no relationship between the amount of chromium in the effluent and the amount of chromium in the soil of a particular microcosm.

Table 7. A summary of the concentration of chromium in the microcosm soils presented in order of decreasing chromium concentrations in the microcosm effluent.

Sample	Location in core	Cr Conc. (mg/kg dry wt.)	Sample	Location in core	Cr Conc. (mg/kg dry wt.)
J19 Acid	Top	15942	K22 Acid	Top	12327
	Bottom	88877		Bottom	1201
J19 Neutral	Top	6132	K22 Neutral	Top	8430
	Bottom	71693		Bottom	1299
P25 Acid	Top	6108	J23 Acid	Top	12135
	Bottom	3127		Bottom	54988
P25 Neutral	Top	7573	J23 Neutral	Top	1676
	Bottom	2777		Bottom	78188
N23 Acid	Top	14298	O22 Acid	Top	6382
	Bottom	21073		Bottom	368
N23 Neutral	Top	10673	O22 Neutral	Top	No Sample
	Bottom	8626		Bottom	5541

One possible explanation for the decreasing chromium concentrations in the microcosm effluent is that chromium is being liberated as a by-product of microbial degradation of the natural organic matter. In this scenario the chromium is bound to

organic matter which is being utilized by microorganisms and chromium is released as a Cr(III)-DOC complex by-product of that reaction. The positive correlation of chromium with DOC in the microcosm samples and the solid phase extraction data strongly indicate a connection between chromium and DOC, which supports this theory. This could also account for the trend in chromium concentrations over time in the microcosm effluent. In this situation, the one-week incubation period did not allow enough degradation of organic matter to create high concentrations of a Cr(III)-DOC complex. A one-month incubation did allow for a large amount of Cr(III)-DOC to be produced, which resulted in higher concentrations. This may also explain the observation that the sites that are usually drier release more chromium. Sites that are unsaturated allow for oxygenated conditions. Oxygen respiration is the most efficient metabolic approach to degrade organic matter and therefore Cr(III)-DOC complexes could build up in the soil. These complexes could then be mobilized with the subsequent influx of water. If these complexes existed in the soil prior to the initiation of the experiment they may have been slowly released over the course of the experiment, which would explain the decrease in chromium concentrations over time.

Another possible explanation for microcosm data is that chromium is being liberated as a Cr(III)-DOC complex that is the result of a thermodynamic, equilibrium reaction. In this scenario chromium is coming into solution in an effort to reach an equilibrium state with a solid phase, which for chromium in this system would likely be $\text{Cr}(\text{OH})_{3\text{am}}$. This chromium hydroxide may be dissolving to form $\text{Cr}(\text{OH})_x^{(3-x)}$ aqueous species, as illustrated in Figure 11, that could then react with the dissolved organic matter to form Cr(III)-DOC complexes. The DOC and solid-phase extraction data also support

this explanation, which could also account for the trend in chromium concentrations over time in the microcosm effluent. In this situation, the one-week incubation period did not allow enough time for the reaction to proceed toward equilibrium. While a one-month incubation did allow for the react to proceed further, which resulted in higher concentrations. Also, if the final concentration was influenced or determined by the availability of organic ligands produced by microbial activity then this may explain the increased chromium concentrations with the one-month incubation period as a result of increased microbial activity due to the longer incubation period. This process is consistent with the conclusions of a thermodynamically driven equilibrium process controlling the chromium concentrations that was suggested for the field data.

It is not possible to determine the exact process by which chromium is entering solution with these data. However, it is apparent that organic ligands play a major role in the solubilization of chromium in these soils. Microorganisms in the soil control the type and abundance of organic ligands in soil pore waters. For these reasons, the second round of microcosm experiments was focused on influencing the microbial processes in the soil cores.

VIII. NUTRIENT MICROCOSMS

8.1 Rational

The results from the preceding work indicate that a significant portion of the chromium in the soils and pore waters is associated with organic matter. If true, changes in the types or rates of degradation of organic matter could influence chromium behavior at the site. The mobilization of chromium could occur as a by-product of the degradation or an increased availability of ligands in solution which complex with inorganic dissolved chromium. A likely method for disturbing the soil organic matter would be the natural microbial degradation of the soil organic matter. During this process natural plant material is broken down into smaller fragments and eventually converted to carbon dioxide and/or methane. The treatments for the second round of microcosm experiments were designed to increase the degradation of soil organic matter by stimulating the microbial community. The hypothesis was that if the degradation of soil organic matter increased the concentration of chromium would increase in the pore water of the microcosms.

One of these treatments attempted to maximize the efficiency of the microbial community by altering the redox state to a higher level. The field data indicated the pore waters were in a reduced (oxygen deficient) state, as expected for an organic rich wetland area, and the microbial degradation of cellulose based plant material is inhibited under reduced conditions (Atlas and Bartha, 1993). Microbial communities use a variety of energy sources or terminal electron acceptors and communities that utilize oxygen as

their predominant terminal electron acceptor are the most efficient at degrading soil organic matter because it is the most energetic terminal electron accepting process (Lovley and Goodwin, 1988; Atlas and Bartha, 1993). However, for the purposes of this experiment oxygen could not be used because it has a very low solubility and it was thought that the amount of oxygen that could be injected with the water would be quickly utilized leaving the remainder of the week to develop anoxic conditions again. The next most energetic TEAP is the reduction of nitrate (Lovley and Goodwin, 1988; Atlas and Bartha, 1993; Lovley et al., 1994). Since nitrate is soluble in water, it was added to the artificial rain solution to make a final concentration of 90 mg/L nitrate.

Another treatment attempted to stimulate microbial processes by increasing the overall nutrient level of the pore water. The objective of this treatment was to add nutrients to the system that were lacking and thereby increase the microbial potential to degrade the soil organic matter. In this treatment nitrate and phosphate were both added in concentrations of 25 mg/L and 2 mg/L respectively to the simulated rain solution. The third treatment was the artificial rain solution, as a control, that was used in the previous microcosm experiments.

Soil cores for these microcosm experiments were collected in the spring of 1998 from the same six locations as the first microcosm experiments. From each site, three soil cores were collected, one core for each treatment, resulting in a total of 18 microcosms. The sampling protocols, microcosm design, and sampling strategies for the microcosms were essentially the same as in the first microcosm experiments. The only differences were that 1) the first sample collected was the first 120 mL of fluid that eluted from the core during the first exchange, and 2) all treatment fluids were de-aerated by

bubbling argon gas through the solutions for one hour prior to pumping them into the microcosms.

8.2 Dissolved Chromium versus DOC Results

The relationship between aqueous chromium concentrations and DOC appears to be more ambiguous for the nutrient-microcosm samples than either the field or the acid-rain microcosm data. The data are presented on four separate plots (Figures 22 a, b, c, and d). When looking at the entire data (Figure 22a) the data are not highly correlated

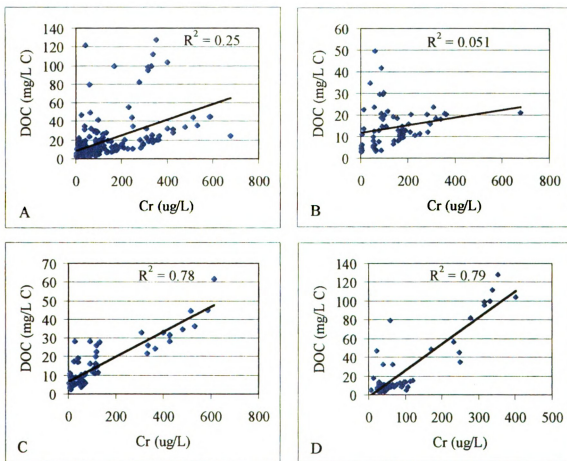


Figure 22. Correlation of chromium versus DOC in the nutrient microcosm effluents. Figure 22a includes the samples from all three treatments (N, N&P, and control) from each site. Figure 22b shows data from the microcosms treated with 90 mg/L nitrate. Figure 22c shows data from the microcosms treated with 25 mg/L nitrate and 2 mg/L phosphate. Figure 22d shows data from the control microcosms treated with the simulated rain solution.

($R^2=0.25$). The poor correlation appears to be primarily the result of a group of samples with high DOC concentrations. However the majority of these data plots in a trend with a slope of between 0.04 and 0.08, which is similar the trends that were observed in the field and acid-microcosm data (Figures 12 and 17).

The data for the 90 mg/L nitrate (N) treatment (Figure 22b) shows a very poor correlation ($R^2=0.051$), but a trend similar to the trends observed in the field and acid-microcosm data is still apparent. The data for the 25 mg/L nitrate and 2 mg/L phosphate (N&P) treatment (Figure 22c) shows a much better correlation ($R^2=0.78$), which is similar to the field and acid-rain microcosm data. The data for the control treatment (Figure 22d) also shows a much better correlation ($R^2=0.78$), however, the correlation is highly dependant on the samples above 150 mg/L chromium. These samples all come from the J19 control microcosm and have DOC concentrations that are much higher as a group than the rest of the data. The control samples below 20 mg/L chromium (Figure 22d) appear to have a linear trend similar to that of Figure 22c.

The treatments were designed to enhance microbial degradation of organic matter and it is likely that this would also impact the concentration and nature of the DOC. This may result in the relationship between dissolved chromium and DOC becoming less clear as seen in the microcosms treated with 90 mg/L nitrate. The relationship may be impacted by a production of ligands faster than the reaction with available chromium can occur. Even though the relationship between chromium and DOC may have become less obvious, all of the figures for the nutrient microcosms show a trend similar to that observed in the field and acid-rain microcosms to a certain extent. By analogy, this

indicates there is a relationship between chromium and DOC in the nutrient microcosm samples.

8.3 Solid Phase Extraction Results

The chelex 100 resin was also used on the nutrient-microcosm samples to aid in identifying the aqueous speciation of chromium. Similar to the previous graphs showing chelex data (Figures 13 and 19), Cr_{Chelex} represents that concentration of chromium remaining in solution after the reaction with chelex resin which should represent negatively charged or neutral chromium. The results of this extraction on the nutrient samples (Figure 23) are similar to previous results using this extraction medium (Figures 13 and 18). The data are highly correlated ($R^2=0.996$) with a slope near one (slope=0.998), which indicate that the dissolved chromium exists as a negatively charged or neutral species and by analogy with the field data is probably a Cr(III)-DOC complex.

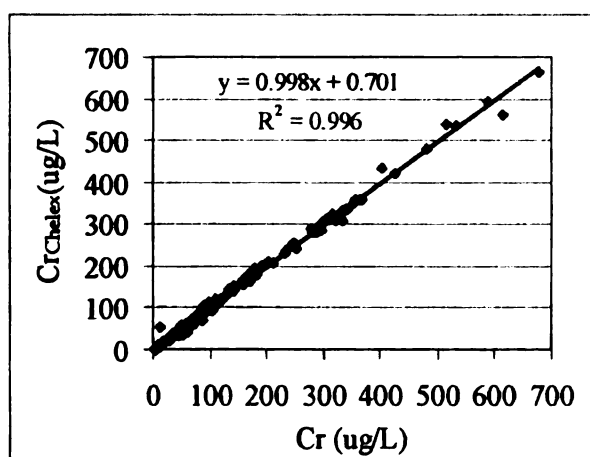


Figure 23. Correlation of total dissolved chromium versus Cr_{Chelex} (negatively charged or neutral chromium) in the effluent water from the nutrient microcosms.

8.4 Changes in Nitrate and Sulfate Concentrations over Time

The concentrations of nitrate and sulfate were monitored to assess whether the treatments were affecting microbial processes. Phosphate was also monitored, but the concentrations were consistently too low to quantify. Nitrate and sulfate are both used as terminal electron acceptors by microbes and their concentrations may give an indication

of the TEAP conditions of the system (Lovley and Goodwin, 1988; Lovley et al., 1994). Sulfate and nitrate were components of the simulated-rain solution and were present in all the treatment solutions used in the microcosm experiments (Appendix L). The concentrations of nitrate and sulfate in the simulated-rain solution were 2.4 mg/L nitrate and 5.6 mg/L sulfate. Also, nitrate was monitored because it was added to both of the nutrient treatments.

The nitrate concentrations from the microcosms treated with 90 mg/L nitrate (N) showed two different trends during first ten weeks of the experiment (Figure 24). The most common trend was that the concentrations tended toward a relatively constant concentration. The microcosms from sites J19, P25, K22 and O22 all showed this trend, with concentrations for the different microcosms ranging between 20 and 40 mg/L. The J19 microcosm core was not saturated with water when collected and the initial sample from that microcosm had a high concentration because it was primarily composed of the incoming treatment water. The other trend consisted of a general increase in concentration from the beginning of the experiment until week ten. The microcosms from sites J23 and N23 showed this trend, with maximum concentrations near 30 mg/L. These trends indicate that nitrate was being utilized by the microbial community to varying degrees in all cores. The concentrations of nitrate decreased dramatically for all microcosms in the last two exchanges for the N treatment microcosms. This may indicate a change in the microbial community to allow for a greater utilization of nitrate that was added.

The nitrate concentrations from the microcosms treated with 25 mg/L nitrate and 2 mg/L phosphate (N&P) showed two different trends during first ten weeks of the

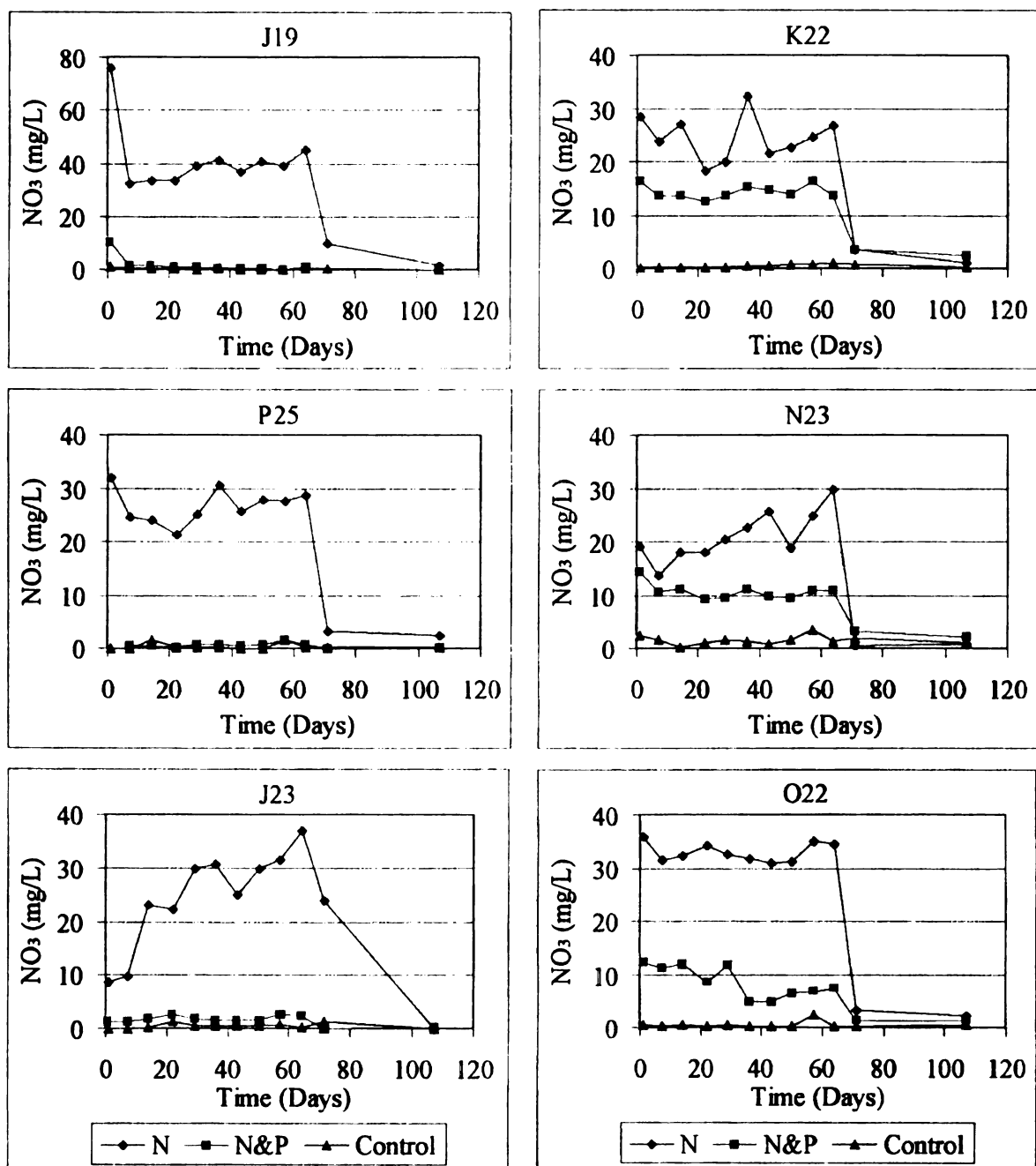


Figure 24. Nitrate concentrations in the effluent of the nutrient microcosms over time for the six microcosm sites. The concentration range is not the same for each graph. N represents the microcosms treated with 90 mg/L nitrate. N&P represents the microcosms treated with 25 mg/L nitrate and 2 mg/L phosphate. Control represents the microcosms treated with the simulated rain solution.

experiment as well (Figure 24). The nitrate concentration trends from microcosms J19, P25, and J23 are all near zero with no concentrations greater than 3 mg/L. This indicates that the microbial community in these microcosms utilized the nitrate almost completely.

The concentration trends from microcosms K22, N23, and O22 tend toward constant concentrations ranging in concentration from 8 to 12 mg/L. These trends indicate that the microbial community was utilizing the added nitrate to a certain extent. As with the N treatment, the concentrations of nitrate decreased dramatically for all microcosms in the last two exchanges for the N&P treatment microcosms. This may indicate a change in the microbial community to allow for a greater utilization of nitrate that was added. The concentrations of nitrate in the control microcosms remained near or below the input concentration of 2.4 mg/L for all microcosms (Figure 24). The nitrate data indicates that the microbial community was utilizing the nitrate added to the system.

The trends in sulfate concentrations in the amended microcosms may be used to support the indication that nitrate was being utilized by the microbial community. Microbes can get a higher energy yield when using nitrate as a terminal electron acceptor as opposed to sulfate (Lovley and Goodwin, 1988; Atlas and Bartha, 1993). When nitrate reduction is the dominant TEAP sulfate can exist in the pore water at higher concentrations than when sulfate reduction is the dominant TEAP (Lovley and Goodwin, 1988; Lovley et al., 1994). Therefore high concentrations of sulfate may indicate that nitrate reduction is the dominant TEAP. Also, the production of sulfate in the microcosms would not occur if the strongly reducing conditions prevailed. The concentration of sulfate in all of the treatment solutions was 5.6 mg/L (Appendix L).

The sulfate concentration trends from microcosms that were treated with 90 mg/L nitrate reduction indicate that nitrate may have been the dominant TEAP in these microcosms (Figure 25). The general trend of sulfate concentrations for these microcosms show a gradual increase in the first ten weeks and then a sharp increase in

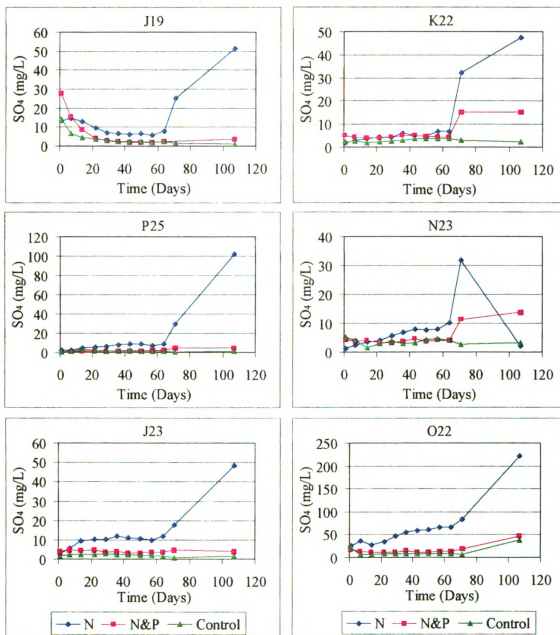


Figure 25. Sulfate concentrations in the effluent of the nutrient microcosms over time for the six microcosm sites. The concentration range is not the same for each graph. N represents the microcosms treated with 90 mg/L nitrate. N&P represents the microcosms treated with 25 mg/L nitrate and 2 mg/L phosphate. Control represents the microcosms treated with the simulated rain solution.

concentration for the last two exchanges. There are two exceptions to this trend. First, concentrations of sulfate in the J19 microcosm initially decrease and level off before increasing in the last two exchanges. Second, the last exchange for the N23 microcosm

decreased significantly from the previous concentrations and may have been an errant data point. In general however, the elevated sulfate concentrations show that the redox state of these microcosms was at least oxidizing enough to allow for the formation of sulfate. The rapid increase in sulfate in the last two exchanges corresponds well with decrease in nitrate for the same exchanges.

Sulfate concentration trends for the first ten weeks were similar in both the N&P and control microcosms. The concentrations were relatively constant with values ranging between 2 and 4 mg/L, except for O22 which were from 8 to 12 mg/L. Concentrations less than 5 indicate that sulfate is being consumed by the microbial community. This indicates that nitrate reduction may not be the dominant TEAP in these microcosms. Concentrations of sulfate in the last two exchanges increased in all of the N&P microcosms, indicating a major shift of the redox state in these microcosms. This corresponds well with the nitrate data, which decreased in these exchanges. Except for the last two exchanges and microcosm O22, sulfate was not forming in these microcosms, which suggests that these microcosms were more reduced than the N microcosms.

The nitrate and sulfate data indicate that microbial processes were influenced by the treatments. One of the goals was to produce a higher redox potential (or TEAP) in the N microcosms and it appears that this was achieved. It also appears that the microbial community utilized the nitrate and phosphate in the N&P treatment fluids and therefore the treatment objective for this treatment was also achieved.

8.5 Changes in Chromium Concentrations over Time

In comparing the trends of chromium concentrations from the acid-rain microcosm experiments to those in the nutrient microcosm experiments, it should be noted that information from the first samples taken are not directly comparable between the two microcosm studies. This is because in the nutrient microcosm experiments the first sample is the first 120 mL of water from the microcosm during the first exchange. In the acid rain microcosms, the first sample was the final 120 mL of water from the microcosm during the first exchange. The nutrient microcosm experiments were conducted for 14 weeks with a normal incubation of one week and a 3-week incubation period between the last two samples. It should also be noted that the first sample for the J19 microcosms consisted primarily of the incoming treatment fluid, because the cores were collected from unsaturated soils.

The level of chromium concentrations in the effluent from the nutrient microcosms (Figure 26) is similar to the level of chromium concentrations from acid-rain microcosms (Figures 20 and 21). The relative level of chromium concentrations among the sites was also similar to what was found in the simulated acid rain experiments and followed the order $J19 > P25 > N23 > J23 \geq K22 > O22$. In general, the chromium mobilized from the soils increased after the initial exchange and also after the longer incubation period, with the exception of the O22 microcosms (Figure 26). The results of the chromium concentration data from the nutrient microcosms shown in Figure 26 are summarized in Table 8. The chromium concentrations for the nutrient microcosms are compared against the control microcosms and each other for each site. The table also

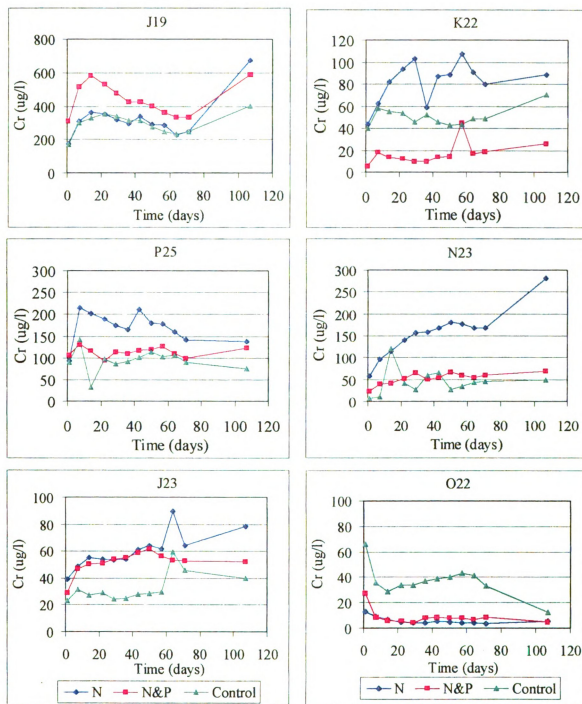


Figure 26. Chromium concentrations in the effluent of the nutrient microcosms over time for the six microcosm sites. The concentration range is not the same for each graph. N represents the microcosms treated with 90 mg/L nitrate. N&P represents the microcosms treated with 25 mg/L nitrate and 2 mg/L phosphate. Control represents the microcosms treated with the simulated rain solution.

includes the change in chromium released after the sample interacted with the treatment solution for the three-week period.

Table 8. Summary comparison of chromium in the effluent from nutrient microcosm experiments.

Comparison	Soil Sampling Site					
	J19	P25	N23	J23	O22	K22
N vs. Control	similar	>	>	>	<	>
N&P vs. Control	>	similar	similar	>	<	<
N vs. N&P	<	>	>	similar	similar	>
N last sample	higher	similar	higher	higher	similar	higher
N&P last sample	higher	slightly >	similar	similar	similar	higher
Control last sample	higher	slightly <	similar	similar	lower	higher
<p><i>Explanation:</i> N = treatment with 90 mg/L NO₃, N&P = 25 mg/L NO₃ and 2 mg/L PO₄; similar means N treatment and control or N&P treatment have similar chromium concentrations; > means N treatment chromium values are greater than control or N&P treatment values; < means treatment chromium values are less than control or N&P treatment values. The last three rows depict the change in the concentration of chromium in the effluent after remaining in the microcosm for 3 weeks.</p>						

The microcosms from site J19 showed the N&P treatment liberated the most chromium, while there was very little difference in the chromium concentration of the effluent between the N and control treatments. Concentrations of chromium in the effluent initially increased from the first samples taken in both treatments and in control samples and then decreased over time. Concentrations of chromium in the effluent increased after the three-week interaction time.

The microcosms from sites P25 and N23 show the N&P and control treatments had similar chromium concentrations, while the highest chromium concentrations were from the N treatment microcosms. Concentrations of chromium decreased in samples from the P25 site and little change in chromium concentrations was found after the three-week incubation time. The N23 microcosms had chromium concentrations in both the N

and N&P treatment samples and the control samples that increased to relatively constant concentrations. Except of the N treatment, concentrations of chromium in the effluent after the three-week incubation period did not change. Concentrations in the N treatment after this time were higher for the N23 microcosm.

The microcosms from J23 show concentrations in the control samples were different from those in the treatment samples. The concentrations and trend of concentrations for chromium in the N and N&P treatments were similar for the J23 microcosms, but higher than those from the control microcosm. In both treatment and control microcosms the chromium concentrations increased to relatively constant values. The concentration of chromium in the N treatment samples was higher after the three-week period. No change was found in the other samples after this period.

The N treatment liberated the most chromium at site K22 followed by the control and then the N&P. Concentrations increased to relatively constant values. There were slight increases of chromium in the leachate in all three types of fluids after the three-week interaction period.

The microcosms from O22 show that the concentrations and trend of chromium concentrations for the N and N&P treatments were also similar, but lower than those from control. Samples from this site were the only ones to show a decrease in chromium concentrations over time including after the three-week interaction time. These cores were composed of silty sand with very little organic matter and thus were very different compositionally from the rest of the cores, which included large percentage of organic matter.

The amount of chromium released from the microcosms does not appear to be related to the amount of chromium in the soil. Table 9 lists the concentration of chromium in soil samples taken from material that was removed from the ends of the microcosm cores during construction. The totals were determined using the method described in section 3.1.4. In many of the cores there was a large difference in the concentrations at the top and those at the bottom of the microcosm core. The highest concentrations were observed in the microcosms from J19, which also had the highest concentration of chromium in the exchange water. However, there are no other apparent relationships between the concentrations in the soil and the amount of chromium released from them, similar to the acid-rain microcosms.

Table 9. A summary of the concentration of chromium in the microcosm soils

Sample	Location in core	Cr Conc. (mg/kg dry wt.)	Sample	Location in core	Cr Conc. (mg/kg dry wt.)
J19 N	Top	3067	K22 N	Top	9665
	Bottom	59957		Bottom	1667
J19 N&P	Top	3953	K22 N&P	Top	8266
	Bottom	62348		Bottom	16873
J19 Control	Top	No Sample	K22 Control	Top	10434
	Bottom	84988		Bottom	No Sample
P25 N	Top	5084	J23 N	Top	21371
	Bottom	4780		Bottom	6298
P25 N&P	Top	8229	J23 N&P	Top	6637
	Bottom	9395		Bottom	67336
P25 Control	Top	2141	J23 Control	Top	9241
	Bottom	4802		Bottom	38377
N23 N	Top	4865	O22 N	Top	287
	Bottom	9362		Bottom	720
N23 N&P	Top	5322	O22 N&P	Top	564
	Bottom	16064		Bottom	927
N23 Control	Top	20187	O22 Control	Top	4107
	Bottom	6731		Bottom	1520

The hypothesis driving the nutrient amended microcosms was that chromium concentrations in the pore water would increase if the degradation of soil organic matter increased. The additions of an alternative terminal electron acceptor and supplemental nutrients did appear to be utilized by the microbial community and should have allowed for greater degradation of organic matter. However, a clear relationship between the effluent chromium concentrations and the treatments applied is not apparent. The microcosm treatment that released the most chromium was usually a N or N&P treatment. This was true for all sites except O22, which as discussed earlier is composed to silty sand and is compositionally different from the rest of the microcosms. The fact that either the N or N&P treatments released the most chromium supports the hypothesis that increased microbial degradation of the soil organic matter may increase the dissolved chromium in the pore water. The inconsistent behavior may be a function of heterogeneity in the soil composition or microbial communities at each site, which result in different responses. It may also be that the time span or incubation period of these experiments did not allow enough time significantly alter the composition of the dissolved organic carbon. Although the fact that the N or N&P microcosms released the most chromium supports this hypothesis, the results are equivocal and can not be used as a predictive tool due to the lack of consistent trends.

IX. SUMMARY AND CONCLUSIONS

9.1 Summary

Chromium appears to be predominantly associated with two phases in these soils. The comparison of chromium and organic matter in the soil indicates that there is an association between chromium and soil organic matter. This is also supported by the sequential extraction data that show chromium is mainly associated with the moderately reducible (MR) and basic oxidizable (OX1) phases in these soils. The association of chromium with the OX1 phase is consistent with the relationship of chromium to organic matter. The proportion of chromium associated with the MR phase increased as the total amount of chromium in the soil increased. The increasing dominance of the MR extraction with increasing chromium concentrations may indicate that there is a limitation to the amount of chromium that can associate with natural organic matter. Considering the results of the sequential extraction data for chromium, the chemistry of the solutions used in the selective chemical attacks, and knowledge of the biogeochemistry of chromium, it is concluded that the dominant forms of chromium in the soils at this wetland are a $\text{Cr}(\text{OH})_3$ mineral/amorphous solid and chromium associated with soil organic matter.

The concentrations of chromium in the surface and pore waters of this site are usually higher than would be expected by inorganic thermodynamic modeling. There was no measurable Cr(VI) observed in any of the samples collected. There was a positive correlation between chromium and dissolved organic carbon, which suggests that

chromium is associated with dissolved organic carbon in these waters. Solid phase extractions performed on the aqueous field samples showed that 96 percent of the chromium acted as anion, 12 percent of the chromium was associated with the hydrophobic organic fraction, and no measurable chromium acted as a cation. The results of the solid phase extractions show that aqueous chromium exists primarily as an anion in these waters. Since no Cr(VI) was observed in these samples, this anion is most probably a complex of chromium with DOC. In the pH range of these waters (near neutral) most of the functional groups on natural dissolved organic matter will have a negative charge. This characteristic supports the assumption that the chromium exists as a Cr(III)-DOC complex.

There is an apparent contradiction between the anion and hydrophobic extraction data. The anion extraction indicates that 96 percent of the chromium is associated with an anionic species, however the hydrophobic extraction indicates that 12 percent of the chromium is associated with hydrophobic compounds. The contradiction arises from the fact that these two extractions combined exceed 100 percent, but if one takes into account the nature and complexity of natural organic matter the significance of this contradiction is diminished. It is completely plausible for organic compound to have both a hydrophobic component and a hydrophilic component (anionic). Another possibility is that the remaining 4 percent of the anionic extraction may be composed of neutral chromium species not associated with DOC, such as $\text{Cr}(\text{OH})_3$. However, the majority of the aqueous chromium exists as an anion, which is most likely a Cr(III)-DOC complex.

The concentrations of chromium and pH values in the exchange water from the control soil samples in the microcosm studies were similar to those found in the native

soil pore waters. This indicates that the microcosms for this study reproduced field conditions and therefore it can be assumed that the microcosm experiments were adequate surrogates for field conditions.

Chromium in the microcosm exchange water was found to be associated with dissolved organic matter, similar to field observations. Also, there was no measurable chromium that existed as a cation. The concentrations of chromium released from the treatment soils in the microcosm studies were also similar to those found in the soil pore waters. These observations suggest that chromium in the microcosm exchange fluid is behaving similarly to chromium in the field samples and therefore likely to be a Cr(III)-DOC complex. This also indicates that the treatments chosen for this study did not enhance the mobility of chromium above the conditions currently found at the site.

The results of the microcosms involving the acid-rain simulations indicate that the buffering capacity of the soil neutralized the acid in the acid-rain solution. Thus, enhanced chromium mobility because of acidification did not take place, during the course of the experiment. The results of the microcosms involving acid rain also indicate that cyclic saturation and unsaturation of the soils may mobilize chromium.

There appears to be no relationship between the amount of chromium in the effluent and the amount of chromium in the soil of a particular microcosm. There appears to be a relationship between the saturation history of a site and the amount of chromium released from a microcosm from that site. Microcosms from sites that were normally wet released the least amount of chromium, despite the fact that some cores contained much more chromium than other microcosms that released more chromium. Microcosms from sites that were variably or cyclically saturated released more chromium

than those continually saturated. The one site that was continually dry released the most chromium.

There are several possible explanations for the behavior of chromium in these waters. One possible explanation for microcosm data is that chromium is being liberated as a by-product of microbial degradation of the natural organic matter. In this scenario the chromium is bound to organic matter which is being utilized by microorganisms and that chromium is released as a Cr(III)-DOC complex as by-product of that reaction. Another possible explanation for microcosm data is that chromium is being liberated as a Cr(III)-DOC complex that is the result of a chemical-equilibrium reaction. In this scenario chromium is coming into solution in effort to reach an equilibrium state. One possible solid phase for chromium would be $\text{Cr}(\text{OH})_3$, which may be dissolving to form inorganic species that can be complexed with DOC. The complexation of chromium with DOC would then allow for more $\text{Cr}(\text{OH})_3$ to dissolve. Further research is necessary to determine which of these processes are controlling chromium mobility. It is possible that both processes are occurring in these soils.

The results of the microcosms involving changes in nutrient concentrations (i.e., phosphorus and nitrogen) indicate that chromium mobility in the soils will be affected by changing nutrient concentrations. However, a clear relationship between the effluent chromium concentrations and the treatments applied is not apparent. The microcosm treatment that released the most chromium was usually an N or N&P treatment. However, the fact that the N or N&P treatments consistently released more chromium supports the hypothesis that increased microbial degradation of the soil organic matter may increase the dissolved chromium in the pore water. The inconsistent behavior may

be a function of different limiting conditions or microbial communities at each site, which result in different responses. Although some of the data support this hypothesis, the results are equivocal and can not be used as a predictive tool due to the lack of consistent trends.

The effects are complex and somewhat dependent on soil type. The N and the N&P treatments affected the soils differently. In turn, the soils responded differently to the treatment. The treatments did impact the dissolved organic carbon in solution as evidenced by a low correlation between chromium and dissolved organic carbon in the microcosms treated with 90 mg/L nitrate, but some of the data appeared to be correlated to a certain extent. However, chromium concentrations in the microcosm studies were not significantly greater than what was found in the soil pore waters.

The release of chromium from the nutrient microcosms was similar to the release observed for the acid-rain microcosms. The relative amounts of chromium leached from the nutrient microcosms were similar to the relative amounts leached found in the acid-rain microcosm. In other words, those soils that tended to leach higher amounts of chromium in the acid-rain simulations were the same soils that leached the higher amounts of chromium the nutrient experiments. Also as in the case of the acid-rain microcosm experiments, the amount of chromium leached was not directly related to the total amount of chromium in the soils.

9.2 Conclusions

Inorganic and organic processes influence the fate and mobility of chromium in wetland environments. The primary hypotheses of this research were that chromium is associated with soil organic matter as Cr(III) and that dissolved chromium will be associated with dissolved organic matter. The results indicate that the solid forms of chromium in these environments will be either a chromium hydroxide or bound to the soil organic matter. Although both chromium hydroxides and soil organic matter appear to sequester chromium, chromium hydroxide is the dominant form at higher concentrations of chromium and so in that respect the hypothesis was not supported as far as the solids are concerned. The dissolved chromium concentrations are higher than would be predicted by inorganic thermodynamic calculations and the dissolved chromium is strongly associated with dissolved organic carbon, which supports the hypothesis. The relationship between chromium and DOC was observed in both the field and laboratory experiments, even though the DOC was not speciated. Aqueous chromium exists as an anion, which is probably a Cr(III)-DOC complex. It appears that the solubility of chromium is controlled by thermodynamic equilibrium processes involving both the solubility of $\text{Cr}(\text{OH})_{3\text{am}}$ and the availability of organic ligands to complex with chromium.

A secondary hypothesis was that the mobility of chromium in these soils is controlled by the stability of the organic matter to which it is bound. This hypothesis was tested with the microcosm experiments and is not strongly supported by the microcosm results or the speciation results. The sequential extraction data indicates that the organically bound chromium is not dominant form of chromium in the soil, which does

not support the hypothesis, however a small fraction can have a large influence on solubility. The results of the microcosm experiments show that the solubility of chromium may also be increased if the soils experience periods cyclic saturation and unsaturation. The results of the nutrient amended microcosms were equivocal, but indicated that there also may be an increased solubility of chromium if the degradation of soil organic matter is increased. The microcosm data showed trends in the chromium versus DOC and chromium versus the negatively charged or neutral chromium species that were similar to those observed for the field data. This indicates that the aqueous speciation of chromium in both the field and laboratory data is similar and that the processes controlling the solubility of chromium in both settings is the same. Therefore, it appears that the solubility of chromium is more likely to be controlled by the availability of organic ligands in solution than the stability of the organic matter to which it may be bound.

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APPENDICES

Appendix A
Table A-1. Sample Location and Soil Core Descriptions

Site ID	Description of sample location	Interval (feet)	Description of soil
B3	Hardwood forest with undergrowth	0.0-0.5	Dark brown silty sand, with roots, grades to rusty medium brown silty sand
		0.5-1.0	Dark brown silty sand, with roots, grades to rusty medium brown silty sand
		1.0-1.5	Rusty medium brown silty sand grades to dark brown silty sand
		1.5-3.0	Rusty medium brown silty sand
		3.0-3.5	Rusty medium brown silty sand
B5	Opening in a forest with undergrowth	0.0-0.5	Dark brown silty sand, with roots and wood chips
		0.5-1.0	Rusty orangish brown silty sand
		1.0-1.5	Rusty organish brown silty sand
		1.5-3.0	Rusty medium brown silty sand grades to rusty tan silty sand
		3.0-3.5	Light tan silty sand
B7	Mixed hardwood and evergreen forest	0.0-0.5	Dark brown/black silty sand, grades to light brown silty sand
		0.5-1.0	Light brown silty sand grades to rusty brownish orange near bottom
		1.0-1.5	Rusty brownish orange silty sand
		1.5-3.0	Rusty brownish silty sand grades to tan silty sand
		3.0-3.5	Tan silty sand then sharp contact with brown silt three inches from top of core
B9	Grassy covered man made berm	0.0-0.5	Dark rusty brown silty sand
		0.5-1.0	Dark rust brown then dark brown silty sand
		1.0-1.5	Rusty dark brown to rusty light brown
		1.5-3.0	Rusty light brown to tan
		3.0-3.5	Tan silty sand
B11	Site is in brush in a wooded area	0.0-0.5	Dark brown silty sand
		0.5-1.0	Dark brown to dark rusty brown silty sand
		1.0-1.5	Rusty light brown silty sand
		1.5-3.0	Rusty light brown silty sand grades to rusty to tan silty sand
		3.0-3.5	Tan silty sand
B13	Site is in a wooded area	0.0-0.5	Black to dark brown silty sand
		0.5-1.0	Dark brown silty sand with dark rusty brown silty sand near one foot
		1.0-1.5	Dark rusty brown silty sand
		1.5-3.0	Dark rusty brown grading to tan silty sand
		3.0-3.5	Light tan silty sand
B15	Opening at edge of hardwood forest	0.0-0.5	Dark brown silty sand, high OM

Table A-1. (continued)

Site ID	Description of sample location	Interval (feet)	Description of soil
B15		0.5-1.0	Dark brown silty sand with melted looking ore - angular reddish brown
		1.0-1.5	Dark brown material, sharp contact with creamy clumpy sand
		1.5-3.0	Creamy tan grades to light brown silt w/lots of hair to dark brown with hair
		3.0-3.5	Dark brown hair with some sand and silt
B17	Wooded area	0.0-0.5	Dark brown/black silty sands with lots of organic material
		0.5-1.0	Dark brown grades into a rusty tan sandy silt
		1.0-1.5	Rusty tan silty sand
		1.5-3.0	Rusty tan silty sand
C2	Small opening in a hard wood forest	3.0-3.5	Rusty tan to dark rusty brown silty clay
		0.0-0.5	Dark brown silty sand, roots present
		0.5-1.0	Brown silty sand, with roots
		1.0-1.5	Medium rusty brown silty sand
C4	Hardwood forest with sparse vegetation rusty scrap metal and trash near site	1.5-3.0	Medium rusty brown silty sand grades to medium rusty brown sand
		3.0-3.5	Light brown silty sand
		0.0-0.5	Dark brown silty sand, roots and wood chips
		0.5-1.0	Dark brown silty sand grades to rusty tan silty sand roots present
C6	Hardwood forest with light underbrush	1.0-1.5	Slightly rusty medium tan silty sand, roots and wood chips present
		1.5-3.0	Medium tan, slightly rusty silty sand, grades to light rusty tan sand with silt
		3.0-3.5	Top rusty brown silty sand, tan rusty coarse sand, then rusty tan silty sand
		0.0-0.5	Black-dark brown silty sand in upper two inches grades to light brown silty sand
C8	Edge of forested area	0.5-1.0	Light brown silty sand grading to rusty brown silty sand
		1.0-1.5	Dark rusty brown silty sand
		1.5-3.0	Rusty tan silty sand grades to light tan silt with fine sand
		3.0-3.5	Light tan silty sand
C10	Brush on the edge of a wooded area	0.0-0.5	Black silty sand, with roots
		0.5-1.0	Dark brown silty sand grades to rusty brown silty sand, with roots
		1.0-1.5	Dark rusty brown silty sand grades to rusty brown silty sand
		1.5-3.0	Rusty brown silty sand grades to light tan silty sand
		3.0-3.5	Light tan silt with fine sand
		0.0-0.5	Dark brown silty sand
		0.5-1.0	Dark brown sand grading to dark rusty brown
		1.0-1.5	Dark rusty brown silty sand and free roots
		1.5-3.0	Dark rusty brown grading to rusty brown and the rusty tan

Table A-1. (continued)

Site ID	Description of sample location	Interval (feet)	Description of soil
C10		3.0-3.5	Rusty brown
C12	Site is in the trees	0.0-0.5	Black silty sand with many roots
		0.5-1.0	Dark rusty brown silty sand
		1.0-1.5	Rusty brown silty sand
		1.5-3.0	Rusty brown silty sand grading to tan silty sand, increasing clay with depth
		3.0-3.5	Dark tan silty sand with clay
C14	Grassy open area	0.0-0.5	Organic rich, dark brown, silty sand
		0.5-1.0	Organic rich, dark brown, silty sand grading to tan silty sand
		1.0-1.5	Tan, silty sand
		1.5-3.0	Tan, silty sand
		3.0-3.5	Tan, silty sand-disturbances occurred regarding core
C16	Opening in a sparse hardwood forest	0.0-0.5	Dark brown silty sand with roots
		0.5-1.0	No sample taken
		1.0-1.5	No sample taken
		1.5-3.0	No sample taken
		3.0-3.5	No sample taken
D3	Fairly open grassy area, near a pine tree	0.0-0.5	Dark brown silty sand
		0.5-1.0	Light brown silty sand grades to bright rusty brown silty sand
		1.0-1.5	Rusty brown silty sand
		1.5-3.0	Rusty brown silty sand grades to light tan silty sand, stones
		3.0-3.5	Light tan silty sand
D7		0.0-0.5	Dark brown silty sand
		0.5-1.0	Dark brown silty sand grades to rusty tan silty sand
		1.0-1.5	Reddish brown silty sand
		1.5-3.0	Reddish tan silty sand
		3.0-3.5	Reddish tan silty sand
D11	Brush on the edge of a small clearing	0.0-0.5	Top four inches dark brown silty sand, bottom two inches tan silty sand
		0.5-1.0	Rusty tan silty sand
		1.0-1.5	Rusty tan silty sand grades to rusty silty sand with clay
		1.5-3.0	Rusty light tan silty sand grades to light tan silty sand with clay
		3.0-3.5	Dark tan to light brown silty sand and clay - sample is wet and muddy
D13	Wooded area	0.0-0.5	Roots, worm, black to dark brown silty sand

Table A-1. (continued)

Site ID	Description of Sample Location	Interval (feet)	Description of Soil
D13		0.5-1.0	Dark brown grading into rusty brown
		1.0-1.5	Rusty brown silty sand
		1.5-3.0	Rusty tan silty sand
		3.0-3.5	Medium tan silty sand
D15	Opening in hardwood forest	0.0-0.5	Dark brown silty sand
		0.5-1.0	Brown silty sand grades to rusty tan silty sand and gravel
		1.0-1.5	Rusty tan silty sand
		1.5-3.0	Rusty tan grades into light tan silty sand
		3.0-3.5	Light tan silty sand
D17	Opening in hardwood forest	0.5-1.0	Dark brown coarse sand w/pebbles, roots present, peat material
		1.0-1.5	Peaty materials with pebbles
		1.5-3.0	Peaty materials with silty clay and pebbles
		3.0-3.5	Peaty materials w/ silty clay and pebbles grades to dark tan silt and clay
D19	Wooded area	0.0-0.5	Dark brown coarse sand grades to coarse sand and gravel, roots throughout
		0.5-1.0	Dark brown gravel
		1.0-1.5	Dark brown gravel
		1.5-3.0	Reddish black gravel grades to clumps of clay then back to gravel
E16	Edge of hardwood forest moderate Underbrush	3.0-3.5	Top three inches -red-black gravel grades to red-brown gravel/coarse sand and clay
		0.0-0.5	Dark rich organic coarse sand
		0.5-1.0	Dark rich organic coarse sand
		1.0-1.5	Dark rich organic coarse sand
E18	Wooded area	1.5-3.0	Green soil with hides and hair, boards were between two and three feet
		3.0-3.5	No sample taken
		0.0-0.5	Brown, OM rich coarse sand/pebbles, last two inches, dark grey/green silty clay
		0.5-1.0	Dark gray green silty clay mixed with brown silty clay, pieces of hide
E20	Wooded area at the edge of a cement pad	1.0-1.5	Dark gray green silty clay mixed with brown silty clay, pieces of hide
		1.5-2.5	Dark gray green silty clay mixed with brown silty clay, pieces of hide
		2.5-	Hit a wooden plank, unable to go farther
		0.0-0.5	Dark brown to rusty brown coarse sand
		0.5-1.0	Dark brown coarse sand
		1.0-1.5	Rusty brown coarse sand and pebbles
		1.5-3.0	Coarse gravel
		3.0-3.5	No Sample Taken

Table A-1. (continued)

Site ID	Description of sample location	Interval (feet)	Description of soil
F13	Edge of wooded area	0.0-0.5	Top five inches, dark brown silty sand with OM; bottom, rusty tan silty sand
		0.5-1.0	Light rusty tan silty sand
		1.0-1.5	Light rusty tan silty sand grading into light rusty tan sandy silt
		1.5-3.0	Light rusty tan sandy silt grades into light tan sand
		3.0-3.5	Fine light tan sand
F15	Grassy open area w/shrubs	0.0-0.5	Dark brown silty sand with clumps of green clay
		0.5-1.0	Dark brown silt
		1.0-1.5	Dark brown silty sand
		1.5-3.0	Rusty tan silty sand
		3.0-3.5	Rusty tan sand, wet sample
F19	Wooded area at top of a ridge	0.0-0.5	Dark brown sand with abundant organic material including roots
		0.5-1.0	Dark rusty brown sand with lots of roots
		1.0-1.5	Rusty brown silty sand
		1.5-3.0	Rusty brown silty sand to light tan silty sand
		3.0-3.5	Light tan silty sand
F21	Small gully at the top of a hill	0.0-0.5	Hair at land surface, dark brown silty sand grades to rusty brown w/root and hair
		0.5-1.0	Rust tan silty sand
		1.0-1.5	Rust tan silty sand
		1.5-3.0	Rust tan silty sand
		3.0-3.5	Rust tan silty sand
G14	Grassy swamp on edge of forest scrap wood and metal nearby	0.0-0.5	Dark brown silty sand grading into greenish gray silty sand
		0.5-1.0	Greenish gray silt sand
		1.0-1.5	Greenish gray silt sand
		1.5-3.0	Greenish gray silt sand to black silty sand with greenish tinge, lots of hair
		3.0-3.5	Black silty sand with a greenish tinge
G16	In cattails with some surface water	0.0-0.5	Roots, smells like H2S, very moist, mostly OM with clay and silt
		0.5-1.0	Roots, smells like H2S, very moist, mostly OM with clay and silt
		1.0-1.5	Roots, smells like H2S, very moist, mostly OM with clay and silt
		1.5-3.0	Roots, smells like H2S, very moist, mostly OM with clay and silt
		3.0-3.5	Roots, smells like H2S, very moist, mostly OM with clay and silt
G18	Along fence in tall shrubs	0.0-0.5	Black silty sand

Table A-1. (continued)

Site ID	Description of Sample Location	Interval (feet)	Description of Soil
G18		0.5-1.0	Dark brown silty sand grades to rusty tan silty sand
		1.0-1.5	Rusty tan silty sand
		1.5-3.0	Tan silty sand grades to silty sand with clay
		3.0-3.5	Tan silty sand
G20	Grassy open area next to fence	0.0-0.5	Brown silty fine sand
		0.5-1.0	Rusty tan silty fine sand
		1.0-1.5	Rusty tan silty sand
		1.5-3.0	Tan silty sand
H15	Swampy grassy area	3.0-3.5	Tan silty sand, wet
		0.0-0.5	Black/dark brown silt with lots of OM
		0.5-1.0	Dark silt grades into light tan sand with pebbles - water in the hole
		1.0-1.5	Light tan silty sand - wet
		1.5-3.0	Light tan silty sand saturates grades to dark brown silty sand - wet
H17	Swampy grassy area	3.0-3.5	Black, saturated silty sand, H2S odor
		0.0-0.5	Dark brown silt and OM, very moist
		0.5-1.0	Same as above
		1.0-1.5	Saturated OM and silty clay, dark brown
		1.5-3.0	Same as above
H19	Grassy open area under a large tree	3.0-3.5	Saturated OM and silty clay, dark brown
		0.0-0.5	Black silty sand with clumps of white gravely material
		0.5-1.0	Black silt with gravel - melted rock/ore
		1.0-1.5	Black silt with clumps of white irregular angular material
		1.5-3.0	Black silt
H21	Open field with waist high brush	3.0-3.5	Reddish black silt with hair and industrial waste
		0.0-0.5	Dark brown silty sand grades to tan sand
		0.5-1.0	Dark brown sandy silt
		1.0-1.5	Brown silty fine sand
		1.5-3.0	Brown fine sand grades to dark tan silty sand grades to rusty tan to tan sand
H23	Grassy, brushy open area	3.0-3.5	Reddish tan silty sand
		0.0-0.5	Very dark brown organic rich sand to rusty tan silty sand
		0.5-1.0	Rusty tan silty sand
		1.0-1.5	Rusty tan silty sand

Table A-1. (continued)

Station	Location	Interval (ft)	Description of soil
H23		1.5-3.0 3.0-3.5	Rusty tan silty sand Rusty tan silty sand
I20	Hardwood forest	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Dark, brown organic rich silty sand with hides near bottom Dark brown organic rich silty sand with tan and green gray hides Dark brown OM rich silty sand with green hides with glass fragments and pebbles Dark brown OM rich silty sand with green hides to dark green/black coarse sand Reddish black gravelly sand with gray green areas and brick
I22	Swampy area with running water 3 in.	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Very dark brown silt with lots of roots and OM Very dark brown silt with lots of roots and OM Very dark brown silt with lots of roots and OM Very dark brown silt with lots of roots and OM, tan silty sand in bottom half foot Dark brown wood and rusty tan silty sand
I24	Dead hard wood forest	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Dark brown silt to rusty tan silty sand Rusty tan silty sand Rusty tan silty sand Rusty tan silty sand Rusty tan silty sand
I26	Grassy open area next to fence	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Black/very dark brown silty sand with OM Black/very dark brown silty sand with OM Black/very dark brown silty sand with OM and coarse sand Black/very dark brown gravelly material No sample taken
J19	Edge of road in a wooded/grassy area scrap metal at surface	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Dark brown organic rich silty sand Dark brown organic rich silty sand Dark brown organic rich silty sand Dark brown organic rich silty sand at top, tannery wastes, hides and hair at two feet Reddish dark brown silty sand and tannery waste
J21	Grassy, semi- open birch tree Forrest	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Very dark brown organic rich silty sand with rusty tan silty sand Rusty tan silty sand to brown silty sand Brown silty sand to very dark brown organic material with wood chips Brown silty sand Wood

Table A-1. (continued)

Site ID	Description of Sample Location	Interval (feet)	Description of soil
J23	Cattail, grass swamp, standing water	0.0-0.5	Very dark brown to red brown organic rich silt with lots of roots
		0.5-1.0	Very dark brown, organic rich silt
		1.0-1.5	Very dark brown, organic rich silt
		1.5-3.0	Very dark brown, organic rich silt, wood at two and a half feet, tan silty sand bottom
		3.0-3.5	Dark brown organic rich material with tan silty sand
J25	Wooded area with lots of urban trash	0.0-0.5	Black organic rich silty sand, large and small roots
		0.5-1.0	Reddish dark brown rich silty clay
		1.0-1.5	Reddish dark brown decaying tree matter with some silt
		1.5-3.0	Reddish brown decaying tree matter with some silt
		3.0-3.5	No sample taken
J27	Grassy open area trash pile of cans and bottles nearby	0.0-0.5	Organic rich very dark brown silty sand, water in the hole
		0.5-1.0	Organic rich very dark brown silty sand grades to gray tan silty sand
		1.0-1.5	Grey tan silty sand
		1.5-3.0	Rock or cement
		3.0-3.5	No sample taken
K20	Low area with grass, cattails and trees	0.0-0.5	Very dark brown silt with lots of roots and OM, wet
		0.5-1.0	Wood
		1.0-1.5	Wood
		1.5-3.0	Reddish black decaying OM
		3.0-3.5	Dark gray silty sand
K22	Low area with cattails and small trees	0.0-0.5	Very dark brown/black organic rich silt with roots, wet
		0.5-1.0	Very dark brown/black organic rich silt with roots, wet
		1.0-1.5	Mostly wood chips
		1.5-3.0	Wood and very dark brown organic rich silt
		3.0-3.5	Brown silty sand
K24	Boggy, grassy area with small trees	0.0-0.5	Silty, dark brown organic rich sediment and roots present, wet
		0.5-1.0	Silty, dark brown OM rich sediment and roots present, wet, with chips of wood
		1.0-1.5	Silty, dark brown OM rich sediment and roots present, wet, with decaying wood
		1.5-3.0	Silty, dark brown organic rich sediment, 2'- wood, bellow tan silty sand
		3.0-3.5	Tan silty sand
K26	Grassy open area, with water at surface	0.0-0.5	Organic rich, very dark brown, coarse sand with roots
		0.5-1.0	Organic rich, very dark brown, coarse sand with roots
		1.0-1.5	Organic rich, very dark brown, coarse sand with roots

Table A-1. (continued)

Site ID	Description of sample location	Interval (cm)	Description of soil
K26		1.5-3.0 3.0-3.5	Organic rich, very dark brown, coarse sand with roots Organic rich, very dark brown, coarse sand with roots
K28	Wooded area	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Organic rich very dark brown silty sand. Water in the hole Organic rich very dark brown silty sand. Organic rich very dark brown silty sand. hit wood, new hole one foot away Wood, trash, telephone receiver No sample taken
L21	Grassy area with small trees	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Dark brown silty sand grades, bottom one inch, tan silty sand Tan silty sand Tan silty sand to gray sand Wood, very dark brown coarse sand and pebbles Wood, very dark brown coarse sand to gray brown silty sand
L23	Small tree, cattails and grass in a swamp	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Black to very dark brown organic rich sediment with clay and silt, wet Black to very dark brown organic rich sediment with clay and silt, wet Black to very dark brown organic rich sediment with clay and silt, wet Black to very dark brown organic rich sediment at two feet, tan coarse sand Tan coarse sand
L25	Wooded area	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Dark brown silty sand Tan silty sand with localized rusty clumps Tan silty sand grades to decaying wood Dark brown decaying tree matter Wood chips and light brown silt
L27	Pond with three inches of water	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Organic rich, very dark brown, coarse sand with roots Organic rich, very dark brown, silty sand Organic rich, very dark brown silty sand in half the core-then disturbances occurred Tan, silty sand Tan silty sand-disturbances occurred retrieving core
M20	Grassy open area	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Dark, brown organic rich silty sand, bottom two inches, rusty tan silty sand Rusty tan silty sand Tan silty sand, wood at bottom two inches Wood No sample taken
M24	A beaver pond shoreline	0.0-0.5	Dark brown silt and decaying OM

Table A-1. (continued)

Site ID	Description of sample location	Interval (feet)	Description of soil
M24		0.5-1.0	Dark brown silt and decaying OM and large red brick
		1.0-1.5	Dark brown silt and decaying OM with chips of red brick
		1.5-3.0	Tan coarse sand
		3.0-3.5	Tan coarse sand
M26	Wooded, swampy area, grass	0.0-0.5	Organic rich, dark brown sand with roots and water in the hole
		0.5-1.0	Organic rich, dark brown sand with roots and water in the hole
		1.0-1.5	Organic rich, dark brown sand with roots and water in the hole
		1.5-3.0	No sample taken-hit wood
		3.0-3.5	No sample taken-hit wood
M28	Shoreline of a pond, water at surface with bricks, rocks, debris	0.0-0.5	Organic rich very dark brown silt.
		0.5-1.0	Organic rich dark brown silt.
		1.0-1.5	Dark gray coarse sand with cobbles couldn't get through, moved to new location
		1.5-3.0	Tan silty sand -- sample taken
		3.0-3.5	No sample taken
N21	Grassy, semi-wooded area	0.0-0.5	Very dark brown silt with lots of roots and other OM
		0.5-1.0	Very dark brown silt with lots of roots and other OM with wood chips
		1.0-1.5	Very dark brown silt with lots of roots and other OM with wood chips
		1.5-3.0	Wood
		3.0-3.5	No sample taken
N23	Grassy open area with standing water	0.0-0.5	Dark brown OM with some silt
		0.5-1.0	Dark brown OM with some silt
		1.0-1.5	Dark brown OM with some silt grades to grey-brown silty sand
		1.5-3.0	Grey silty sand grades to coarse sand, back to gray silty sand with wood and hair
		3.0-3.5	Grey silty sand, Obtained core by pushing tube into auger.
N25	Wooded area 25 ft N of a beaver pond	0.0-0.5	Dark brown organic rich silty sand at top dark grades to gray silty sand at bottom
		0.5-1.0	Dark gray silty sand grades to pebbly, coarse, dark gray sand
		1.0-1.5	Dark gray coarse sand with wood, water in the hole
		1.5-3.0	Wood then dark gray silty with some fine sand
		3.0-3.5	Some wood at the top, mostly dark gray silty sand
O22	Grassy open area	0.0-0.5	Dark brown organic rich silty sand with hair
		0.5-1.0	Dark brown organic rich silty sand with hair
		1.0-1.5	Dark brown silty sand with lesser OM and hair
		1.5-3.0	Dark brown silty sand grades to dark gray silty sand, water in the hole at two feet
		3.0-3.5	Dark gray silty sand

Table A-1. (continued)

Site ID	Description of sample location	Interval (feet)	Description of soil
O24	Wooded area	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Very dark brown, OM silty with roots, water in the hole Very dark brown, OM silty with roots, water in the hole Very dark brown, OM silty with roots, water in the hole Very dark brown, OM rich silty, hair, grades to gray silty sand, water in the hole Gray silty sand
P23	Grassy open area	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Dark brown organic rich silty sand with hair and roots Dark brown organic rich silty sand with hair and leather grades to tan silty sand Tan silty sand with chunks of grayish green hair, water in the hole Tan silty sand with hair grades to dark hair rich silt then to dark gray silty sand Dark gray silty sand with hair
P25	Swamp, with grass and standing	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Very dark brown decaying OM, with some silt Very dark brown decaying OM, with some silt and hair Very dark brown decaying OM, with some silt and hair Very dark brown decaying OM, with some silt and hair grades to gray/brown sand Gray/brownish sand
Q24	Grassy open area	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Dark Brown organic rich silty sand Dark Brown organic rich silty sand grades to tan silty sand at bottom Brown silty sand with a lot of hair and other OM Brown silty sand with hair and OM, hit wood, sample taken two and a half feet
Q26	Low lying wooded area	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Black mud, rich detrital clay Wood boards No sample taken Wood boards No sample taken
R25	Grassy/weedy open area	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0 3.0-3.5	Very dark brown organic rich clay Very dark brown organic rich clay, wet and hair present Very dark brown organic rich clay, wet, brown sand at bottom of the core Dark brown sand Dark brown sand
R27	Cattail swamp with surface water	0.0-0.5 0.5-1.0 1.0-1.5 1.5-3.0	Very dark brown with cattail roots and silt Very dark brown with cattail roots and silt Very dark brown with cattail roots and silt Very dark brown with cattail roots and silt, hit a board, then sand then clay

Table A-1. (continued)

Site ID	Description of sample location	Interval (feet)	Description of soil
S26	Grassy open area	3.0-3.5	Wood sand and clay
		0.0-0.5	Very dark brown silt with lots of organic material
		0.5-1.0	Very dark brown silt with lots of organic material with bricks
		1.0-1.5	Very dark brown silt with lots of organic material, with boards
		1.5-3.0	Wood boards
T27	Near shore in a brushy area	3.0-3.5	No sample taken
		0.0-0.5	Very dark brown silt, organic rich with roots and hair
		0.5-1.0	Mostly roots and hair with some silt and clay and green hide chunks
		1.0-1.5	Mostly roots and hair with some silt and clay and green hide chunks
		1.5-3.0	Wood
		3.0-3.5	No sample taken
U26	On the beach with grass and shrubs	0.0-0.5	Brown sand
		0.5-1.0	Brown sand to dark brown sand with hides, hair, and OM, wet
		1.0-1.5	Dark brown sand with a lot of OM, hair, and roots
		1.5-3.0	Dark brown sand grading into greenish black sand, increasing clay with depth
		3.0-3.5	Dark brown sand with OM

Appendix B

Sequential Chemical Extraction Procedure

Soil cores were frozen (-20°C) until just prior to beginning the sequential extraction procedure. After the cores were thawed, they were placed in a glove bag, which was then evacuated and purged twice with N₂ (g) or Ar (g) to ensure an inert atmosphere. A Teflon police man was used to transfer about 50 grams of soil from the bottom of each core into acid washed 120mL plastic vials for homogenization. Large objects, such as roots, wood, rocks, and urban waste, were excluded from the material that was homogenized. After homogenization, five grams (± 0.5 g) of wet soil were weighed out on an acid washed watch glass for wet weight/ dry weight determination. A separate one gram (± 0.2 g) aliquot was placed into an acid washed 30 ml centrifuge tube for sequential chemical extractions. The remaining homogenized soil was saved for organic carbon determination by loss on combustion. Once the weighing was completed in the glove bag the watch glasses were placed in a convection oven for 24 hours at 50°C to dry the soils.

Each sequential chemical extraction step began with the addition of a chemical reagent under an inert atmosphere, followed by agitation of the tightly secured centrifuge tubes to completely mix the soil/chemical mixture. Each chemical addition reacts with the soil to strip off the bound metals from targeted solid phases. After each prescribed reaction time the leachate was separated from the soil by centrifugation at 15,000 rpm for 20 minutes. Leachate fluids were siphoned off or decanted into acid washed 30 ml syringes, then filtered through 0.4 μ m acid washed Nucleopore membrane filters into acid washed NalgeneTM polypropylene bottles and acidified to pH< 2 to prevent adsorption to

the container walls and precipitation of metals from solution. Samples were stored in a dark 4°C refrigerator until analysis. A copy of the detailed procedure, which was adapted from Matty (1992), is on the following two pages.

Procedure for the Sequential Chemical Extraction of Metals
(modified from Matty, 1992)

From each homogenous sample remove two aliquots.

Aliquot 1: place on tared watch glass; dry in oven at 50°C for 24 hours; reweigh and record percent water; perform HNO₃ microwave digestion.

Aliquot 2: place in tared centrifuge tube; perform sequential chemical extractions under N₂ using the following procedures:

I. Exchangeable Fraction

1. Place 1.0 g wet sediment into acid-washed tared centrifuge tube.
2. To each sample, SRM, and blank, add 10 mL 1.0M MgCl₂ (pH 7); with wrist action shaker agitate continuously for 1 hour at 20°C.
3. Centrifuge for 20 minutes at 15,000 rpm.
4. Remove leachate with a syringe and filter through 0.4µm Nuclepore filter into an acid-washed 8 or 30 mL bottle. Acidify to pH<2 with optima HNO₃.
5. Rinse sediment with 10 mL DDW in vortex mixer; centrifuge for 20 minutes at 15,000 revolutions per minute (rpm); remove supernatant and discard.

II. Weak-Acid Soluble Fraction

1. To sediment from (I) add 10 mL of 1.0M NaOAc (pH 5 with HOAc) and agitate with shaker for 5 hours at 20°C.
4. Centrifuge for 20 minutes at 15,000 rpm.
5. Remove leachate with a syringe and filter through 0.4µm Nuclepore filter into an acid-washed 8 or 30 mL bottle. Acidify to pH<2 with optima HNO₃.
6. Rinse sediment with 10 mL DDW in vortex mixer; centrifuge for 20 minutes at 15,000 rpm; remove supernatant and discard.

III. Easily Reducible Fraction

1. To sediment from (II) add 25 mL of 0.1M NH₂OH·HCl in 0.01N HNO₃ and agitate in shaker for 0.5 hours at 20°C.
2. Centrifuge for 20 minutes at 15,000 rpm.
3. Remove leachate with a syringe and filter through 0.4µm Nuclepore filter into an acid-washed 30 mL bottle.
4. Rinse sediment with 10 mL DDW in vortex mixer; centrifuge for 20 minutes at 15,000 rpm; remove supernatant and discard.

IV. Moderately Reducible Fraction

1. To sediment from (III) add 20 mL of 0.04M $\text{NH}_2\text{OH}\cdot\text{HCl}$ in 25% (v/v) HOAc. Place sample in a water bath at 96°C for 6 hours; agitate every 30 minutes.
2. Centrifuge for 20 minutes at 15,000 rpm.
3. Remove leachate with a syringe and filter through 0.4 μm Nuclepore filter into an acid-washed 30 mL bottle.
4. Rinse sediment with 10 mL DDW in vortex mixer; centrifuge for 20 minutes at 15,000 rpm; remove supernatant and discard.

V. Oxidizable Fraction I (not done under N_2)

1. To sediment from (IV) add 6 mL of NaOCl (pH 9.5 with HCl just prior to use). Place sample in a water bath at 96°C for 15 minutes.
2. Centrifuge for 20 minutes at 15,000 rpm.
3. Remove leachate with a syringe and filter through 0.4 μm Nuclepore filter into an acid-washed 30 mL bottle.
4. Repeat steps 1 through 3 two more times (except for the third step of the third addition), using the vortex mixer to resuspend the sample after each addition of NaOCl.
5. Add 5 mL of 3.2M NH_4OAc to the solution-sample mixture of the last NaOCl addition. Agitate with shaker for 1 hour at 20°C.
6. Centrifuge for 20 minutes at 15,000 rpm.
7. Remove leachate with a syringe and filter through 0.4 μm Nuclepore filter into an acid-washed 30 mL bottle.
8. Rinse sediment with 10 mL DDW in vortex mixer; centrifuge for 20 minutes at 15,000 rpm; remove supernatant and discard.

VI. Oxidizable Fraction II (not done under N_2)

1. To sediment from (V) add 3 mL of 0.02N HNO_3 and 8 mL of 30% H_2O_2 (pH 2 with HNO_3) in 500 μL aliquots; agitate every 30 minutes for 5 hours in a water bath heated to 85°C; leave caps unscrewed.
2. Place samples in Wrist Action Shaker to cool.
3. Add 5 mL of 3.2M NH_4OAc (pH 2 with HNO_3). Agitate with shaker for 1 hour at 20°C.
4. Centrifuge for 20 minutes at 15,000 rpm.
5. Remove leachate with a syringe, empty the syringe into an acid-washed 25 mL volumetric flask and dilute up to 25 mL with DDW. Filter the diluted solution through a 0.4 μm Nuclepore filter. Transfer solution to an acid washed 30 mL bottle.
6. Rinse sediment with 10 mL DDW in vortex mixer; centrifuge for 20 minutes at 15,000 rpm; remove supernatant and discard.

APPENDIX C

Field Aqueous Sampling

The material the peepers and barrels are made from has the capacity to adsorb O₂ and therefore needs to be de-oxygenated prior to emplacement in anoxic systems. The de-oxygenation was accomplished by submerging the samplers in DDDW and bubbling with N₂ or Argon gas for a minimum of three days. The samplers were maintained in DDDW until they were installed. All components of the samplers, including the dialysis membranes, were acid washed with 10% HCl prior to assembly.

The peepers and barrels were installed below the land surface in saturated areas. The samplers were left in place for at least two weeks to allow biogeochemical equilibration to occur between the sampler and the pore water (Hesslein 1976; Carignan et al., 1985; Tessier et al. 1996). In order to obtain sufficient fluid for analysis, four to six adjacent peeper ports were sampled to make up one sample. An example of the sampling scheme is presented in Figure A2.1.

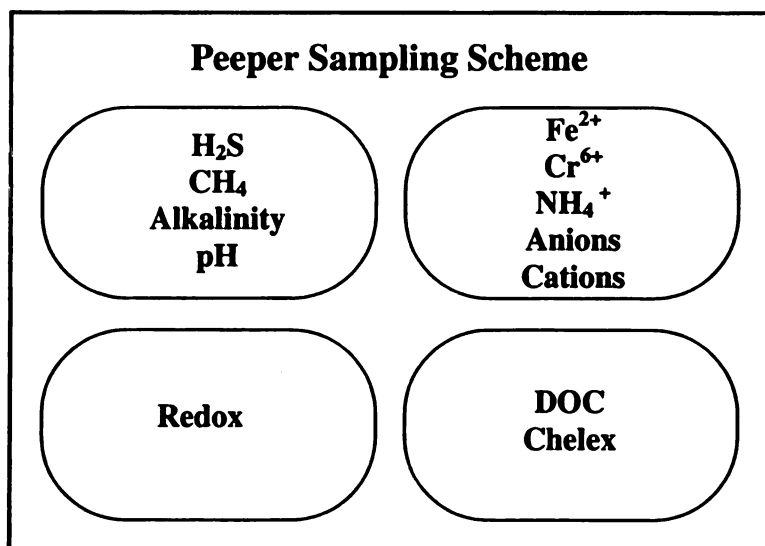


Figure C 1. A schematic diagram showing the ports from which fluid was taken for the various parameters.

The sampling of the peepers was conducted in the field at site the where the peeper was installed. The peepers were removed from the ground and the outside of the membranes were rinsed with DDDW. The peeper was then placed on a portable table and samples were taken for the various analyses. Samples were obtained by puncturing the membrane with a plastic pipette tip and withdrawing a sample with a pipettor or a syringe fitted with a plastic pipette tip. Methane samples were collected by simultaneously piercing the nylon mebrane of a sampler and the butyl rubber septum of an evacuated, 30 ml, glass bottle. This allowed the collection of a sample with a headspace that has not come into contact with the air.

The most redox sensitive parameters were sampled and/or analyzed first. Aliquots for CH_4 , NH_4^+ , S^{2-} , and Fe^{2+} were taken first. This included preservation or treatment of these redox sensitive parameters. When the redox sensitive parameters were stabilized or preserved, aliquots for cations, anions, pH, alkalinity, and DOC were obtained. Usually the complete sampling was achieved within ten minutes by a team of three to four personnel. After all the samples were obtained, the quantification of those parameters measured in the field was performed. Parameters measured in the field included temperature, pH, Eh, S^{2-} , Cr(VI), Fe^{2+} , and alkalinity.

Sampling of the barrels required a slightly different approach. Three barrels bound together constituted one sample and a diagram of the sampling scheme is presented in Figure A2.2. When the barrels were removed from the ground they were rinsed off with DDDW. Snap on caps were fitted to the ends of the barrels and they were transported to a central location in an argon filled plastic bag. Transportation to the central location was generally accomplished with in five minutes. Once at the central

location, the membranes were punctured and the samples extracted. The barrel from which the redox sensitive samples were taken was processed in an argon filled bag. As with the peepers, the actual splitting of samples for the various parameters generally took less than ten minutes.

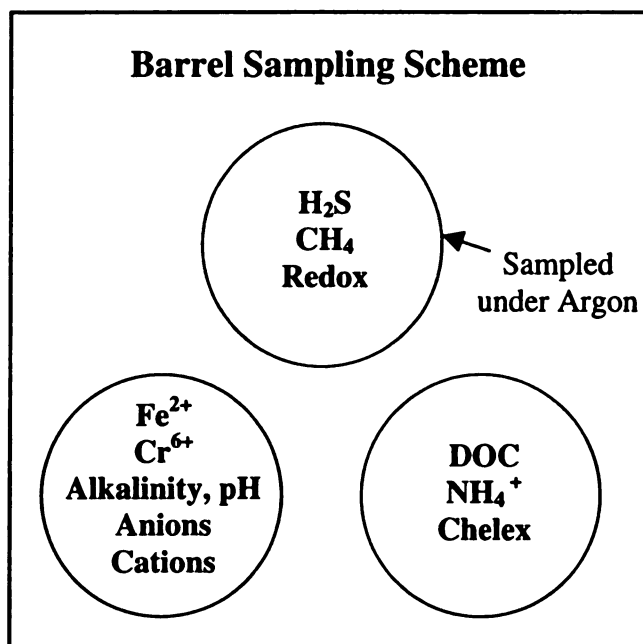


Figure C 2. A schematic diagram showing the barrels from which fluid was taken for the various parameters.

Appendix D
Table D-1: Sequential Chemical Extraction Data for Chromium
sol'n indicates concentration detected in leachate solution, mg/L
sed indicates concentration in sediment, mg/kg (dry weight basis)
bd indicates below detection, -- indicates not measured

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
B3a0-0.5	bd	bd	0.03	0.33	bd	bd	0.07	1.51	0.14	3.29	bd	bd	5.38
B3b0-0.5	bd	bd	0.03	0.30	bd	bd	0.06	1.43	0.12	3.14	bd	bd	5.01
B3c0-0.5	bd	bd	0.03	0.27	bd	bd	0.07	1.32	0.10	2.19	bd	bd	3.88
B31-1.5	bd	bd	0.00	0.03	bd	bd	0.01	0.19	0.09	2.28	bd	bd	2.50
B33-3.5	bd	bd	0.01	0.12	bd	bd	0.05	1.03	0.07	1.66	bd	bd	2.81
B50-0.5	bd	bd	0.01	0.09	bd	bd	0.05	0.97	0.09	2.11	bd	bd	3.20
B51-1.5	bd	bd	0.01	0.10	bd	bd	0.06	1.25	0.05	1.13	bd	bd	2.49
B53-3.5	bd	bd	0.02	0.18	bd	bd	0.19	4.44	0.09	2.40	bd	bd	7.09
B70-0.5	bd	bd	0.01	0.08	bd	bd	0.01	0.24	0.07	1.50	bd	bd	1.88
B71-1.5	bd	bd	bd	bd	0.00	0.11	0.02	0.39	0.04	0.94	bd	bd	1.47
B73-3.5	bd	bd	0.00	0.05	0.01	0.21	0.02	0.47	0.04	0.92	bd	bd	1.65
B9a0-0.5	bd	bd	0.02	0.20	0.01	0.25	0.12	2.50	0.33	8.00	bd	bd	10.94
B9b0-0.5	bd	bd	0.01	0.10	bd	bd	0.09	2.03	0.30	7.62	bd	bd	9.93
B9c0-0.5	bd	bd	0.01	0.07	bd	bd	0.10	2.05	0.29	6.97	bd	bd	9.29
B91-1.5	bd	bd	0.02	0.21	0.01	0.34	0.07	1.42	0.07	1.61	bd	bd	3.58
B93-3.5	bd	bd	0.01	0.09	bd	bd	0.04	0.77	0.01	0.31	bd	bd	1.32
B110-0.5	bd	bd	0.08	0.94	--	--	--	--	1.06	29.89	bd	bd	30.83
B111-1.5	bd	bd	0.02	0.21	bd	bd	0.05	1.04	0.03	0.71	bd	bd	1.96
B113-3.5	bd	bd	0.01	0.13	0.00	0.10	0.05	1.21	0.04	0.96	bd	bd	2.41
B130-0.5	bd	bd	0.03	0.28	0.01	0.25	0.08	1.70	0.15	3.58	bd	bd	5.81
B13a1-1.5	bd	bd	0.03	0.32	0.03	0.69	0.06	1.32	0.06	1.39	bd	bd	3.71

Table D-1: Chromium (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
B13b1-1.5	bd	bd	0.03	0.31	0.02	0.57	0.07	1.61	0.05	1.20	bd	bd	3.69
B13c1-1.5	bd	bd	0.03	0.33	0.02	0.55	0.07	1.59	0.05	1.27	bd	bd	3.73
B133-3.5	bd	bd	0.01	0.08	bd	bd	0.06	1.29	0.04	0.86	bd	bd	2.23
B150-0.5	bd	bd	0.05	0.58	0.11	2.85	0.26	5.63	0.79	19.66	bd	bd	28.71
B151-1.5	bd	bd	0.07	0.80	0.10	2.91	0.12	2.73	0.42	10.75	bd	bd	17.19
B153-3.5	bd	bd	0.06	0.90	0.02	0.74	0.07	2.17	0.15	5.51	bd	bd	9.32
B170-0.5	bd	bd	0.58	6.22	0.68	18.11	3.79	80.74	4.50	110.24	bd	bd	215.30
B171-1.5	bd	bd	0.02	0.21	0.02	0.53	0.11	2.29	0.16	3.81	bd	bd	6.83
B173-3.5	bd	bd	0.35	7.43	0.03	1.75	0.05	2.23	0.20	9.75	bd	bd	21.16
C20-0.5	bd	bd	0.02	0.19	0.01	0.34	0.15	3.14	0.24	5.95	bd	bd	9.62
C21-1.5	bd	bd	0.00	0.03	0.01	0.21	0.04	0.80	0.04	0.99	bd	bd	2.03
C23-3.5	bd	bd	0.01	0.08	0.01	0.25	0.12	2.48	0.05	1.24	bd	bd	4.06
C40-0.5	bd	bd	0.03	0.35	0.02	0.56	0.16	3.38	0.28	6.97	bd	bd	11.26
C41-1.5	bd	bd	0.02	0.19	0.02	0.56	0.14	2.96	0.06	1.49	bd	bd	5.20
C43-3.5	bd	bd	0.02	0.15	0.02	0.57	0.13	2.42	0.08	1.73	bd	bd	4.86
C60-0.5	bd	bd	0.01	0.10	bd	bd	0.03	0.65	0.06	1.34	bd	bd	2.15
C61-1.5	bd	bd	0.01	0.14	0.01	0.18	0.07	1.32	0.06	1.37	bd	bd	3.01
C63-3.5	bd	bd	bd	bd	0.00	0.08	0.04	0.83	0.03	0.59	bd	bd	1.54
C80-0.5	bd	bd	0.07	0.75	0.02	0.42	0.11	2.31	0.79	19.79	bd	bd	23.27
C81-1.5	bd	bd	0.01	0.12	0.01	0.28	0.04	0.86	0.07	1.76	bd	bd	3.03
C83-3.5	bd	bd	0.01	0.11	0.02	0.54	0.04	0.81	0.07	1.58	bd	bd	3.04
C100-0.5	bd	bd	0.03	0.31	0.02	0.67	0.17	3.87	0.51	13.39	bd	bd	18.24
C101-1.5	bd	bd	0.01	0.11	0.00	0.04	0.05	1.08	0.04	0.91	bd	bd	2.14
C103-3.5	bd	bd	bd	bd	0.01	0.14	0.04	0.83	0.05	1.27	bd	bd	2.33
C120-0.5	bd	bd	0.13	1.44	0.08	2.27	0.51	11.33	1.45	37.05	bd	bd	52.08

Table D-1: Chromium (continued)

Sample	EX Sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 Sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
C121-1.5	bd	bd	bd	bd	0.02	0.43	0.07	1.39	0.11	2.57	bd	bd	4.49
C123-3.5	bd	bd	bd	bd	bd	bd	0.06	1.43	0.02	0.55	bd	bd	2.19
C140-0.5	bd	bd	0.17	2.05	0.26	7.67	1.54	36.36	3.91	106.15	bd	bd	152.23
C141-1.5	bd	bd	0.01	0.10	0.02	0.53	0.10	2.05	0.05	1.19	bd	bd	3.87
C143-3.5	bd	bd	0.01	0.08	bd	bd	0.19	4.25	0.07	1.75	bd	bd	6.14
C160-0.5	bd	bd	0.06	0.70	0.08	2.31	0.38	8.95	0.65	17.61	bd	bd	29.57
D50-0.5	bd	bd	0.02	0.17	0.01	0.21	0.10	1.90	0.16	3.49	bd	bd	5.77
D51-1.5	bd	bd	0.01	0.15	0.02	0.40	0.06	1.31	0.04	0.98	bd	bd	2.85
D53-3.5	bd	bd	0.01	0.14	0.02	0.45	0.14	3.27	0.05	1.42	bd	bd	5.28
D70-0.5	bd	bd	0.08	0.89	0.03	0.94	0.17	3.75	0.86	22.17	bd	bd	27.76
D71-1.5	bd	bd	0.01	0.11	bd	bd	0.03	0.66	0.04	1.00	bd	bd	1.96
D73-3.5	bd	bd	0.01	0.11	0.02	0.48	0.05	1.17	0.09	2.31	bd	bd	4.07
D90-0.5	bd	bd	0.04	0.38	0.01	0.38	0.13	2.73	0.90	21.31	bd	bd	24.79
D91-1.5	bd	bd	0.01	0.17	bd	bd	0.03	0.59	0.04	1.12	bd	bd	2.06
D93-3.5	bd	bd	0.01	0.12	0.01	0.30	0.05	1.10	0.07	1.76	bd	bd	3.28
D963-3.5	bd	bd	0.01	0.11	0.07	1.85	0.10	2.19	0.11	2.77	bd	bd	6.91
D9c3-3.5	bd	bd	0.01	0.13	0.02	0.63	0.06	1.31	0.08	2.20	bd	bd	4.26
D110-0.5	bd	bd	0.03	0.26	0.03	0.70	0.20	3.78	0.26	5.65	bd	bd	10.43
D111-1.5	bd	bd	0.02	0.17	0.01	0.39	0.21	4.43	0.07	1.74	bd	bd	6.77
D113-3.5	bd	bd	0.01	0.08	0.01	0.14	0.07	1.49	0.03	0.67	bd	bd	2.42
D130-0.5	bd	bd	0.44	4.60	0.12	3.06	0.42	8.78	2.11	51.14	bd	bd	67.58
D131-1.5	bd	bd	0.02	0.15	0.01	0.25	0.06	1.22	0.02	0.38	bd	bd	2.00
D133-3.5	bd	bd	0.01	0.14	0.00	0.12	0.10	2.18	0.04	1.05	bd	bd	3.49
D150-0.5	bd	bd	0.06	0.70	0.08	2.13	0.19	4.08	0.73	18.39	bd	bd	25.30
D151-1.5	bd	bd	0.03	0.34	0.04	1.04	0.16	3.24	0.08	1.80	bd	bd	6.42

Table D-1: Chromium (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 Sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
D153-3.5	bd	bd	0.12	1.25	0.03	0.84	0.13	2.62	0.06	1.36	bd	bd	6.08
D170-0.5	bd	bd	3.12	48.48	2.90	112.66	104.20	3238.39	148.70	5314.60	0.61	23.70	8737.84
D171-1.5	bd	bd	0.11	1.68	0.26	9.51	1.01	29.57	3.30	111.10	bd	bd	151.86
D173-3.5	bd	bd	0.06	0.74	0.05	1.61	0.09	2.09	0.01	0.34	bd	bd	4.79
D190-0.5	bd	bd	3.64	44.82	4.76	146.54	155.80	3837.17	88.20	2498.10	1.86	57.26	6583.90
D191-1.5	bd	bd	4.88	92.52	4.07	192.90	17.52	664.29	52.00	2267.38	3.76	178.21	3395.28
D193-3.5	bd	bd	0.04	0.46	0.07	2.14	0.05	1.27	0.08	2.15	bd	bd	6.02
E140-0.5	bd	bd	0.05	0.57	0.06	1.62	0.37	7.78	0.35	8.46	bd	bd	18.43
E141-1.5	bd	bd	0.01	0.17	0.02	0.65	0.25	5.68	0.13	3.47	bd	bd	9.96
E143-3.5	bd	bd	0.02	0.21	0.02	0.51	0.19	4.13	0.08	1.97	bd	bd	6.82
E160-0.5	bd	bd	0.04	0.56	0.03	1.26	1.05	31.65	2.80	97.05	bd	bd	130.52
E161-1.5	bd	bd	0.02	0.47	0.02	1.15	1.40	53.29	1.92	84.04	bd	bd	138.95
E163-3.5	bd	bd	13.00	309.71	114.30	6807.59	2815.00	134127	33.20	1819.17	bd	bd	143063.2
E180-0.5	bd	bd	17.56	257.30	30.10	1102.60	1835.00	53774.5	889.00	29959.9	98.70	3615.5	88709.69
E181-1.5	bd	bd	16.16	393.67	6.19	376.98	3100.00	151036	109.70	6146.45	18.18	1107.2	159060.8
E200-0.5	bd	bd	0.38	4.28	0.61	17.34	3.59	81.63	7.16	187.24	bd	bd	290.49
E201-1.5	bd	bd	0.14	1.41	0.16	3.84	0.88	17.31	1.92	43.43	bd	bd	66.00
F130-0.5	bd	bd	0.16	1.55	0.13	3.11	0.35	6.87	0.58	13.09	bd	bd	24.62
F131-1.5	bd	bd	0.08	0.77	0.06	1.51	0.27	5.47	0.16	3.69	bd	bd	11.45
F133-3.5	bd	bd	0.03	0.30	0.03	0.77	0.29	6.27	0.08	2.10	bd	bd	9.44
F150-0.5	0.10	1.45	3.48	53.03	92.20	3512.18	133.80	4077.48	79.00	2768.60	bd	bd	10412.74
F151-1.5	0.04	0.42	0.21	2.06	0.31	7.63	2.04	40.19	2.08	47.12	bd	bd	97.42
F153-3.5	bd	bd	0.01	0.12	0.03	0.74	0.29	6.11	0.22	5.33	bd	bd	12.33
F170-0.5	bd	bd	0.60	7.52	0.46	14.41	6.69	167.63	5.76	165.98	bd	bd	355.54
F171-1.5	bd	bd	0.02	0.23	0.02	0.48	0.06	1.37	0.03	0.64	bd	bd	2.71

Table D-1: Chromium (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
F17a3-3.5	bd	bd	bd	bd	0.00	0.16	0.08	2.15	0.03	0.74	bd	bd	3.06
F17b3-3.5	bd	bd	bd	bd	0.01	0.19	0.09	1.89	0.03	0.85	bd	bd	2.99
F17c3-3.5	bd	bd	bd	bd	bd	bd	0.09	1.91	0.03	0.71	bd	bd	2.77
F190-0.5	bd	bd	0.80	8.90	0.20	5.56	4.59	102.07	4.60	117.64	bd	bd	234.16
F191-1.5	bd	bd	0.05	0.54	0.04	1.01	0.16	3.35	0.05	1.10	bd	bd	6.00
F193-3.5	bd	bd	bd	bd	0.01	0.39	0.15	3.26	0.03	0.87	bd	bd	4.60
F210-0.5	bd	bd	0.21	2.34	0.07	1.88	0.95	21.34	0.33	8.52	bd	bd	34.09
F211-1.5	bd	bd	0.10	0.94	0.04	0.96	0.27	5.34	0.00	0.00	bd	bd	7.25
F213-3.5	0.00	0.00	0.11	1.06	0.05	1.30	0.22	4.41	0.05	1.16	bd	bd	7.93
G140-0.5	0.08	1.28	7.41	112.36	75.04	2844.7	56.32	1708.01	12.48	435.25	bd	bd	5101.57
G141-1.5	bd	bd	0.04	0.73	0.35	14.43	1.00	32.98	0.73	27.69	bd	bd	75.90
G143-3.5	0.01	0.06	0.23	2.36	0.33	8.60	1.12	23.36	0.22	5.28	bd	bd	39.66
G160-0.5	0.17	10.01	1.20	72.51	28.08	4241.9	140.50	16979.55	24.84	3452.23	bd	bd	24756.16
G161-1.5	0.01	0.15	0.05	0.76	0.71	28.18	15.44	490.24	4.66	170.16	bd	bd	689.48
G163-3.5	bd	bd	0.05	0.69	0.64	22.85	4.28	122.22	1.83	60.10	bd	bd	205.92
G180-0.5	bd	bd	0.52	6.06	0.11	3.10	8.72	203.21	7.32	196.17	bd	bd	408.55
G181-1.5	bd	bd	0.03	0.31	0.03	0.74	0.23	5.08	0.04	0.96	bd	bd	7.10
G183-3.5	bd	bd	0.03	0.36	0.02	0.42	0.27	5.55	0.07	1.61	bd	bd	7.95
G200-0.5	bd	bd	0.10	1.26	0.05	1.61	0.29	6.97	0.27	7.47	bd	bd	17.31
G201-1.5	bd	bd	0.03	0.29	0.02	0.41	0.13	2.66	0.06	1.47	bd	bd	4.83
G203-3.5	bd	bd	0.03	0.36	0.01	0.26	0.35	7.54	0.08	1.97	bd	bd	10.13
G220-0.5	bd	bd	0.25	2.84	0.18	5.18	1.97	44.38	1.42	36.79	bd	bd	89.18
G221-1.5	bd	bd	0.08	0.89	0.08	2.13	0.21	4.55	0.35	8.73	bd	bd	16.29
G223-3.5	bd	bd	0.02	0.17	0.02	0.58	0.23	4.98	0.05	1.32	bd	bd	7.05
H150-0.5	0.13	2.50	6.32	119.08	24.80	1168.2	55.68	2098.16	24.92	1079.90	bd	bd	4467.80

Table D-1: Chromium (continued)

Sample	EX sol'n	EX mg/kg	WAS sol'n	WAS mg/kg	ER sol'n	ER mg/kg	MR sol'n	MR mg/kg	OX1 Sol'n	OX1 mg/kg	OX2 sol'n	OX2 mg/kg	Total sed
H151-1.5	bd	0.02	0.03	0.46	0.16	6.58	0.40	13.30	0.32	12.23	bd	bd	32.68
H153-3.5	bd	0.29	0.40	7.35	3.68	168.95	3.60	132.22	4.11	173.60	bd	bd	482.40
H170-0.5	bd	bd	5.16	131.84	26.36	1683.8	5080.00	259590.4	30.72	1805.28	bd	bd	263211.2
H171-1.5	bd	bd	5.35	257.10	77.90	9358.9	1560.00	149935.3	35.16	3886.21	bd	bd	163437.6
H173-3.5	bd	bd	1.04	13.43	27.88	899.97	360.00	9296.66	14.96	444.28	bd	bd	10654.33
H190-0.5	bd	bd	0.28	3.98	0.29	10.17	2.24	62.81	7.24	233.48	bd	bd	310.43
H191-1.5	bd	bd	0.03	0.64	0.03	1.69	0.33	13.88	1.04	50.32	bd	bd	66.53
H193-3.5	bd	bd	0.04	1.90	0.01	1.67	0.05	5.04	0.12	13.04	bd	bd	21.65
H210-0.5	bd	bd	bd	bd	bd	bd	0.07	1.35	0.02	0.46	bd	bd	2.01
H211-1.5	bd	bd	1.04	19.13	0.58	26.64	12.64	464.93	21.04	889.99	bd	bd	1400.69
H213-3.5	bd	bd	0.02	0.22	0.03	0.65	0.26	5.44	0.05	1.22	bd	bd	7.53
H23a0-0.5	bd	bd	0.06	0.74	0.03	1.03	0.31	7.46	0.25	6.92	bd	bd	16.15
H23b0-0.5	bd	bd	0.06	0.67	0.03	0.92	0.31	6.83	0.25	6.33	bd	bd	14.75
H23c0-0.5	bd	bd	0.06	0.67	0.03	0.98	0.30	7.29	0.23	6.42	bd	bd	15.37
H231-1.5	bd	bd	0.03	0.20	0.02	0.39	0.29	4.59	0.04	0.76	bd	bd	5.93
H233-3.5	bd	bd	bd	bd	0.01	0.38	0.22	5.06	0.03	0.77	bd	bd	6.27
I200-0.5	0.18	4.65	15.10	384.17	7.17	456.04	636.00	32361.66	110.60	6471.82	1.14	72.51	39750.84
I201-1.5	0.23	8.67	10.30	387.73	4.86	457.37	127.00	9561.44	59.10	5116.88	1.61	151.51	15683.59
I203-3.5	0.05	3.26	21.30	1308.62	11.45	1758.7	182.40	22412.46	15.90	2246.78	2.67	410.10	28139.87
I220-0.5	0.07	2.25	5.81	179.26	3.47	267.66	504.00	31100.55	54.70	3881.71	bd	bd	35431.42
I221-1.5	0.07	3.17	4.02	173.90	1.91	206.56	136.20	11783.41	49.20	4895.05	3.18	343.90	17405.98
I223-3.5	bd	bd	0.07	0.87	0.03	1.00	0.75	18.47	0.09	2.42	bd	bd	22.82
I240-0.5	bd	bd	0.13	1.74	0.04	1.30	0.54	14.38	0.78	23.89	bd	bd	41.31
I241-1.5	bd	bd	0.06	0.71	0.02	0.73	0.20	4.90	0.03	0.94	bd	bd	7.29
I243-3.5	bd	bd	0.07	0.80	0.02	0.66	0.26	5.98	0.07	1.86	bd	bd	9.30
I260-0.5	bd	bd	0.25	2.87	0.28	8.00	2.18	49.83	3.97	104.35	bd	bd	165.05

Appendix D-1: Chromium (continued)

Sample	EX sol'n	EX sed	WAS sol'n	WAS sed	ER sol'n	ER sed	MR sol'n	MR sed	OX1 Sol'n	OX1 sed	OX2 sol'n	OX2 sed	Total sed
I26a1-1.5	bd	bd	0.10	1.10	0.12	3.30	0.65	13.94	0.81	19.97	bd	bd	38.31
I26b1-1.5	bd	bd	0.10	1.07	0.12	2.99	0.68	14.09	0.74	17.64	bd	bd	35.79
I26c1-1.5	bd	bd	0.10	1.08	0.11	3.10	0.57	12.55	0.58	14.68	bd	bd	31.41
J19a0-0.5	bd	bd	4.28	143.09	2.72	227.34	500.00	33431.93	111.10	8542.86	0.69	57.67	42402.88
J19b0-0.5	bd	bd	5.04	162.42	3.64	293.27	635.00	40928.51	148.10	10977.54	1.07	86.21	52447.95
J19c0-0.5	bd	bd	4.68	162.54	3.25	282.18	615.00	42718.21	118.80	9489.69	1.44	125.03	52777.66
J191-1.5	bd	bd	7.20	245.95	9.00	768.60	436.00	29787.44	105.60	8296.76	29.32	2503.9	41602.66
J193-3.5	bd	bd	8.32	283.11	3.69	313.90	241.00	16401.27	37.20	2911.40	4.57	388.76	20298.44
J210-0.5	bd	bd	1.76	21.40	1.20	36.47	20.60	500.91	11.40	318.78	bd	bd	877.56
J211-1.5	bd	bd	0.09	0.97	0.06	1.66	0.61	12.75	0.41	9.85	bd	bd	25.23
J230-0.5	bd	bd	2.68	172.25	2.01	322.96	288.00	37020.32	37.96	5611.41	bd	bd	43126.93
J231-1.5	bd	bd	12.16	567.01	10.45	1218.19	851.00	79362.80	55.68	5971.51	bd	bd	87119.52
J233-3.5	bd	bd	0.03	0.27	0.03	0.89	0.31	6.45	0.08	1.95	bd	bd	9.55
J250-0.5	bd	bd	0.05	0.76	0.11	4.24	0.32	9.70	1.16	40.45	bd	bd	55.15
J251-1.5	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	1.17
J253-3.5	bd	bd	0.03	0.28	0.03	0.73	0.29	6.07	0.24	5.81	bd	bd	12.88
J270-0.5	bd	bd	0.03	0.33	0.02	0.60	0.32	8.22	1.03	30.43	bd	bd	39.59
J271-1.5	bd	bd	0.01	0.14	0.01	0.36	0.08	1.80	0.05	1.39	bd	bd	3.69
K200-0.5	bd	bd	1.72	101.07	1.16	170.41	48.00	5641.25	43.32	5854.91	bd	bd	11767.64
K203-3.5	bd	bd	0.11	1.46	0.04	1.27	1.10	28.43	0.49	14.56	bd	bd	45.72
K220-0.5	bd	bd	1.08	332.58	1.03	792.96	56.48	34785.68	30.60	21673.30	bd	bd	57584.52
K221-1.5	bd	bd	0.72	34.05	0.98	115.88	10.84	1025.39	16.32	1775.32	bd	bd	2950.64
K223-3.5	bd	bd	0.02	0.22	0.01	0.33	0.28	5.18	0.03	0.57	bd	bd	6.30
K240-0.5	bd	bd	6.28	257.33	4.09	418.97	405.00	33190.12	111.50	10508.16	bd	bd	44374.57
K241-1.5	bd	bd	1.44	64.63	0.89	99.86	47.90	4299.44	43.40	4479.86	bd	bd	8943.79
K243-3.5	bd	bd	0.04	0.46	0.02	0.54	0.61	13.08	0.12	3.07	bd	bd	17.15

Table D-1: Chromium (continued)

Sample	EX sol'n	EX mg/kg sed	WAS sol'n	WAS mg/kg sed	ER sol'n	ER mg/kg sed	MR sol'n	MR mg/kg sed	OX1 Sol'n	OX1 mg/kg sed	OX2 sol'n	OX2 mg/kg sed	Total sed mg/kg
K260-0.5	bd	bd	0.07	0.97	0.08	2.58	0.40	10.79	0.63	19.54	bd	bd	33.87
K261-1.5	bd	bd	0.20	9.21	0.09	10.45	1.66	151.41	5.47	573.76	bd	bd	744.83
K263-3.5	bd	bd	0.56	10.01	0.49	21.90	8.09	289.29	15.17	623.83	bd	bd	945.04
K280-0.5	bd	bd	0.05	1.05	0.02	1.36	1.15	52.04	2.06	107.20	bd	bd	161.64
K281-1.5	bd	bd	0.03	0.88	0.01	0.86	0.05	3.61	0.25	19.16	bd	bd	24.52
L210-0.5	bd	bd	0.05	0.48	0.17	4.41	0.84	17.74	0.81	19.67	bd	bd	42.30
L211-1.5	bd	bd	0.53	5.56	0.07	1.91	0.85	17.91	0.91	22.05	bd	bd	47.44
L230-0.5	bd	bd	0.24	16.36	0.24	40.89	6.50	885.90	13.04	2043.83	bd	bd	2986.97
L231-1.5	bd	bd	0.84	51.55	1.02	156.50	19.80	2430.41	22.20	3133.76	bd	bd	5772.23
L233-3.5	bd	bd	0.03	0.35	0.00	0.05	0.22	4.74	0.09	2.35	bd	bd	7.49
L250-0.5	bd	bd	0.25	2.63	0.14	3.77	1.30	27.51	1.32	32.12	bd	bd	66.03
L251-1.5	bd	bd	0.02	0.96	0.01	0.99	0.11	8.18	0.80	71.33	bd	bd	81.46
L25a3-3.5	bd	bd	0.15	5.82	0.10	9.59	4.11	311.61	6.24	544.08	bd	bd	871.10
L25b3-3.5	bd	bd	0.11	4.77	0.07	8.13	3.21	286.84	3.29	338.09	bd	bd	637.82
L25c3-3.5	bd	bd	0.16	5.80	0.10	8.80	4.35	310.97	6.06	498.19	bd	bd	823.76
L270-0.5	bd	bd	0.21	10.58	0.09	11.49	1.93	196.17	5.39	630.02	bd	bd	848.26
L271-1.5	bd	bd	0.11	2.63	0.05	3.10	1.21	56.97	1.47	79.59	bd	bd	142.29
L273-3.5	bd	bd	0.02	0.19	0.02	0.57	0.13	2.82	0.11	2.62	bd	bd	6.20
M200-0.5	bd	bd	1.40	16.05	0.75	21.50	23.10	529.68	10.40	274.24	bd	bd	841.47
M201-1.5	bd	bd	0.04	0.79	0.02	0.93	0.24	10.51	0.59	29.71	bd	bd	41.94
M220-0.5	bd	bd	0.10	1.75	0.03	1.34	0.67	24.47	1.40	58.81	bd	bd	86.38
M221-1.5	bd	bd	0.19	2.76	0.08	2.84	1.63	47.78	1.90	64.05	bd	bd	117.43
M223-3.5	bd	bd	0.96	10.21	0.04	0.94	0.80	16.96	0.30	7.31	bd	bd	35.42
M240-0.5	bd	bd	0.31	7.32	0.26	15.37	1.57	74.25	4.92	267.59	bd	bd	364.54
M241-1.5	bd	bd	0.09	4.39	0.06	7.08	0.58	56.38	3.38	377.83	bd	bd	445.68
M243-3.5	bd	bd	0.02	0.22	0.01	0.22	0.09	2.10	0.02	0.46	bd	bd	3.01

Table D-1: Chromium (continued)

Sample	EX sol'n	EX sed	WAS sol'n	WAS sed	ER sol'n	ER sed	MR sol'n	MR sed	OX1 Sol'n	OX1 sed	OX2 sol'n	OX2 sed	Total sed
M260-0.5	bd	bd	0.23	5.33	0.15	2.22	15.20	7.05	391.26	13.01	830.34	bd	1244.01
M261-1.5	bd	bd	0.26	7.21	0.22	8.35	3.96	180.87	11.71	615.07	bd	bd	809.63
M280-0.5	bd	bd	1.20	26.20	1.00	54.59	31.90	1393.06	36.00	1807.92	bd	bd	3281.77
M281-1.5	bd	bd	0.23	4.50	0.15	7.11	1.72	65.94	0.91	40.12	bd	bd	117.67
M283-3.5	bd	bd	0.02	0.18	0.03	0.78	0.16	3.50	0.04	0.96	bd	bd	5.43
N210-0.5	bd	bd	2.88	103.37	3.11	279.06	90.10	6467.75	70.40	5811.65	bd	bd	12661.83
N211-1.5	bd	bd	1.48	45.61	1.99	153.31	55.00	3389.87	21.48	1522.48	2.37	182.59	5293.86
N230-0.5	bd	bd	1.80	103.30	1.63	233.87	52.30	6003.10	40.30	5319.57	bd	bd	11659.85
N231-1.5	bd	bd	0.52	6.23	0.31	9.20	8.67	205.85	1.52	41.50	bd	bd	262.78
N233-3.5	bd	bd	0.37	4.70	0.25	7.97	7.28	185.59	2.53	74.17	bd	bd	272.43
N250-0.5	bd	bd	0.09	1.01	0.05	1.48	1.24	28.85	1.40	37.46	bd	bd	68.79
N251-1.5	bd	bd	0.03	0.66	0.02	1.37	0.36	16.77	1.32	70.71	bd	bd	89.52
N253-3.5	bd	bd	bd	bd	0.03	0.91	0.46	11.22	0.39	10.94	bd	bd	23.14
O220-0.5	bd	bd	1.84	64.12	1.47	128.06	326.00	22719.83	48.48	3885.51	bd	bd	26797.51
O22a1-1.5	bd	bd	24.08	930.17	6.40	618.06	272.00	21013.91	41.88	3720.85	bd	bd	26283.00
O22b1-1.5	bd	bd	20.92	808.11	6.91	667.31	232.00	17923.63	39.68	3525.39	bd	bd	22924.44
O22c1-1.5	bd	bd	24.52	921.34	7.92	743.99	270.00	20290.51	42.04	3633.20	bd	bd	25589.04
O223-3.5	bd	bd	5.36	70.51	1.41	46.37	77.20	2031.04	8.60	260.19	bd	bd	2408.11
O240-0.5	bd	bd	4.16	195.59	3.89	457.24	88.50	8322.00	55.52	6003.88	bd	bd	14978.71
O241-1.5	bd	bd	1.80	38.71	0.87	46.77	148.00	6365.63	41.32	2043.80	bd	bd	8494.92
O243-3.5	bd	bd	1.84	25.37	0.79	27.23	14.38	396.50	5.06	160.45	bd	bd	609.54
P230-0.5	bd	bd	17.64	934.68	37.50	4967.47	510.00	54046.12	54.12	6595.53	bd	bd	66543.81
P231-1.5	bd	bd	3.96	50.97	12.60	405.45	47.28	1217.13	5.80	171.71	bd	bd	1845.27
P23a3-3.5	bd	bd	0.03	0.39	0.04	1.49	0.29	8.54	0.33	11.17	bd	bd	21.64
P23b3-3.5	bd	bd	0.03	0.46	0.05	1.60	0.29	7.65	0.42	12.73	bd	bd	22.46
P23c3-3.5	bd	bd	0.04	0.49	0.04	1.24	0.27	7.51	0.33	10.56	bd	bd	19.81

Table D-1: Chromium (continued)

Sample	EX sol'n	EX mg/kg	WAS sol'n	WAS mg/L	ER sol'n	ER mg/kg	MR sol'n	MR mg/kg	OX1 Sol'n	OX1 mg/kg	OX2 sol'n	OX2 mg/L	OX2 mg/kg	Total sed
P250-0.5	0.02	1.44	0.88	53.15	0.44	66.44	41.12	4967.57	60.92	8463.47	bd	bd	bd	13552.08
P251-1.5	0.04	1.67	1.12	52.53	0.53	62.14	56.28	5279.23	38.96	4202.74	0.84	98.49	9696.81	
P253-3.5	bd	bd	0.08	1.00	0.04	1.31	1.56	38.92	0.61	17.50	bd	bd	bd	58.78
Q240-0.5	0.16	3.99	5.60	143.25	11.24	718.83	363.00	18571.92	205.00	12061.52	9.66	617.78	32117.30	
Q24a1-1.5	0.19	5.29	4.32	118.51	5.72	392.27	84.90	4657.92	44.88	2831.62	bd	bd	bd	8005.60
Q24b1-1.5	0.20	5.30	4.20	112.23	5.44	363.42	85.80	4585.55	44.76	2751.01	bd	bd	bd	7817.52
Q24c1-1.5	0.19	5.30	4.20	115.21	4.92	337.41	83.50	4581.11	40.44	2551.48	bd	bd	bd	7590.51
Q243-3.5	0.02	0.46	6.28	160.05	9.28	591.27	122.50	6244.00	24.60	1441.98	bd	bd	bd	8437.76
Q260-0.5	bd	bd	0.03	0.34	0.07	2.15	120.10	2942.96	0.08	2.14	bd	bd	bd	2947.65
R250-0.5	0.08	2.89	3.68	130.45	1.97	174.58	102.60	7274.02	66.60	5430.00	bd	bd	bd	13011.94
R251-1.5	0.03	0.68	1.12	22.37	0.68	33.95	33.20	1326.12	35.30	1621.50	bd	bd	bd	3004.62
R253-3.5	0.01	0.07	0.80	9.71	0.30	9.10	9.37	227.42	4.08	113.88	bd	bd	bd	360.19
R270-0.5	0.03	1.14	3.04	115.29	1.40	132.74	219.40	16641.38	42.12	3674.00	bd	bd	bd	20564.55
R271-1.5	0.02	1.31	3.36	181.15	1.97	265.52	189.10	20390.12	23.84	2956.19	bd	bd	bd	23794.29
R273-3.5	bd	bd	0.76	25.53	0.38	31.91	17.32	1163.70	6.08	469.78	bd	bd	bd	1690.95
S260-0.5	0.09	2.44	1.56	41.09	1.56	102.72	87.20	4593.52	99.80	6045.85	bd	bd	bd	10785.63
S261-1.5	bd	bd	0.04	1.99	0.05	6.01	1.37	135.72	3.28	373.68	bd	bd	bd	517.66
T270-0.5	0.17	4.34	2.20	55.40	3.41	214.69	260.00	13095.22	78.00	4517.85	7.32	460.85	18348.35	
T271-1.5	0.09	3.69	1.88	77.86	1.83	189.47	177.50	14702.14	46.48	4427.37	bd	bd	bd	19400.53
U260-0.5	0.02	0.21	0.92	9.56	0.78	20.27	75.10	1561.51	8.92	213.29	bd	bd	bd	1804.84
U261-1.5	0.02	0.25	3.52	39.85	4.57	129.34	448.00	10143.67	36.84	959.26	bd	bd	bd	11272.37
U263-3.5	0.01	0.14	3.80	43.20	3.52	100.05	163.50	1717.79	10.92	285.55	bd	bd	bd	4146.74

Appendix D

Table D -2: Replicate Sample Analysis for Chromium

sed indicates concentration in sediment (dry weight basis)
 AVG indicates the average of the three replicate samples. RSD indicates the relative standard deviation of the three replicates. SRM 2704 is NIST Buffalo River Sediment

Sample Replicate	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1 sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
B3a0-0.5	bd	0.33	bd	1.51	3.29	bd	5.38
B3b0-0.5	bd	0.30	bd	1.43	3.14	bd	5.01
B3c0-0.5	bd	0.27	bd	1.32	2.19	bd	3.88
AVG	bd	0.30	bd	1.42	2.87	bd	4.76
RSD	--	9.79	--	6.54	20.66	--	16.45
B9a0-0.5	bd	0.20	0.25	2.50	8.00	bd	10.94
B9b0-0.5	bd	0.10	bd	2.03	7.62	bd	9.93
B9c0-0.5	bd	0.07	bd	2.05	6.97	bd	9.29
AVG	bd	0.12	0.25	2.19	7.53	bd	10.05
RSD	--	53.61	--	12.08	6.90	--	8.30
B13a1-1.5	bd	0.32	0.69	1.32	1.39	bd	3.71
B13b1-1.5	bd	0.31	0.57	1.61	1.20	bd	3.69
B13c1-1.5	bd	0.33	0.55	1.59	1.27	bd	3.73
AVG	bd	0.32	0.60	1.51	1.28	bd	3.71
RSD	--	3.58	12.74	10.94	7.40	--	0.52

Table D-2: Chromium (continued)

Sample Replicate	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1 sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
D9a3-3.5	bd	0.12	0.30	1.10	1.76	bd	3.28
D9b3-3.5	bd	0.11	1.85	2.19	2.77	bd	6.91
D9c3-3.5	bd	0.13	0.63	1.31	2.20	bd	4.26
AVG	bd	0.12	0.92	1.53	2.24	bd	4.82
RSD	--	4.59	88.49	37.68	22.47	--	39.05
F17a3-3.5	bd	bd	0.16	2.15	0.74	bd	3.06
F17b3-3.5	bd	bd	0.19	1.89	0.85	bd	2.99
F17c3-3.5	bd	bd	bd	1.91	0.71	bd	2.77
AVG	bd	bd	0.17	1.98	0.77	bd	2.94
RSD	--	--	14.37	7.10	9.69	--	5.23
I26a1-1.5	bd	1.10	3.30	13.94	19.97	bd	38.31
I26b1-1.5	bd	1.07	2.99	14.09	17.64	bd	35.79
I26c1-1.5	bd	1.08	3.10	12.55	14.68	bd	31.41
AVG	bd	1.09	3.13	13.52	17.43	bd	35.17
RSD	--	1.40	5.01	6.30	15.21	--	9.93
J19a0-0.5	bd	143.09	227.34	33431.93	8542.86	57.67	42402.88
J19b0-0.5	bd	162.42	293.27	40928.51	10977.54	86.21	52447.95
J19c0-0.5	bd	162.54	282.18	42718.21	9489.69	125.03	52777.66
AVG	bd	156.02	267.60	39026.22	9670.03	89.64	49209.50
RSD	--	7.18	13.19	12.62	12.69	37.72	11.98

Table D-2: Chromium (continued)

Sample Replicate	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1 sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
L25a3-3.5	bd	5.82	9.59	311.61	544.08	bd	871.10
L25b3-3.5	bd	4.77	8.13	286.84	338.09	bd	637.82
L25c3-3.5	bd	5.80	8.80	310.97	498.19	bd	823.76
AVG	bd	5.46	8.84	303.14	460.12	bd	777.56
RSD	--	11.02	8.26	4.66	23.50	--	15.86
O22a1-1.5	bd	930.17	618.06	21013.91	3720.85	bd	26283.00
O22b1-1.5	bd	808.11	667.31	17923.63	3525.39	bd	22924.44
O22c1-1.5	bd	921.34	743.99	20290.51	3633.20	bd	25589.04
AVG	bd	886.54	676.45	19742.69	3626.48	bd	24932.16
RSD	--	7.68	9.38	8.19	2.70	--	7.11
P23a3-3.5	bd	0.39	1.49	8.54	11.17	bd	21.64
P23b3-3.5	bd	0.46	1.60	7.65	12.73	bd	22.46
P23c3-3.5	bd	0.49	1.24	7.51	10.56	bd	19.81
AVG	bd	0.45	1.44	7.90	11.49	bd	21.30
RSD	--	10.74	12.84	7.06	9.77	--	6.36
Q24a1-1.5	5.29	118.51	392.27	4657.92	2831.62	bd	8005.60
Q24b1-1.5	5.30	112.23	363.42	4585.55	2751.01	bd	7817.52
Q24c1-1.5	5.30	115.21	337.41	4581.11	2551.48	bd	7590.51
AVG	5.29	115.32	364.37	4608.19	2711.37	bd	7804.55
RSD	0.15	2.72	7.53	0.94	5.32	--	2.66

Table D-2: Chromium (continued)

Sample Replicate	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1 sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
SRM2704 2/3/97	0.15	3.70	12.50	36.48	27.26	0.00	80.10
SRM2704 2/17/97	0.14	3.89	12.89	36.96	25.06	0.00	78.95
SRM2704 2/24/97	0.13	4.50	10.78	41.61	24.57	0.00	81.60
SRM2704 3/10/97	0.11	4.02	13.58	38.02	25.45	0.00	81.17
SRM2704 3/24/97	0.15	4.19	11.90	39.23	29.78	0.00	85.25
SRM2704 4/7/97	0.11	3.58	14.53	33.97	27.50	0.00	79.68
AVG	0.13	3.98	12.70	37.71	26.60	0.00	81.12
RSD	13.42	8.43	10.28	6.88	7.36	--	2.77

Appendix E
Table E-1. Soil Organic Matter Content

Sample ID	%OM	Sample ID	%OM	Sample ID	%OM
B3a0-0.5	2.2	B31-1.5	5.2	B33-3.5	1.0
B50-0.5	0.8	B51-1.5	0.7	B53-3.5	1.1
B70-0.5	0.6	B71-1.5	0.6	B73-3.5	0.3
B9a0-0.5	2.4	B91-1.5	2.8	B93-3.5	0.3
B110-0.5	NA	B111-1.5	0.8	B113-3.5	0.9
B130-0.5	2.3	B13a1-1.5	1.8	B133-3.5	0.5
B150-0.5	5.3	B151-1.5	15.2	B153-3.5	35.8
B170-0.5	5.5	B171-1.5	0.6	B173-3.5	21.5
C20-0.5	2.3	C21-1.5	0.3	C23-3.5	0.3
C40-0.5	2.3	C41-1.5	1.1	C43-3.5	0.6
C60-0.5	0.4	C61-1.5	1.0	C63-3.5	0.1
C80-0.5	4.2	C81-1.5	0.7	C83-3.5	0.9
C100-0.5	2.1	C101-1.5	1.3	C103-3.5	2.0
C120-0.5	2.9	C121-1.5	0.4	C123-3.5	0.2
C140-0.5	5.2	C141-1.5	0.3	C143-3.5	0.4
C160-0.5	1.8	C161-1.5	NA	C163-3.5	NA
D50-0.5	1.8	D51-1.5	1.1	D53-3.5	0.7
D70-0.5	4.2	D71-1.5	0.4	D73-3.5	0.7
D90-0.5	3.7	D91-1.5	0.7	D9a3-3.5	0.6
D110-0.5	0.7	D111-1.5	0.3	D113-3.5	0.2
D130-0.5	3.7	D131-1.5	0.5	D133-3.5	0.6
D150-0.5	2.1	D151-1.5	1.8	D153-3.5	0.8
D170-0.5	32.1	D171-1.5	30.6	D173-3.5	4.3
D190-0.5	19.2	D191-1.5	71.0	D193-3.5	18.8
E140-0.5	1.9	E141-1.5	3.5	E143-3.5	0.4
E160-0.5	28.2	E161-1.5	49.8	E163-3.5	35.8
E180-0.5	34.5	E181-1.5	55.7	E183-3.5	NA
E200-0.5	2.2	E201-1.5	1.8	E203-3.5	NA
F130-0.5	1.8	F131-1.5	0.9	F133-3.5	0.3
F150-0.5	20.7	F151-1.5	20.4	F153-3.5	0.3
F170-0.5	5.5	F171-1.5	0.6	F17a3-3.5	0.2
F190-0.5	5.4	F191-1.5	1.4	F193-3.5	0.5
F210-0.5	0.7	F211-1.5	0.6	F213-3.5	0.8
G140-0.5	7	G141-1.5	4.5	G143-3.5	0.6
G160-0.5	65.8	G161-1.5	8	G163-3.5	6.4
G180-0.5	4.9	G181-1.5	0.6	G183-3.5	0.3
G200-0.5	2.8	G201-1.5	0.8	G203-3.5	0.3
G220-0.5	1.9	G221-1.5	2.3	G223-3.5	0.4
H150-0.5	14.8	H151-1.5	5.9	H153-3.5	15.8
H170-0.5	34.2	H171-1.5	56.7	H173-3.5	5.8
H190-0.5	22.9	H191-1.5	23.1	H193-3.5	70.2

Table E-1. Organic Matter Content (continued)

Sample ID	%OM	Sample ID	%OM	Sample ID	%OM
H210-0.5	0.2	H211-1.5	8.5	H213-3.5	0.4
H23a0-0.5	2	H231-1.5	0.5	H233-3.5	0.2
I200-0.5	48.9	I201-1.5	79.4	I203-3.5	66.6
I220-0.5	65.3	I221-1.5	74.5	I223-3.5	0.4
I240-0.5	3	I241-1.5	0.3	I243-3.5	0.3
I260-0.5	16.7	I26a1-1.5	5.1	I263-3.5	NA
J19a0-0.5	65.3	J191-1.5	76.3	J193-3.5	92.1
J210-0.5	2.6	J211-1.5	1.2	J213-3.5	NA
J230-0.5	74.4	J231-1.5	70.7	J233-3.5	0.4
J250-0.5	23.8	J251-1.5	96	J253-3.5	2.3
J270-0.5	9.6	J271-1.5	0.5	J273-3.5	NA
K200-0.5	81.3	K201-1.5	NA	K203-3.5	3
K220-0.5	76.5	K221-1.5	81.7	K223-3.5	0.2
K240-0.5	72.2	K241-1.5	77.7	K243-3.5	1.1
K260-0.5	4.7	K261-1.5	60.3	K263-3.5	30.1
K280-0.5	25.8	K281-1.5	35.8	K28-3.5	NA
L210-0.5	2.1	L211-1.5	2.9	L213-3.5	NA
L230-0.5	77.3	L231-1.5	86.6	L233-3.5	1.2
L250-0.5	2.1	L251-1.5	76.1	L25a3-3.5	49.5
L270-0.5	77.5	L271-1.5	12.8	L273-3.5	0.3
M200-0.5	2.7	M201-1.5	22.2	M203-3.5	NA
M220-0.5	12.5	M221-1.5	13.5	M223-3.5	2.1
M240-0.5	25.0	M241-1.5	75.0	M243-3.5	0.2
M260-0.5	35.3	M261-1.5	50.0	M263-3.5	NA
M280-0.5	19.3	M281-1.5	15.2	M283-3.5	0.6
N210-0.5	68.4	N211-1.5	58.0	N213-3.5	NA
N230-0.5	77.3	N231-1.5	2.2	N233-3.5	4.6
N250-0.5	3.4	N251-1.5	34.9	N253-3.5	3.7
O220-0.5	69.9	O22a1-1.5	38.1	O223-3.5	4.5
O240-0.5	54.3	O241-1.5	18.8	O243-3.5	3.2
P230-0.5	61.9	P231-1.5	2.1	P23a3-3.5	8.4
P250-0.5	62.1	P251-1.5	58.2	P253-3.5	4.4
Q240-0.5	54.4	Q24a1-1.5	25.0	Q243-3.5	34.4
Q260-0.5	15.7	Q261-1.5	NA	Q263-3.5	NA
R250-0.5	51.5	R251-1.5	17.4	R253-3.5	2.7
R270-0.5	37.2	R271-1.5	59.4	R273-3.5	51.2
S260-0.5	35.8	S261-1.5	66.1	S263-3.5	NA
T270-0.5	46.7	T271-1.5	60.3	T273-3.5	NA
U260-0.5	1.0	U261-1.5	5.6	U263-3.5	3.1

NA – indicates that no sample was taken for that interval

Appendix F Aqueous Field Samples

Appendix F-1: Pore water data for samples taken on 7/26/97.

Two dashes (--) indicates a parameter that was not measured and
 bd indicates that the amount in the sample was below detection.
 Samples with top or bottom in the name indicate the relative depth
 that the samples were taken on a peeper.
 Samples with spring or surface in the name were samples collected
 at the surface.

Sample	Temp. (C)	pH	Eh	Alkalinity as HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	Br ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	S ²⁻ (mg/L)
J23 top	17.5	6.49	-100.0	202.60	41.60	bd	1.60	bd	1.45
J23 bottom	--	6.85	-148.0	173.93	39.60	bd	0.70	bd	1.44
K22 top	14.0	6.97	-15.0	324.93	37.40	bd	bd	bd	0.19
K22 bottom	--	7.06	-22.0	164.37	32.90	bd	6.20	bd	0.19
N23 top	16.5	6.54	-51.0	277.14	19.10	bd	1.70	bd	0.23
N23 bottom	--	6.58	-48.0	244.65	23.70	bd	0.60	bd	0.24
P25 top	17.5	7.32	150.0	91.74	21.00	bd	2.40	0.86	0.21
P25 bottom	--	--	-35.0	221.71	19.50	bd	bd	bd	0.21
Sample	DOC (mg/L)	CH ₄ (mg/L)	NH ₃ (mg/L)	Fe(total) (mg/L)	Fe ²⁺ (mg/L)	K (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)
J23 top	--	8.67	0.13	1.26	1.20	12.60	21.06	45.50	2.25
J23 bottom	--	2.58	0.43	1.32	1.20	12.45	19.91	43.00	3.92
K22 top	--	3.37	0.38	8.32	3.90	14.35	18.46	57.50	2.87
K22 bottom	--	0.31	0.13	3.32	3.00	11.23	19.21	40.00	2.01
N23 top	--	11.61	0.46	47.40	50.00	14.37	14.54	65.50	2.02
N23 bottom	--	20.32	1.30	36.36	34.80	13.50	16.00	58.50	1.67
P25 top	--	bd	0.12	7.08	2.15	6.55	14.02	25.50	1.22
P25 bottom	--	12.26	4.11	9.72	9.10	6.72	14.20	30.00	1.36
Sample	Cd (µg/l)	Co (µg/l)	Cu (µg/l)	Cr (µg/l)	Mn (µg/l)	Ni (µg/l)	Pb (µg/l)	Zn (µg/l)	Sr (µg/l)
J23 top	--	0.42	0.46	11.54	156.86	3.65	bd	--	--
J23 bottom	--	0.50	1.83	84.84	54.85	3.16	1.61	--	--
K22 top	--	0.44	bd	44.88	496.22	1.06	0.53	--	--
K22 bottom	--	0.20	bd	29.82	245.34	0.84	0.26	--	--
N23 top	--	1.48	0.78	137.60	973.35	7.27	0.34	--	--
N23 bottom	--	0.68	bd	164.30	645.66	2.99	3.18	--	--
P25 top	--	0.23	0.87	19.20	19.59	2.25	0.12	--	--
P25 bottom	--	0.94	0.05	70.00	464.08	3.07	bd	--	--

Appendix F-2
Pore water data for samples taken on 8/13/97.

Sample	Temp. (C)	pH	Eh	Alkalinity as HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	Br ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	S ²⁻ (mg/L)
I22 barrel	7.1	7.08	-140	160.55	--	--	--	--	0.79
J23 barrel	13.9	6.57	-152	168.20	--	--	--	--	2.67
K28 barrel	10.4	6.59	-101	179.67	--	--	--	--	0.44
L27 barrel	11.9	6.81	-52	374.62	--	--	--	--	0.24
M28 barrel	12.5	6.41	-45	324.93	--	--	--	--	0.32
N25 barrel	15.7	6.6	-71	217.89	--	--	--	--	0.41
Q26 barrel	13.4	6.65	-27	237.01	--	--	--	--	0.17
S26 barrel	14.8	7.5	-10	202.60	--	--	--	--	0.14
Sample	DOC (mg/L)	CH ₄ (mg/L)	NH ₃ (mg/L)	Fe(total) (mg/L)	Fe ²⁺ (mg/L)	K (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)
I22 barrel	2.35	0.27	1.11	1.49	1.43	11.84	19.19	42.50	2.26
J23 barrel	6.74	11.49	1.52	0.71	0.69	12.48	23.50	47.00	3.70
K28 barrel	5.57	0.13	0.91	5.00	5.02	15.76	22.16	48.00	3.14
L27 barrel	7.09	15.3	1.14	2.63	2.88	31.60	24.39	72.50	1.91
M28 barrel	10.27	31.02	5.07	29.67	30.62	15.44	15.94	59.50	3.85
N25 barrel	7.17	2.43	1.05	5.14	4.80	14.75	19.24	61.00	1.38
Q26 barrel	31.32	16.82	6.11	17.06	17.49	12.32	13.49	58.50	5.54
S26 barrel	6.05	4.21	1.45	1.62	1.44	8.05	6.83	57.00	1.57
Sample	Cd (µg/l)	Co (µg/l)	Cu (µg/l)	Cr (µg/l)	Mn (µg/l)	Ni (µg/l)	Pb (µg/l)	Zn (µg/l)	Sr (µg/l)
I22 barrel	--	0.22	2.08	25.12	0.03	3.33	--	--	--
J23 barrel	--	0.21	1.68	11.40	0.09	3.99	--	--	--
K28 barrel	--	0.52	0.48	2.02	0.15	2.70	--	--	--
L27 barrel	--	0.48	0.13	3.04	0.51	3.33	--	--	--
M28 barrel	--	0.31	1.10	40.96	1.20	3.45	--	--	--
N25 barrel	--	0.29	1.22	6.64	0.21	3.09	--	--	--
Q26 barrel	--	1.45	5.17	5.72	3.18	3.11	--	--	--
S26 barrel	--	0.49	0.88	22.60	5.41	1.96	--	--	--

Appendix F-3
Pore water data for samples collected 10/8/97

Sample	Temp. (C)	pH	Eh	Alkalinity as HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	S ²⁻ (mg/L)	Cr ^{Chel} (ug/L)
J23 top	9.5	6.51	-105	156.73	48.80	0.60	bd	1.67	16.43
J23 bottom	9.5	6.7	-125	137.62	48.40	0.80	bd	0.89	40.67
K22 top	9.9	6.76	-188	210.25	22.20	0.60	bd	0.12	63.69
K22 bottom	9.9	6.99	-157	129.97	37.40	5.60	bd	bd	26.52
N23	11	6.24	6	175.84	21.10	0.80	bd	bd	96.14
O22	11.7	7.02	-160	424.32	11.00	1.60	bd	0.46	43.36
P25 top	12.4	6.37	19	91.74	31.80	bd	bd	bd	144.66
P25 bottom	12.4	6.15	21	126.15	22.00	bd	bd	bd	167.90
P25 Surf.	--	--	--	--	34.80	1.60	1.68	bd	442.05
Q26 barrel	15.2	6.71	-95	137.62	29.30	0.80	bd	bd	10.47
U26a	15.90	7.15	95.00	84.10	3.50	3.10	bd	bd	3.70
U26b		7.52	25.00	137.62	4.10	3.70	bd	bd	4.31
Sample	DOC (mg/L)	CH ₄ (mg/L)	NH ₃ (mg/L)	Fe(total) (mg/L)	Fe ²⁺ (mg/L)	K (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)
J23 top	11.32	3.01	0.26	0.64	0.45	4.92	25.00	41.00	13.00
J23 bottom	6.47	2.25	0.62	0.84	0.69	3.32	25.00	42.00	12.50
K22 top	8.33	6.34	0.55	3.56	3.41	4.53	14.00	40.00	11.00
K22 bottom	3.35	bd	0.58	3.56	3.31	3.23	20.50	50.00	14.50
N23	14.86	9.86	0.82	11.44	9.54	1.20	13.50	32.50	9.00
O22	11.33	19.61	20.42	0.8	0.61	0.39	5.50	135.00	2.50
P25 top	26.86	bd	0.86	7.64	9.54	1.95	19.00	26.50	7.50
P25 bottom	11.95	4.61	3.20	9.36	10.53	1.41	15.00	25.50	6.50
P25 Surf.	27.72	--	--	16.04	--	0.37	19.50	30.50	7.00
Q26 barrel	12.45	bd	2.44	11.36	7.96	2.32	12.00	32.50	8.50
U26a	4.07	0.43	bd	0.18	bd	0.54	2.50	23.00	3.50
U26b	11.30	bd	bd	0.22	bd	1.24	3.00	40.50	5.00
Sample	Ba (ug/L)	Co (ug/L)	Cu (ug/L)	Cr (ug/L)	Mn (ug/L)	Ni (ug/L)	Pb (ug/L)	Zn (ug/L)	Sr (ug/L)
J23 top	57.28	0.16	3.01	16.43	70.19	2.14	1.70	2.43	187.61
J23 bottom	51.47	0.16	3.36	40.67	32.24	2.39	0.91	12.14	189.41
K22 top	111.90	0.20	5.08	63.69	270.77	1.90	0.03	55.61	161.48
K22 bottom	127.04	0.18	6.54	26.52	395.47	1.99	0.09	93.63	201.89
N23	132.59	0.35	8.53	96.14	402.94	2.67	1.98	150.68	67.88
O22	1403.05	0.39	4.40	43.36	270.15	9.78	0.50	162.19	187.82
P25 top	62.90	0.85	8.76	144.66	361.96	3.74	1.84	242.62	70.34
P25 bottom	54.48	1.26	1.70	167.90	302.84	4.67	0.83	217.78	59.31
P25 Surf.	109.05	1.77	5.20	442.05	391.70	3.56	2.82	21.71	62.32
Q26 barrel	68.18	0.61	2.27	10.47	1410.10	2.32	3.72	14.40	130.39
U26a	32.31	0.42	15.47	3.70	391.28	3.14	1.48	5.63	44.57
U26b	41.09	0.34	4.43	4.31	680.85	2.23	bd	0.79	70.53

Appendix F-4
Pore Water Data Collected on 11/20/97

Sample	Temp. (C)	pH	Eh	Alk. As HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	S ²⁻ (mg/L)	Cr _{Chel} (µg/L)
J23 barrel	--	6.8	-82	156.73	49.20	12.94	bd	0.66	3.04
K22 barrel	2.7	6.75	58	141.44	26.30	5.23	bd	bd	21.8
N23barrel	1.8	6.43	47	141.44	24.00	0.66	bd	bd	106.6
O22 barrel	5.6	7.19	-17	428.14	12.60	5.72	bd	0.17	39.5
P25 peeper		6.65	13.00	99.39	31.50	bd	bd	bd	302
P25 barrel	1.5	6.57	42	122.33	31.00	bd	bd	bd	98.5
P25 surface	--	--	--	--	--	--	--	--	--
Sample	DOC (mg/L)	CH ₄ (mg/L)	NH ₃ (mg/L)	Fe(total) (mg/L)	Fe ²⁺ (mg/L)	K (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)
J23 barrel	4.81	0.07	0.61	0.32	0.21	4.16	26.50	43.50	13.00
K22 barrel	4.85	1.98	0.61	1.98	1.59	4.34	18.00	44.00	14.00
N23barrel	12.36	1.75	0.22	13.66	12.43	0.69	16.50	34.50	9.50
O22 barrel	7.98	8.48	12.99	1.56	1.49	0.45	7.00	134.50	4.00
P25 peeper	28.64	0.71	1.65	33.48	27.19	0.82	18.00	35.00	7.00
P25 barrel	19.11	1.17	1.09	7.44	7.09	2.72	14.00	26.50	7.00
P25 surface	19.99	--	--	12.90	11.86	1.29	13.50	26.00	6.00
Sample	Ba (µg/L)	Co (µg/L)	Cu (µg/L)	Cr (µg/L)	Mn (µg/L)	Ni (µg/L)	Pb (µg/L)	Zn (µg/L)	Sr (µg/L)
J23 barrel	48.59	0.11	5.35	3.83	73.48	2.11	0.64	10.82	197.32
K22 barrel	110.48	0.22	3.44	35.88	392.61	1.60	bd	14.05	179.09
N23barrel	120.04	0.42	4.44	124.19	517.20	1.88	0.32	83.51	68.80
O22 barrel	990.85	0.31	9.16	41.16	404.66	1.72	0.73	2.34	215.58
P25 peeper	106.31	2.19	4.31	327.91	592.45	3.31	0.32	18.25	65.35
P25 barrel	56.60	0.63	1.99	122.54	350.16	2.27	1.46	17.87	68.29
P25 surface	90.24	1.68	1.46	314.23	512.15	3.36	0.42	15.11	54.37

Appendix F-5
Pore water data for samples collected 6/9/98

Sample	Temp. (C)	pH	Eh	Alkalinity as HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	Br ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	S ²⁻ (mg/L)
K22	11	7.09	-118	282.95	44.07	2.60	1.39	57.16	0.024
J23	8.3	7.15	50	134.57	49.56	1.41	bd	bd	0.036
N23	9.4	6.35	-20	319.18	21.40	bd	bd	bd	0.107
P25	11	6.47	25	89.71	24.57	bd	bd	bd	bd
O22	7.3	7.22	-77	517.59	13.26	0.66	bd	bd	0.092
L22 surface	13.5	6.98	40	131.12	35.39	3.64	bd	bd	
Sample	DOC (mg/L)	CH ₄ (mg/L)	NH ₃ (mg/L)	Fe(total) (mg/L)	Fe ²⁺ (mg/L)	K (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)
K22	14.53	--	--	14.99	16.08	8.43	21.69	65.30	17.70
J23	1.47	--	--	0.25	0.14	7.56	20.03	38.46	12.14
N23	8.78	--	--	19.31	22.94	3.57	13.90	45.84	13.51
P25	13.07	--	--	4.49	2.19	2.16	16.13	21.48	5.49
O22	10.20	--	--	0.51	1.46	4.06	7.414	153.79	1.89
L22 surface	9.90	--	--	1.47	0.88	5.00	19.44	33.00	10.03
Sample	Ba (µg/L)	Co (µg/L)	Cu (µg/L)	Cr (µg/L)	Mn (µg/L)	Ni (µg/L)	Pb (µg/L)	Zn (µg/L)	Sr (µg/L)
K22	238.25	0.28	0.30	53.83	1397.01	1.54	0.53	3.13	294.64
J23	46.62	0.16	0.82	3.58	1.59	1.19	0.58	7.67	173.35
N23	112.66	0.26	0.13	65.36	404.11	1.08	0.41	3.14	105.21
P25	54.39	0.45	1.09	61.59	308.85	1.25	2.14	22.17	56.45
O22	866.56	0.42	0.57	29.32	182.93	6.39	1.67	27.50	278.20
L22 surface	179.02	0.16	0.30	26.42	151.34	1.86	0.85	7.03	134.72

Appendix F-6
Pore water data for samples collected 8/22/98

Sample	Temp. (C)	pH	Eh	Alkalinity as HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	Br ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	S ²⁻ (mg/L)
H21 spring	8.5	8.3	35.4	140	39.00	bd	14.54	3.32	bd
I22 pipe peeper	15.4	7.13	-54.9	157	26.94	bd	1.05	bd	0.055
I22 spring	9.3	6.95	232.5	128	38.72	bd	16.42	5.58	bd
J19 pit peeper	14.3	6.85	-252.6	314	65.72	1.41	24.61	bd	5.237
K20 surface	17.3	9.05	179.8	140	36.68	bd	12.01	bd	bd
K22 surface	13.4	6.35	-47.7	126	38.17	bd	6.30	bd	0.077
L21 peeper	16.7	6.13	8.6	156	34.57	bd	5.76	bd	0.731
L21 surface	16.8	6.38	165.8	191	39.49	0.40	2.39	bd	bd
N23 peeper	15.7	6.37	-38.7	280	26.71	1.12	1.31	bd	bd
N23 surface	18.4	6.37	130.7	70.7	10.36	bd	1.94	1.13	bd
P25 surface	17	6.68	5.3	174	40.78	bd	1.27	bd	bd
Sample	DOC (mg/L)	CH ₄ (mg/L)	NH ₃ (mg/L)	Fe(total) (mg/L)	Fe ²⁺ (mg/L)	K (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)
H21 spring	4.74	--	--	0.207	0.79	2.42	20.12	43.27	13.21
I22 pipe peeper	18.14	--	--	34.08	32.86	6.26	13.90	60.12	12.48
I22 spring	2.47	--	--	0.202	0.24	2.52	20.01	41.29	13.17
J19 pit peeper	15.49	--	--	0.419	0.32	2.39	34.76	90.24	21.54
K20 surface	15.81	--	--	0.188	0.14	3.72	24.03	34.96	11.63
K22 surface	7.66	--	--	1.884	1.75	4.17	19.35	37.93	11.10
L21 peeper	9.62	--	--	1.055	0.84	2.26	20.10	40.79	12.19
L21 surface	11.77	--	--	0.418	0.37	3.49	21.56	42.90	13.12
N23 peeper	8.68	--	--	33.12	43.10	1.83	17.41	52.35	14.13
N23 surface	31.08	--	--	0.399	0.51	6.43	4.87	19.24	5.43
P25 surface	8.42	--	--	0.198	0.22	3.44	20.93	45.50	13.02
Sample	Ba (μg/L)	Co (μg/L)	Cu (μg/L)	Cr (μg/L)	Mn (μg/L)	Ni (μg/L)	Pb (μg/L)	Zn (μg/L)	Sr (μg/L)
H21 spring	64.25	0.14	0.15	10.15	42.48	0.5	0.12	4.33	167.1
I22 pipe peeper	219.53	19.1	0.28	9.18	596.32	2.24	0.63	185.99	169.87
I22 spring	47.12	0.11	1.22	4.35	2.65	0.88	0.29	2.59	166.15
J19 pit peeper	264.43	0.25	0.27	46.05	89.72	1.4	0.32	55.07	150.68
K20 surface	450.89	0.17	0.65	78.79	131.13	0.38	0.74	29.59	104.34
K22 surface	93.68	0.15	0.12	10.59	62.95	0.55	0.17	1.3	161.96
L21 peeper	273.58	0.16	0.26	28.03	193.03	0.43	0.39	35.08	175.28
L21 surface	312.24	0.21	0.24	30.02	321.5	0.58	0.34	2.15	153.94
N23 peeper	196.73	0.21	0.17	71.74	405.29	0.97	0.55	116.51	99.13
N23 surface	25.91	0.27	0	8.87	164.45	0.75	0.23	4.64	50.59
P25 surface	77.22	0.16	0	4.29	74.89	1.18	0.22	1.4	198.17

Appendix F-7
Pore water data for samples collected 10/10/98

Sample	Temp. (C)	pH	Eh	Alkalinity as HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	Br ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	S ²⁻ (mg/L)
H21 pipe peeper	8.8	6.51	-87.7	182	23.09	bd	bd	bd	bd
H21 pipe surface	9.6	7.02	-54.7	184	35.80	bd	8.11	bd	bd
I22 surface	8.9	6.95	-41.7	160	37.58	bd	11.50	bd	bd
J19 peeper	7.5	6.8	-200.3	241	56.72	bd	2.13	5.98	3.937
J19 surface	10.1	6.26	-50.6	133	36.51	bd	116.04	bd	bd
J19 peeper	7.5	6.76	-192.6	261	58.89	bd	4.91	2.62	2.946
K22 surface	7.9	6.43	35.8	118	39.31	bd	15.65	1.63	bd
L21 peeper	8.1	6.68	-143.3	152	38.00	bd	0.76	bd	1.226
M22 surface	14.5	6.55	2.8	130	39.00	bd	5.81	bd	bd
N23 peeper	8.1	6.28	-50.6	331	27.46	bd	1.10	bd	0.376
O24 surface	6.13	6.13	-17.3	174	38.65	bd	0.55	bd	bd
P25 surface	9.7	5.49	129.3	23.9	57.59	bd	21.25	bd	bd
Sample	DOC (mg/L)	CH ₄ (mg/L)	NH ₃ (mg/L)	Fe(total) (mg/L)	Fe ²⁺ (mg/L)	K (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)
H21 pipe peeper	15.80	--	--	27.68	34.885	3.619	9.359	33.90	7.25
H21 pipe surface	62.40	--	--	9.75	10.873	14.42	13.25	48.99	11.77
I22 surface	3.14	--	--	4.94	5.351	3.804	18.87	42.55	12.41
J19 peeper	8.18	--	--	0.30	0.155	1.741	58.84	71.41	14.80
J19 surface	20.81	--	--	0.47	0.324	4.517	25.88	41.39	27.08
J19 peeper	9.29	--	--	0.32	0.199	1.818	64.08	56.70	12.47
K22 surface	4.40	--	--	0.50	0.497	2.368	19.50	34.98	10.86
L21 peeper	11.15	--	--	1.47	1.491	4.368	21.78	34.03	11.94
M22 surface	5.30	--	--	0.65	0.613	2.49	15.66	35.32	11.02
N23 peeper	11.83	--	--	38.25	55.384	1.499	14.75	57.84	15.46
O24 surface	9.85	--	--	4.27	4.541	3.958	20.65	99.64	29.13
P25 surface	18.47	--	--	1.63	1.540	0.499	23.41	50.88	9.60
Sample	Ba (µg/L)	Co (µg/L)	Cu (µg/L)	Cr (µg/L)	Mn (µg/L)	Ni (µg/L)	Pb (µg/L)	Zn (µg/L)	Sr (µg/L)
H21 pipe peeper	155.26	0.19	0.11	5.90	555.83	1.07	0.09	64.24	111.79
H21 pipe surface	121.70	0.82	3.01	15.61	632.82	1.53	2.29	16.31	154.03
I22 surface	80.75	0.21	2.29	1.30	413.43	1.13	0.16	4.01	177.89
J19 peeper	106.51	0.20	4.30	48.56	73.02	1.91	0.70	60.02	99.97
J19 surface	335.02	0.61	1.25	304.28	100.17	2.71	27.67	613.90	73.37
J19 peeper	134.07	0.19	2.87	58.44	61.43	2.21	0.26	31.50	98.52
K22 surface	58.93	0.06	bd	3.74	15.90	0.06	0.19	1.39	151.97
L21 peeper	791.85	0.10	0.06	79.95	432.16	0.90	0.21	303.55	106.56
M22 surface	124.61	0.08	bd	11.52	117.20	bd	0.22	0.75	139.75
N23 peeper	210.43	0.36	0.12	107.98	575.42	2.25	0.44	325.13	109.55
O24 surface	87.60	0.17	1.65	19.13	215.91	1.22	0.24	8.19	170.89
P25 surface	75.55	0.77	2.41	228.71	246.93	1.03	0.94	136.94	49.94

Appendix G

Appendix G -1: Solid Phase Extraction Data – Chromium

Chelex Cr is the amount of chromium in solution after reaction with the Chelex resin.

Sep-Pak Cr is the amount of chromium in solution after reaction with the Sep-Pak resin.

AG Cr is the amount of chromium in solution after reaction with the AG resin.

Sample	Cr (µg/L)	Chelex Cr (µg/L)	Sep-Pak Cr (µg/L)	AG Cr (µg/L)
Samples collected on during the 8/98 sampling trip				
H21 Spring	11.77	10.53	9.75	2.3
I22 Pipe	9.7	14.68	6.7	2.35
I22 Spring	3.45	3.77	1.8	0.7
J19 Pit	52.87	53.03	49.25	3.5
K20 Surface	93.03	89.23	84.15	4.35
K22 Surface	13.71	14.74	10.55	1.45
L21	33.07	32.52	27.8	3.4
L21 Surface	35.91	35.59	28.85	0.95
N23	89.49	89.7	59.2	5.6
N23 Surface	3.55	3.75	2.6	1.6
P25 Surface	5.96	6.57	5.25	1.95
Samples collected on during the 10/98 sampling trip				
H21 Pipe Surface	15.61	13.81	10.8	7.2
H21 Pipe	6.09	5.99	4.3	2.75
I22 Surface	1.39	0.94	5	0
J19 Surface	304.28	304.32	264.75	9
J19 Upper	53.94	52.21	52.95	9.4
J19 Lower	39.98	40.82	36.95	11.85
K22 Surface	5.49	4.58	3.6	7.05
L21	88.35	90.46	77.3	27.65
M22 Surface	11.52	11.9	9.55	4
N23	130.72	141.75	112.55	14.25
O24 Surface	19.13	19.46	14.3	4.8
P25 Surface	228.71	230.78	205.15	12.7
Samples collected on during the 6/98 sampling trip				
J23	3.58	3.04		
K22	53.83	49.03		
L21	26.42	27.31		
N23	65.36	54.94		
O22	29.32	31.86		
P25	61.59	71.31		

Appendix G -2: Solid Phase Extraction Data – Manganese

Chelex Mn is the amount of manganese in solution after reaction with the Chelex resin.
 Sep-Pak Mn is the amount of manganese in solution after reaction with the Sep-Pak resin.
 AG Mn is the amount of manganese in solution after reaction with the AG resin.

Sample	Mn (µg/L)	Chelex Mn (µg/L)	Sep-Pak Mn (µg/L)	AG Mn (µg/L)
Samples collected on during the 8/98 sampling trip				
H21 Spring	44.81	0.29	44.75	45.95
I22 Pipe	648.33	4.32	633.5	649.5
I22 Spring	1.57	0.14	1.4	2.65
J19 Pit	85.17	0.61	89.8	90.6
K20 Surface	143.74	0.6	138.3	150.6
K22 Surface	67.4	0.62	64.25	69.9
L21	291.36	1.64	294.05	290.1
L21 Surface	344.25	1.37	333.45	317.35
N23	512.7	2.88	474.2	538.7
N23 Surface	167.27	1.87	152.05	167.55
P25 Surface	82.28	0.38	76.55	79.95
Samples collected on during the 10/98 sampling trip				
H21 Pipe Surface	632.82	38.32	617.1	545.65
H21 Pipe	578.25	106.99	561.5	446.05
I22 Surface	413.43	31.46	412.55	351.85
J19 Surface	100.17	1.51	97.55	86.45
J19 Upper	64.65	2.55	65.6	56.1
J19 Lower	83.14	4.43	89.25	79.35
K22 Surface	15.9	1.77	16.1	22.9
L21	342.41	12.57	338.45	285.3
M22 Surface	117.2	13.6	116.3	104.15
N23	819.87	5.87	847.2	816.7
O24 Surface	215.91	11.61	219.65	186.4
P25 Surface	246.93	20.96	247.75	206.95

Appendix H

Table H-1. Sequential Chemical Extraction Data for Iron

sol'n indicates concentration detected in leachate solution, mg/L
sed indicates concentration in sediment, mg/kg (dry weight basis)
bd indicates below detection, -- indicates not measured

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
B3a0-0.5	0.42	4.3	5.52	55.9	8.36	211.6	88.00	1781.9	bd	bd	bd	bd	2053.7
B3b0-0.5	0.38	4.2	5.56	61.3	7.16	197.4	77.90	1718.0	bd	bd	bd	bd	1980.9
B3c0-0.5	0.38	3.6	5.96	57.2	6.92	166.1	82.30	1580.3	bd	bd	bd	bd	1807.3
B31-1.5	bd	bd	2.04	21.6	7.28	193.0	23.70	502.6	4.68	114.1	bd	bd	831.4
B33-3.5	bd	bd	2.48	25.2	4.32	109.6	69.60	1412.7	bd	bd	bd	bd	1547.5
B50-0.5	bd	bd	0.44	4.3	3.08	75.7	44.90	882.9	bd	bd	bd	bd	962.9
B51-1.5	bd	bd	1.40	15.2	2.52	68.3	59.50	1289.4	bd	bd	bd	bd	1372.8
B53-3.5	bd	bd	2.04	24.1	2.00	59.1	112.20	2652.5	bd	bd	bd	bd	2735.7
B70-0.5	bd	bd	1.40	13.4	2.80	67.0	11.50	220.0	bd	bd	bd	bd	300.4
B71-1.5	bd	bd	2.00	19.8	4.72	117.0	52.20	1035.3	bd	bd	bd	bd	1172.2
B73-3.5	bd	bd	2.04	22.3	2.04	55.8	14.00	306.5	bd	bd	bd	bd	384.6
B9a0-0.5	bd	bd	0.80	8.4	5.44	143.3	232.40	4898.4	bd	bd	bd	bd	5050.2
B9b0-0.5	bd	bd	0.84	9.3	5.32	147.0	230.70	5098.7	bd	bd	bd	bd	5254.9
B9c0-0.5	bd	bd	0.84	8.8	5.44	142.1	239.50	5006.4	bd	bd	bd	bd	5157.4
B91-1.5	bd	bd	2.76	29.6	2.48	66.5	165.10	3543.6	bd	bd	bd	bd	3639.7
B93-3.5	bd	bd	1.28	13.7	1.20	32.0	28.70	613.2	bd	bd	bd	bd	658.9
B110-0.5	bd	bd	1.64	20.1	7.56	231.7	--	--	bd	bd	bd	bd	--
B111-1.5	bd	bd	3.04	33.6	3.48	96.2	63.60	1406.7	bd	bd	bd	bd	1536.5
B113-3.5	bd	bd	2.32	26.5	1.44	41.1	61.70	1409.0	bd	bd	bd	bd	1476.6
B130-0.5	bd	bd	3.28	35.1	10.76	288.2	200.40	4293.7	1.30	32.0	0.75	20.1	4669.2
B13a1-1.5	0.12	1.3	7.04	73.5	11.44	298.6	97.10	2027.7	bd	bd	bd	bd	2401.1

Table H-1. Iron (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
B13b1-1.5	0.12	1.3	6.60	74.1	10.64	298.7	92.00	2066.2	bd	bd	bd	bd	2440.4
B13c1-1.5	0.18	2.1	6.56	75.8	10.72	309.7	102.40	2366.8	bd	bd	bd	bd	2754.4
B133-3.5	bd	bd	2.96	30.9	2.96	77.3	54.50	1138.2	bd	bd	bd	bd	1246.4
B150-0.5	bd	bd	1.36	14.7	14.00	378.7	72.50	1568.8	0.92	22.9	0.12	3.2	1988.3
B151-1.5	0.94	10.5	5.28	58.8	19.12	531.9	129.40	2880.1	4.12	105.5	0.59	16.4	3603.1
B153-3.5	bd	bd	1.08	17.0	57.24	2258.1	733.00	23132.8	29.84	1083.0	bd	bd	26490.9
B170-0.5	bd	bd	1.80	19.2	20.00	532.6	133.80	2850.3	1.18	28.9	2.02	53.8	3484.8
B171-1.5	bd	bd	4.84	48.9	9.68	244.5	107.90	2180.2	bd	bd	bd	bd	2473.6
B173-3.5	1.52	31.9	42.52	891.6	42.52	2228.9	234.10	9817.1	4.96	239.2	0.56	29.4	13238.0
C20-0.5	bd	bd	0.92	9.8	5.08	134.8	143.30	3042.6	bd	bd	bd	bd	3187.2
C21-1.5	bd	bd	1.00	9.6	1.80	43.1	32.20	617.4	bd	bd	bd	bd	670.2
C23-3.5	bd	bd	1.00	10.1	1.36	34.4	51.10	1033.3	bd	bd	bd	bd	1077.7
C40-0.5	bd	bd	1.20	13.0	4.32	117.2	134.30	2916.0	bd	bd	bd	bd	3046.2
C41-1.5	bd	bd	2.64	27.3	4.32	111.7	92.40	1912.0	bd	bd	bd	bd	2051.0
C43-3.5	bd	bd	4.00	38.4	4.96	119.2	118.20	2271.6	bd	bd	bd	bd	2429.0
C60-0.5	bd	bd	1.24	12.1	1.32	32.2	12.70	247.8	bd	bd	bd	bd	292.0
C61-1.5	bd	bd	2.12	20.5	6.08	147.2	98.30	1904.1	bd	bd	bd	bd	2071.9
C63-3.5	bd	bd	1.32	12.8	1.08	26.1	22.30	431.4	bd	bd	bd	bd	470.3
C80-0.5	0.14	1.5	4.00	43.6	12.16	331.1	56.30	1226.3	bd	bd	bd	bd	1602.4
C81-1.5	0.68	8.0	2.28	26.8	2.08	61.0	35.70	837.7	bd	bd	bd	bd	933.5
C83-3.5	bd	bd	2.48	25.6	2.56	66.0	29.60	610.9	bd	bd	bd	bd	702.6
C100-0.5	bd	bd	1.16	13.2	3.84	109.6	83.50	1906.2	bd	bd	bd	bd	2029.0
C101-1.5	bd	bd	3.48	34.4	4.20	103.7	106.20	2097.1	bd	bd	bd	bd	2235.1
C103-3.5	bd	bd	4.04	43.3	6.64	177.9	139.80	2996.9	bd	bd	bd	bd	3218.2
C120-0.5	bd	bd	1.92	21.3	5.40	150.0	113.80	2528.2	bd	bd	bd	bd	2699.5

Table H-1. Iron (continued)

Sample	EX sol'n	EX mg/kg sed	WAS sol'n	WAS mg/kg sed	ER sol'n	ER mg/kg sed	MR sol'n	MR mg/kg sed	OX1 Sol'n	OX1 mg/kg sed	OX2 sol'n	OX2 mg/kg sed	Total sed mg/kg
C121-1.5	bd	bd	2.84	27.9	3.36	82.4	61.00	1197.4	bd	bd	bd	bd	1307.7
C123-3.5	bd	bd	1.04	12.2	1.68	49.1	39.50	923.1	bd	bd	bd	bd	984.3
C140-0.5	bd	bd	1.28	15.1	19.60	578.4	105.40	2488.3	1.34	36.4	0.24	7.1	3125.2
C141-1.5	bd	bd	3.16	33.2	3.76	98.7	47.80	1004.2	bd	bd	bd	bd	1136.2
C143-3.5	bd	bd	1.64	18.6	5.12	145.1	134.60	3051.8	bd	bd	bd	bd	3215.5
C160-0.5	bd	bd	1.32	15.5	10.52	309.7	90.80	2138.6	bd	bd	0.35	10.3	2474.2
D50-0.5	bd	bd	0.60	5.8	3.44	83.7	84.40	1643.6	bd	bd	bd	bd	1733.1
D51-1.5	bd	bd	2.28	24.4	3.24	86.8	68.20	1461.7	bd	bd	bd	bd	1572.9
D53-3.5	bd	bd	2.00	22.9	2.20	62.9	100.80	2306.2	bd	bd	bd	bd	2392.0
D70-0.5	bd	bd	12.88	144.4	19.96	559.2	42.20	945.9	bd	bd	bd	bd	1649.5
D71-1.5	bd	bd	2.80	27.2	3.36	81.5	26.50	514.0	bd	bd	bd	bd	622.6
D73-3.5	bd	bd	2.48	29.3	4.44	131.0	27.30	644.2	bd	bd	bd	bd	804.4
D90-0.5	bd	bd	1.12	11.5	4.72	121.5	71.50	1471.9	bd	bd	bd	bd	1604.8
D91-1.5	bd	bd	0.92	10.2	1.28	35.5	16.20	359.0	bd	bd	bd	bd	404.6
D9a3-3.5	bd	bd	1.24	13.8	2.56	71.3	25.10	559.4	bd	bd	bd	bd	644.5
D9b3-3.5	bd	bd	1.48	16.6	3.32	93.1	29.00	650.6	bd	bd	bd	bd	760.3
D9c3-3.5	bd	bd	1.32	15.5	2.76	80.8	26.80	627.7	bd	bd	bd	bd	724.0
D110-0.5	bd	bd	0.60	5.7	4.00	94.5	82.50	1558.6	bd	bd	bd	bd	1658.7
D111-1.5	0.60	6.2	0.42	4.4	1.20	31.1	52.00	1078.0	bd	bd	bd	bd	1119.7
D113-3.5	1.48	14.7	0.72	7.2	0.40	10.0	21.00	418.1	bd	bd	bd	bd	450.0
D130-0.5	0.24	2.5	8.44	88.9	14.00	368.8	162.60	3426.7	bd	bd	bd	bd	3886.9
D131-1.5	0.14	1.3	4.60	44.0	3.32	79.4	42.40	811.2	bd	bd	bd	bd	935.9
D133-3.5	bd	bd	2.56	28.6	3.48	97.3	69.20	1547.2	bd	bd	bd	bd	1673.0
D150-0.5	bd	bd	1.68	18.4	13.88	380.1	100.10	2193.1	bd	bd	bd	bd	2591.6
D151-1.5	bd	bd	4.32	43.1	12.80	319.0	259.60	5176.3	bd	bd	bd	bd	5538.4

Table H-1. Iron (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 Sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
D153-3.5	bd	bd	5.68	58.7	8.68	224.1	81.40	1681.5	bd	bd	bd	bd	1964.3
D170-0.5	0.10	1.6	4.76	74.0	26.64	1034.9	257.50	8002.7	27.72	990.7	3.08	119.7	10223.6
D171-1.5	0.22	3.2	1.40	20.5	23.56	862.2	90.90	2661.1	29.86	1005.3	0.93	34.0	4586.3
D173-3.5	0.18	2.1	8.68	103.2	40.84	1213.8	104.70	2489.5	bd	bd	bd	bd	3808.7
D190-0.5	bd	bd	2.72	33.5	22.16	682.2	255.40	6290.2	7.98	226.0	4.08	125.6	7357.5
D191-1.5	0.58	11.0	7.44	141.0	22.96	1088.2	101.40	3844.7	32.50	1417.1	1.66	78.7	6580.7
D193-3.5	bd	bd	47.00	559.4	108.24	3220.5	34.30	816.4	bd	bd	1.59	47.3	4643.6
E140-0.5	bd	bd	1.00	10.5	9.84	258.5	66.80	1404.0	bd	bd	bd	bd	1673.0
E141-1.5	bd	bd	6.48	73.6	23.48	666.7	340.00	7723.4	bd	bd	bd	bd	8463.7
E143-3.5	bd	bd	2.00	21.7	12.00	326.1	176.40	3834.6	bd	bd	bd	bd	4182.4
E160-0.5	bd	bd	0.96	14.5	6.72	253.2	42.60	1284.0	2.98	103.3	1.47	55.4	1710.3
E161-1.5	bd	bd	0.80	15.2	3.40	161.8	39.00	1484.5	1.74	76.2	5.44	258.8	1996.5
E163-3.5	bd	bd	4.84	115.3	21.52	1281.7	71.30	3397.2	bd	bd	0.49	29.2	4823.4
E180-0.5	bd	bd	7.48	109.6	33.56	1229.3	170.80	5005.3	bd	bd	3.17	116.1	6460.3
E181-1.5	bd	bd	1.60	39.0	1.84	112.1	18.40	896.5	bd	bd	0.24	14.6	1062.1
E200-0.5	bd	bd	1.32	15.0	8.60	244.4	49.50	1125.6	bd	bd	bd	bd	1385.1
E201-1.5	bd	bd	1.40	13.8	6.28	154.4	56.70	1115.4	bd	bd	bd	bd	1283.6
F130-0.5	bd	bd	4.52	44.4	11.64	285.6	88.00	1727.1	bd	bd	bd	bd	2057.1
F131-1.5	bd	bd	2.48	25.1	8.76	221.9	205.30	4160.9	bd	bd	bd	bd	4407.9
F133-3.5	bd	bd	0.68	7.4	2.24	60.5	56.70	1226.0	bd	bd	bd	bd	1293.9
F150-0.5	bd	bd	1.28	19.5	16.80	640.0	103.00	3138.9	4.32	151.4	0.49	18.7	3968.4
F151-1.5	bd	bd	1.60	15.8	22.40	551.6	88.00	1733.7	bd	bd	bd	bd	2301.1
F153-3.5	bd	bd	1.40	14.7	13.20	347.4	126.00	2653.1	bd	bd	0.31	8.2	3023.4
F170-0.5	bd	bd	0.92	11.5	10.20	319.5	124.20	3112.1	bd	bd	0.26	8.1	3451.3
F171-1.5	bd	bd	4.72	50.7	4.92	132.1	47.40	1018.4	bd	bd	bd	bd	1201.3

Table H-1. Iron (continued)

Sample	EX sol'n	EX sed	WAS sol'n	WAS sed	ER sol'n	ER sed	MR sol'n	MR sed	OX1 Sol'n	OX1 sed	OX2 sol'n	OX2 sed	Total sed
F17a3-3.5	bd	bd	0.96	12.2	2.68	85.4	56.50	1440.3	bd	bd	bd	bd	1537.9
F17b3-3.5	bd	bd	1.08	11.8	3.80	103.9	64.50	1411.3	bd	bd	bd	bd	1527.0
F17c3-3.5	bd	bd	1.04	11.3	4.12	112.2	65.70	1431.6	bd	bd	bd	bd	1555.2
F190-0.5	bd	bd	2.48	27.6	10.04	279.1	165.70	3684.8	0.96	24.6	0.10	2.8	4018.8
F191-1.5	bd	bd	10.60	111.1	6.80	178.1	187.00	3919.2	bd	bd	bd	bd	4208.4
F193-3.5	bd	bd	4.20	47.2	3.08	86.6	96.40	2167.5	bd	bd	bd	bd	2301.3
F210-0.5	bd	bd	1.04	11.7	3.52	98.8	77.60	1743.1	bd	bd	bd	bd	1853.6
F211-1.5	bd	bd	2.96	29.3	4.76	117.7	129.80	2567.9	bd	bd	bd	bd	2714.9
F213-3.5	bd	bd	4.64	46.5	4.56	114.2	109.10	2185.3	bd	bd	bd	bd	2346.0
G140-0.5	bd	bd	14.16	214.7	104.00	3942.5	97.00	2941.7	bd	bd	bd	bd	7098.9
G141-1.5	bd	bd	1.84	30.3	47.60	1962.3	28.00	923.4	bd	bd	bd	bd	2916.1
G143-3.5	bd	bd	25.08	261.5	9.20	239.9	23.00	479.7	bd	bd	bd	bd	981.1
G160-0.5	1.96	118.4	12.48	754.1	8.80	1329.4	7.00	846.0	9.96	1384.2	2.32	350.5	4782.6
G161-1.5	0.32	5.1	21.06	334.3	78.00	3095.8	21.00	666.8	bd	bd	bd	bd	4102.0
G163-3.5	1.74	24.8	502.80	7179.2	156.40	5582.8	28.00	799.6	bd	bd	0.19	6.8	13593.2
G180-0.5	bd	bd	1.32	15.4	5.52	160.8	63.10	1470.5	bd	bd	0.08	2.3	1649.0
G181-1.5	bd	bd	2.32	25.6	2.80	77.4	80.10	1770.3	bd	bd	bd	bd	1873.3
G183-3.5	bd	bd	1.76	18.1	2.52	64.8	73.40	1509.8	bd	bd	bd	bd	1592.7
G200-0.5	18.30	220.0	24.48	294.3	17.00	510.9	83.10	1998.1	bd	bd	bd	bd	3023.3
G201-1.5	bd	bd	6.72	70.0	5.28	137.5	161.80	3370.4	bd	bd	bd	bd	3577.9
G203-3.5	bd	bd	1.92	20.7	3.04	81.8	57.00	1227.7	bd	bd	bd	bd	1330.2
G220-0.5	bd	bd	1.52	17.1	10.52	296.2	91.90	2070.2	bd	bd	bd	bd	2383.6
G221-1.5	bd	bd	2.40	26.0	18.92	512.9	57.70	1251.3	bd	bd	0.20	5.4	1795.7
G223-3.5	bd	bd	2.20	23.8	13.36	361.7	125.10	2709.3	bd	bd	bd	bd	3094.8
H150-0.5	bd	bd	6.76	127.4	41.60	1959.5	82.00	3090.0	1.22	52.9	0.15	7.1	5236.8

Table H-1. Iron (continued)

Sample	EX sol'n	EX mg/kg sed	WAS mg/L sol'n	WAS mg/kg sed	ER mg/L sol'n	ER mg/kg sed	MR mg/L sol'n	MR mg/kg sed	OX1 mg/L sol'n	OX1 mg/kg sed	OX2 mg/L sol'n	OX2 mg/kg sed	Total mg/kg sed
H151-1.5	bd	bd	1.84	30.6	87.20	3623.9	60.00	1994.8	bd	bd	bd	bd	5649.2
H153-3.5	0.44	8.1	15.92	292.4	71.60	3287.2	24.00	881.5	bd	bd	0.13	6.0	4475.1
H170-0.5	bd	bd	1.20	30.7	5.60	357.7	20.00	1022.0	bd	bd	bd	bd	1410.4
H171-1.5	bd	bd	2.92	140.3	8.40	1009.2	6.00	576.7	0.38	42.0	bd	bd	1768.2
H173-3.5	1.62	20.9	170.80	2205.4	54.80	1768.9	20.00	516.5	bd	bd	0.20	6.5	4518.2
H190-0.5	bd	bd	0.72	10.1	9.28	325.3	130.20	3651.0	8.02	258.6	1.52	53.3	4298.3
H191-1.5	bd	bd	0.64	13.5	16.84	885.6	123.50	1595.8	14.48	700.6	0.32	16.8	6812.3
H193-3.5	1.94	93.7	25.20	1216.7	42.56	5137.3	89.60	8652.3	6.46	717.4	1.12	135.2	15952.6
H210-0.5	bd	bd	0.60	5.5	3.00	68.8	50.20	921.0	bd	bd	bd	bd	995.3
H211-1.5	0.26	4.8	1.24	22.8	9.32	428.5	109.30	4020.3	2.60	110.0	0.20	9.2	4595.6
H213-3.5	bd	bd	2.08	21.8	6.88	179.9	61.50	1286.5	bd	bd	bd	bd	1488.2
H23a0-0.5	bd	bd	14.24	171.3	17.56	528.2	85.70	2062.1	bd	bd	bd	bd	2761.6
H23b0-0.5	bd	bd	15.76	173.5	18.52	509.8	90.10	1984.2	bd	bd	bd	bd	2667.6
H23c0-0.5	bd	bd	15.92	193.3	20.08	609.6	95.40	2316.9	bd	bd	bd	bd	3119.9
H231-1.5	13.90	109.9	22.20	175.5	11.84	234.0	100.50	1589.3	bd	bd	0.75	14.8	2123.6
H233-3.5	bd	bd	0.88	10.1	5.68	163.2	62.40	1434.6	bd	bd	bd	bd	1607.9
H200-0.5	bd	bd	3.24	82.4	7.56	480.8	65.50	3332.8	4.26	249.3	0.63	40.1	4185.5
H201-1.5	0.18	6.8	7.40	278.6	26.44	2488.2	219.50	16525.5	10.70	926.4	1.76	165.6	20391.1
H203-3.5	0.28	17.2	8.36	513.6	4.20	645.1	4.90	602.1	6.46	912.8	34.40	5283.6	7974.5
H220-0.5	1.6	32.7	4.40	135.8	5.00	385.7	9.40	580.0	bd	bd	0.18	13.9	1148.1
H221-1.5	0.76	32.9	2.68	115.9	3.56	385.0	4.56	394.5	4.10	407.9	4.11	444.5	1780.7
H223-3.5	bd	bd	1.24	15.3	3.04	93.6	20.72	510.3	bd	bd	bd	bd	619.2
H240-0.5	3.88	51.7	4.68	62.3	15.32	510.0	65.20	1736.3	bd	bd	bd	bd	2360.2
H241-1.5	8.70	106.6	4.72	57.9	5.00	153.2	39.20	961.0	bd	bd	bd	bd	1278.7
H243-3.5	1.18	13.6	3.08	35.4	9.76	280.7	63.50	1461.2	bd	bd	bd	bd	1790.9
H260-0.5	0.16	1.8	1.40	16.0	15.24	435.4	196.40	4489.1	5.68	149.3	1.82	52.0	5143.6

Table H-1. Iron (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
I26a1-1.5	bd	bd	1.48	15.9	28.24	756.8	291.70	6254.0	1.88	46.4	0.23	6.2	7079.2
I26b1-1.5	bd	bd	1.88	19.5	28.56	739.9	285.40	5914.9	1.92	45.8	0.59	15.3	6735.4
I26c1-1.5	bd	bd	1.76	19.4	27.72	762.6	272.30	5993.0	0.92	23.3	0.19	5.2	6803.5
J19a0-0.5	0.20	6.7	1.48	49.5	4.56	381.1	122.60	8197.5	3.80	292.2	1.65	137.9	9064.9
J19b0-0.5	0.16	5.2	1.68	54.1	5.84	470.5	139.40	8984.9	3.20	237.2	1.46	117.6	9869.6
J19c0-0.5	0.18	6.3	1.44	50.0	5.08	441.1	132.60	9210.5	4.76	380.2	1.04	90.3	10783.3
J191-1.5	bd	bd	5.80	198.1	22.80	1947.1	54.90	3750.8	1.10	86.4	0.33	28.2	6010.6
J193-3.5	0.22	7.5	1.96	66.7	2.04	173.5	2.28	155.2	0.30	23.5	0.67	57.0	483.4
J210-0.5	0.14	1.7	2.76	33.6	12.52	380.5	86.50	2103.3	bd	bd	bd	bd	2519.1
J211-1.5	13.00	135.8	4.84	50.6	10.56	275.9	64.20	1341.7	bd	bd	bd	bd	1803.9
J230-0.5	0.10	6.4	1.48	95.1	2.32	372.8	5.60	719.8	bd	bd	0.36	57.8	1252.0
J231-1.5	1.4	48.5	4.28	199.6	8.52	993.2	18.70	1743.9	bd	bd	1.13	131.7	3116.9
J233-3.5	bd	bd	0.52	5.4	5.16	134.2	46.80	973.5	bd	bd	bd	bd	1113.1
J250-0.5	0.28	4.2	0.52	7.9	17.00	644.3	122.50	3714.2	12.86	448.4	2.15	81.5	4900.6
J251-1.5	bd	bd	0.12	3.9	2.00	161.9	1.79	115.9	bd	bd	0.20	16.2	297.9
J253-3.5	bd	bd	0.68	7.1	6.40	167.4	30.40	636.2	0.00	bd	0.14	3.7	814.4
J270-0.5	4.42	56.8	2.24	28.8	8.64	277.5	32.80	842.7	1.26	37.2	0.16	5.1	1248.1
J271-1.5	bd	bd	0.92	10.1	2.36	64.8	26.10	573.4	bd	bd	bd	bd	648.3
K200-0.5	2.7	1216.4	2.32	136.3	7.84	1151.8	10.50	1234.0	0.94	127.0	0.46	67.6	3933.1
K203-3.5	bd	bd	17.72	229.0	17.56	567.2	59.00	1524.7	bd	bd	0.11	3.6	2324.4
K220-0.5	0.32	98.5	0.92	283.3	14.44	11116.9	23.50	14473.5	18.24	12919.0	7.02	5404.5	44295.7
K221-1.5	bd	bd	2.92	138.1	43.64	5160.1	74.80	7075.6	10.52	1144.4	0.19	22.5	13540.6
K223-3.5	0.28	2.6	5.36	49.6	3.24	74.9	21.50	397.6	bd	bd	0.06	1.4	526.0
K240-0.5	11.90	487.6	15.12	619.5	24.44	2503.6	56.80	4654.8	2.90	273.3	0.98	100.4	8639.3
K241-1.5	8.70	390.5	2.96	132.8	11.64	1306.0	10.30	924.5	7.38	761.8	10.05	1127.6	4643.2
K243-3.5	4.88	52.3	8.48	90.9	7.64	204.8	37.40	802.2	bd	bd	0.05	1.3	1151.6

Table H-1. Iron (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
K260-0.5	0.22	3.0	1.20	16.2	37.40	1260.6	125.70	3389.5	1.96	60.8	0.88	29.7	4759.7
K261-1.5	bd	bd	0.64	29.2	16.00	1824.2	26.30	2398.8	6.94	727.9	1.16	132.3	5112.4
K263-3.5	0.86	15.4	1.16	20.7	20.52	917.2	75.20	2689.1	5.76	236.9	1.05	46.9	3926.2
K280-0.5	2.92	66.1	0.76	17.2	12.60	712.7	34.40	1556.6	5.40	281.0	0.36	20.4	2653.9
K281-1.5	4.92	164.0	4.88	162.6	21.44	1786.2	45.10	3005.9	18.62	1427.2	0.79	65.8	6611.8
L210-0.5	bd	bd	0.32	3.4	37.72	995.8	143.90	3039.3	bd	bd	0.05	1.3	4039.8
L211-1.5	bd	bd	3.76	39.6	16.20	426.7	106.90	2252.4	bd	bd	0.06	1.6	2720.3
L230-0.5	bd	bd	0.40	27.3	9.84	1676.4	14.40	1962.6	1.14	178.7	0.42	71.6	3916.5
L231-1.5	bd	bd	1.48	90.8	31.28	4799.4	53.80	6603.8	2.56	361.4	0.42	64.4	11919.9
L233-3.5	7.80	84.0	5.92	63.8	11.56	311.2	52.60	1132.9	bd	bd	bd	bd	1591.9
L250-0.5	bd	bd	7.40	78.3	16.96	448.6	105.60	2234.7	bd	bd	0.08	2.1	2763.7
L251-1.5	35.60	1380.1	0.44	17.1	7.28	705.6	14.80	1147.5	2.18	194.4	0.25	24.2	3468.9
L253-3.5	5.18	196.4	0.92	34.9	10.72	1016.0	32.30	2448.9	6.18	538.8	0.92	87.2	4322.2
L253-3.5	4.34	193.9	2.48	110.8	9.04	1009.7	23.60	2108.8	5.18	532.3	17.04	1903.3	5858.9
L253-3.5	6.10	218.0	0.88	31.5	11.48	1025.8	37.50	2680.7	6.90	567.2	0.87	77.7	4601.0
L270-0.5	bd	bd	0.44	22.4	11.52	1463.6	11.40	1158.7	2.28	266.5	1.80	228.7	3139.9
L271-1.5	bd	bd	0.28	6.6	6.12	360.2	22.90	1078.1	1.88	101.8	0.16	9.4	1556.1
L273-3.5	bd	bd	6.20	66.5	10.92	292.9	42.60	914.0	bd	bd	bd	bd	1273.3
M200-0.5	bd	bd	1.12	12.8	10.16	291.2	61.30	1405.6	bd	bd	bd	bd	1709.6
M201-1.5	2.9	457.5	0.72	15.8	7.40	405.0	14.50	634.8	2.64	132.9	0.07	3.8	1649.9
M220-0.5	46.80	854.8	18.68	341.2	20.28	926.0	49.40	1804.5	1.00	42.0	0.09	4.1	3972.5
M221-1.5	18.00	263.8	2.68	39.3	9.80	359.1	37.10	1087.5	3.62	122.0	0.07	2.6	1874.2
M223-3.5	3.42	36.3	8.64	91.6	11.44	303.1	50.70	1074.8	bd	bd	0.03	0.8	1506.6
M240-0.5	4.40	104.0	0.80	18.9	13.04	770.9	27.10	1281.7	8.36	454.7	0.39	23.1	2653.3
M241-1.5	0.32	15.6	0.22	10.7	8.96	1088.7	7.50	729.0	30.52	3411.6	1.28	155.5	5411.1
M243-3.5	0.26	2.9	4.72	53.2	2.32	65.4	17.60	397.0	bd	bd	bd	bd	518.6

Table H-1. Iron (continued)

Sample	EX sol'n	EX mg/kg sed	WAS sol'n	WAS mg/kg sed	ER sol'n	ER mg/kg sed	MR sol'n	MR mg/kg sed	OX1 sol'n	OX1 mg/kg sed	OX2 sol'n	OX2 mg/kg sed	Total sed mg/kg
M260-0.5	6.70	153.0	2.24	51.2	24.92	1422.8	96.80	4421.3	9.18	482.2	1.02	58.2	6588.6
M261-1.5	1.46	40.5	0.68	18.9	10.56	732.6	19.40	1076.7	7.70	491.4	0.70	48.6	2408.6
M280-0.5	39.40	860.3	17.44	380.8	53.08	2897.5	81.80	3572.2	3.50	175.8	0.38	20.7	7907.3
M281-1.5	6.00	115.0	11.88	227.7	19.40	929.7	57.10	2189.0	bd	bd	0.31	14.9	3476.3
M283-3.5	1.82	20.4	9.28	104.2	17.36	487.5	57.50	1291.9	bd	bd	0.03	0.8	1904.9
N210-0.5	2.00	717.8	9.32	334.5	16.80	1507.5	23.80	1708.5	1.08	89.2	0.25	22.4	4379.9
N211-1.5	1.30	40.1	1.92	59.2	7.20	554.7	9.00	554.7	11.06	783.9	5.58	429.9	2422.5
N230-0.5	41.20	2364.5	5.16	296.1	16.04	2301.4	18.00	2066.1	1.16	153.1	0.68	97.6	7278.8
N231-1.5	5.58	66.2	2.12	25.2	3.56	105.7	13.80	327.6	bd	bd	0.15	4.5	529.2
N233-3.5	12.90	164.4	6.16	78.5	9.48	302.1	31.10	792.9	bd	bd	0.09	2.9	1340.8
N250-0.5	24.40	283.8	10.12	117.7	16.32	474.6	50.30	1170.2	bd	bd	0.27	7.9	2054.2
N251-1.5	13.20	307.4	2.92	68.0	13.48	784.9	20.70	964.3	2.04	109.3	0.36	21.0	2254.9
N253-3.5	4.18	51.0	1.56	19.0	10.96	334.3	51.10	1246.8	bd	bd	0.61	18.6	1669.7
O220-0.5	bd	bd	1.28	44.6	8.72	759.7	66.60	4641.5	2.10	168.3	0.26	22.7	5636.7
O22a1-1.5	bd	bd	8.08	312.1	22.16	2140.0	60.80	4697.2	0.60	53.3	bd	bd	6173.8
O22b1-1.5	bd	bd	7.92	305.9	20.56	1985.5	50.00	3862.9	0.22	19.5	bd	bd	7202.7
O22c1-1.5	bd	bd	7.88	296.1	23.36	2194.4	53.50	4020.5	0.42	36.3	bd	bd	6547.3
O223-3.5	bd	bd	71.80	944.5	27.04	889.2	35.40	931.3	bd	bd	bd	bd	2765.1
O240-0.5	15.00	705.3	10.00	470.2	23.44	2755.2	28.00	2632.9	2.08	224.9	0.37	43.5	6832.0
O241-1.5	12.00	258.1	4.36	93.8	7.68	412.9	69.10	2972.1	bd	bd	0.10	5.4	3742.2
O243-3.5	2.94	40.5	18.16	250.4	22.36	770.7	47.90	1320.8	bd	bd	0.02	0.7	2383.0
P230-0.5	bd	bd	3.12	165.3	13.60	1801.5	42.70	4525.0	0.44	53.6	0.66	87.4	6632.9
P231-1.5	bd	bd	6.92	89.1	7.60	244.6	27.50	707.9	0.16	4.7	0.12	3.9	1050.2
P23a3-3.5	0.94	13.8	20.72	304.9	25.60	941.9	60.70	1786.6	0.18	6.1	bd	bd	3053.4
P23b3-3.5	1.56	20.6	16.32	215.1	29.08	958.3	61.90	1631.8	0.54	16.4	bd	bd	2842.2
P23c3-3.5	3.26	45.3	11.84	164.7	28.68	997.1	62.50	1738.4	0.12	3.8	bd	bd	2949.3

Table H-1. Iron (continued)

Sample	EX mg/L	EX sed mg/kg	WAS mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
P250-0.5	13.80	833.6	2.52	152.2	9.60	1449.7	21.00	2536.9	2.40	333.4	0.28	42.3	5348.1
P251-1.5	25.80	1210.1	2.88	135.1	8.96	1050.6	22.10	2073.0	bd	bd	0.54	63.3	4532.1
P253-3.5	3.74	46.7	2.04	25.4	4.56	142.2	12.10	301.9	bd	bd	0.17	5.3	521.5
Q240-0.5	bd	bd	1.52	38.9	13.56	867.2	92.90	4753.0	12.06	709.6	1.71	109.4	6478.0
Q24a1-1.5	0.12	3.3	3.60	98.8	11.64	798.3	40.70	2232.9	0.62	39.1	0.45	30.9	3203.2
Q24b1-1.5	0.46	12.3	3.48	93.0	10.96	732.2	40.30	2153.8	0.56	34.4	0.15	10.0	3035.7
Q24c1-1.5	0.50	13.7	4.44	121.8	10.60	726.9	38.10	2090.3	0.34	21.5	0.22	15.1	2989.3
Q243-3.5	bd	bd	5.12	130.5	12.80	815.5	20.10	1024.5	4.74	277.8	7.08	451.1	2699.5
Q260-0.5	0.68	8.3	96.00	1176.2	133.30	4083.0	145.10	3555.6	3.08	86.8	1.29	39.5	8949.4
R250-0.5	31.20	1106.0	16.36	579.9	27.88	2470.8	65.70	4657.9	3.66	298.4	0.30	26.6	9139.6
R251-1.5	11.00	219.7	2.52	50.3	10.52	525.3	39.80	1589.7	1.00	45.9	0.26	13.0	2443.9
R253-3.5	14.00	169.9	17.40	211.2	20.28	615.3	35.70	866.5	bd	bd	0.16	4.9	1867.7
R270-0.5	31.00	1175.7	10.40	394.4	13.28	1259.1	30.20	2290.7	0.18	15.7	0.34	32.2	5167.8
R271-1.5	7.30	393.6	5.88	317.0	6.36	857.2	17.80	1919.3	1.74	215.8	0.66	89.0	3791.9
R273-3.5	4.60	154.5	2.36	79.3	12.08	1014.5	28.10	1888.0	2.94	227.2	15.12	1269.9	4633.4
S260-0.5	bd	bd	1.60	42.1	21.44	1411.8	105.20	5541.7	7.62	461.6	1.00	65.8	7523.1
S261-1.5	21.60	1069.9	3.16	156.5	16.72	2070.5	38.40	3804.2	5.02	571.9	0.13	16.1	7689.1
T270-0.5	bd	bd	1.40	35.3	16.00	1007.3	75.90	3822.8	4.66	269.9	2.19	137.9	5273.2
T271-1.5	9.80	405.9	2.68	111.0	9.92	1027.1	30.80	2551.1	0.90	85.7	0.34	35.2	4216.0
U260-0.5	bd	bd	3.48	36.2	6.44	167.4	48.30	1004.3	bd	bd	0.12	3.1	1210.9
U261-1.5	5.70	64.5	6.28	71.1	14.52	411.0	66.10	1496.6	bd	bd	0.11	3.1	2046.3
U263-3.5	6.52	74.1	14.56	165.5	13.72	390.0	40.40	918.6	bd	bd	0.19	5.4	1553.7

Appendix H

Table H-2. Replicate Sample Analysis for Iron

sed indicates concentration in sediment (dry weight basis)

AVG indicates the average of three replicate samples. RSD indicates the relative standard deviation of the three replicates. SRM 2704 is NIST Buffalo River Sediment

Sample Replicate	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1 sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
B3a0-0.5	4.25	55.89	211.61	1781.95	bd	bd	2053.69
B3b0-0.5	4.19	61.31	197.38	1717.99	bd	bd	1980.87
B3c0-0.5	3.65	57.22	166.10	1580.33	bd	bd	1807.29
AVG	4.03	58.14	191.69	1693.42	bd	bd	1947.29
RSD	8.24	4.86	12.14	6.08	--	--	6.50
B9a0-0.5	bd	8.43	143.33	4898.43	bd	bd	5050.19
B9b0-0.5	bd	9.28	146.97	5098.65	bd	bd	5254.90
B9c0-0.5	bd	8.78	142.15	5006.45	bd	bd	5157.37
AVG	bd	8.83	144.15	5001.18	bd	bd	5154.16
RSD	--	4.85	1.74	2.00	--	--	1.99
B13a1-1.5	1.25	73.51	298.62	2027.71	bd	bd	2401.09
B13b1-1.5	1.35	74.11	298.70	2066.20	bd	bd	2440.36
B13c1-1.5	2.08	75.81	309.71	2366.76	bd	bd	2754.36
AVG	1.56	74.48	302.35	2153.56	bd	bd	2531.94
RSD	29.02	1.60	2.11	8.62	--	--	7.65

Table H-2. Iron (continued)

Sample Replicate	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1 sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
D9a3-3.5	bd	13.82	71.31	559.36	bd	bd	644.49
D9b3-3.5	bd	16.60	93.10	650.57	bd	bd	760.27
D9c3-3.5	bd	15.46	80.81	627.74	bd	bd	724.01
AVG	bd	15.29	81.74	612.56	bd	bd	709.59
RSD	--	9.15	13.36	7.75	--	--	8.35
F17a3-3.5	bd	12.24	85.40	1440.27	bd	bd	1537.90
F17b3-3.5	bd	11.82	103.93	1411.27	bd	bd	1527.02
F17c3-3.5	bd	11.33	112.22	1431.62	bd	bd	1555.17
AVG	bd	11.79	100.52	1427.72	bd	bd	1540.03
RSD	--	3.84	13.66	1.04	--	--	0.92
I26a1-1.5	bd	15.87	756.82	6253.98	46.35	6.16	7079.19
I26b1-1.5	bd	19.48	739.89	5914.95	45.76	15.28	6735.36
I26c1-1.5	bd	19.37	762.61	5993.04	23.29	5.23	6803.53
AVG	bd	18.24	753.11	6053.99	38.47	8.89	6872.69
RSD	--	11.27	1.57	2.93	34.19	62.48	2.65
J19a0-0.5	6.69	49.48	381.12	8197.51	292.20	137.91	9064.90
J19b0-0.5	5.16	54.14	470.52	8984.94	237.19	117.63	9869.57
J19c0-0.5	6.25	50.01	441.07	9210.46	380.23	90.30	10178.33
AVG	6.03	51.21	430.90	8797.64	303.20	115.28	9704.27
RSD	13.07	4.98	10.57	6.05	23.80	20.72	5.92

Table H-2. Iron (continued)

Sample Replicate	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1 sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
L25a3-3.5	196.37	34.88	1015.97	2448.94	538.84	87.19	4322.20
L25b3-3.5	193.91	110.80	1009.74	2108.84	532.30	1903.32	5858.92
L25c3-3.5	218.03	31.45	1025.83	2680.73	567.24	77.74	4601.03
AVG	202.77	59.04	1017.18	2412.84	546.13	689.42	4927.38
RSD	6.55	75.97	0.80	11.92	3.40	152.49	16.62
O22a1-1.5	bd	312.12	2140.02	4697.23	53.31	bd	7202.67
O22b1-1.5	bd	305.94	1985.51	3862.85	19.55	bd	6173.84
O22c1-1.5	bd	296.09	2194.38	4020.53	36.30	bd	6547.30
AVG	bd	304.72	2106.64	4193.54	36.38	bd	6641.27
RSD	--	2.65	5.14	10.57	46.40	--	7.84
P23a3-3.5	13.83	304.93	941.88	1786.64	6.09	0.00	3053.38
P23b3-3.5	20.56	215.12	958.28	1631.84	16.37	0.00	2842.17
P23c3-3.5	45.34	164.66	997.12	1738.35	3.84	0.00	2949.30
AVG	26.58	228.24	965.76	1718.94	8.77	0.00	2948.29
RSD	62.42	31.13	2.94	4.61	76.20	--	3.58
Q24a1-1.5	3.29	98.75	798.26	2232.95	39.12	30.86	3203.24
Q24b1-1.5	12.29	92.99	732.19	2153.82	34.42	10.02	3035.74
Q24c1-1.5	13.72	121.80	726.94	2090.30	21.45	15.09	2989.30
AVG	9.77	104.52	752.47	2159.02	31.66	18.66	3076.09
RSD	57.87	14.58	5.28	3.31	28.90	58.26	3.66

Table H-2. Iron (continued)

Sample Replicate	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1 sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
SRM27042/3/97	1.7	657.2	2661.1	5174.1	bd	bd	8494.1
SRM27042/17/97	1.4	830.1	2696.5	4644.0	bd	bd	8171.9
SRM27042/24/97	1.3	1196.6	2266.2	5411.4	bd	bd	8875.5
SRM27043/10/97	0.6	811.0	2964.9	5758.8	bd	bd	9535.4
SRM27043/24/97	1.0	875.8	2510.8	5360.6	bd	bd	8748.2
SRM27044/7/97	0.9	635.1	3077.1	5698.3	bd	bd	9411.4
AVG	1.13	834.30	2696.10	5341.21	bd	bd	8872.74
RSD	33.98	24.25	10.98	7.59	--	--	5.92

Appendix I

Table I-1. Sequential Chemical Extraction Data for Copper

sol'n indicates concentration detected in leachate solution, mg/L
sed indicates concentration in sediment, mg/kg (dry weight basis)
bd indicates below detection, -- indicates not measured

Sample	EX sol'n μg/L	EX sed mg/kg	WAS sol'n μg/L	WAS sed mg/kg	ER sol'n μg/L	ER sed mg/kg	MR sol'n μg/L	MR sed mg/kg	OX1 sol'n μg/L	OX1 sed mg/kg	OX2 sol'n μg/L	OX2 sed mg/kg	Total sed mg/kg
B30-0.5	--	--	--	--	28.9	0.7	22.5	0.5	--	--	1.7	0.0	1.2
B31-1.5	--	--	bd	bd	15.60	0.41	5.50	0.12	446.00	10.88	1.00	0.03	11.43
B33-3.5	--	--	bd	bd	13.10	0.33	9.20	0.19	3.50	0.08	1.00	0.03	0.63
B50-0.5	--	--	bd	bd	45.20	1.11	8.20	0.16	7.60	0.17	3.00	0.07	1.52
B51-1.5	--	--	bd	bd	11.70	0.32	6.60	0.14	bd	bd	2.00	0.05	0.51
B53-3.5	--	--	bd	bd	24.80	0.73	11.80	0.28	10.10	0.27	3.00	0.09	1.38
B70-0.5	--	--	bd	bd	30.30	0.72	1.90	0.04	bd	bd	5.00	0.12	0.88
B71-1.5	--	--	34.40	0.34	23.30	0.58	bd	bd	bd	bd	1.00	0.02	0.94
B73-3.5	--	--	27.00	0.30	8.40	0.23	18.80	0.41	bd	bd	3.00	0.08	1.02
B90-0.5	--	--	19.9	0.2	78.3	2.1	13.0	0.3	bd	bd	2.5	0.1	2.8
B91-1.5	--	--	17.20	0.18	10.90	0.29	6.70	0.14	bd	bd	2.42	0.06	0.69
B93-3.5	--	--	bd	bd	bd	bd	20.80	0.44	bd	bd	4.50	0.12	0.56
B110-0.5	--	--	bd	bd	750.00	22.99	0.00	0.00	441.00	12.44	79.50	2.44	37.86
B111-1.5	--	--	bd	bd	25.00	0.69	6.50	0.14	7.60	0.19	2.30	0.06	1.09
B113-3.5	--	--	bd	bd	39.00	1.11	27.90	0.64	5.60	0.15	6.32	0.18	2.08
B130-0.5	--	--	51.30	0.55	250.00	6.70	110.00	2.36	390.00	9.61	46.50	1.25	20.46
B131-1.5	--	--	bd	bd	5.7	0.2	6.4	0.1	bd	bd	13.0	0.3	0.4
B133-3.5	--	--	bd	bd	13.30	0.35	53.00	1.11	4.30	0.10	56.20	1.47	3.02

Table I-1. Copper (continued)

Sample	EX sol'n µg/L	EX sed mg/kg	WAS sol'n µg/L	WAS sed mg/kg	ER sol'n µg/L	ER sed mg/kg	MR sol'n µg/L	MR sed mg/kg	OX1 sol'n µg/L	OX1 sed mg/kg	OX2 sol'n µg/L	OX2 sed mg/kg	Total sed mg/kg
B150-0.5	--	--	51.70	0.56	270.00	7.30	57.60	1.25	413.00	10.28	18.50	0.50	19.89
B151-1.5	--	--	86.60	0.96	100.00	2.78	90.00	2.00	523.00	13.39	27.50	0.77	19.90
B153-3.5	--	--	37.50	0.59	250.00	9.86	110.00	3.47	1415.00	51.35	93.00	3.67	68.95
B170-0.5	--	--	54.50	0.58	330.00	8.79	100.00	2.13	461.00	11.29	55.00	1.46	24.26
B171-1.5	--	--	bd	bd	33.40	0.84	39.70	0.80	7.40	0.17	5.32	0.13	1.95
B173-3.5	--	--	bd	bd	27.70	1.45	6.50	0.27	235.00	11.33	4.50	0.24	13.29
C20-0.5	--	--	bd	bd	104.10	2.76	35.20	0.75	252.00	6.15	7.50	0.20	9.86
C21-1.5	--	--	bd	bd	15.20	0.36	11.10	0.21	1.30	0.03	bd	bd	0.61
C23-3.5	--	--	bd	bd	17.10	0.43	71.60	1.45	4.00	0.09	1.50	0.04	2.01
C40-0.5	--	--	bd	bd	1882.00	51.08	14.70	0.32	21.60	0.54	5.00	0.14	52.07
C41-1.5	--	--	bd	bd	19.91	0.51	46.00	0.95	7.20	0.17	0.50	0.01	1.65
C43-3.5	--	--	bd	bd	28.30	0.68	66.30	1.27	1.80	0.04	0.50	0.01	2.01
C60-0.5	--	--	bd	bd	8.20	0.20	2.90	0.06	2.56	0.06	1.36	0.03	0.35
C61-1.5	--	--	bd	bd	13.50	0.33	18.70	0.36	3.40	0.08	3.24	0.08	0.84
C63-3.5	--	--	bd	bd	9.10	0.22	70.40	1.36	1.40	0.03	0.00	0.00	1.61
C80-0.5	--	--	7310.00	79.61	43492.0	1184.12	9354.00	203.74	67140.00	1681.73	20180.00	549.43	3698.63
C81-1.5	--	--	bd	bd	0.60	0.02	6.00	0.14	226.00	6.10	60.50	1.77	8.03
C83-3.5	--	--	bd	bd	9.30	0.24	80.30	1.66	198.00	4.70	1.50	0.04	6.64
C100-0.5	--	--	34.10	0.39	19.80	0.56	14.30	0.33	27.30	0.72	3.60	0.10	2.10
C101-1.5	--	--	27.20	0.27	11.40	0.28	4.60	0.09	157.00	3.57	2.42	0.06	4.27
C103-3.5	--	--	29.50	0.32	17.60	0.47	bd	bd	2.00	0.05	3.20	0.09	0.92

Table 1-1. Copper (continued)

Sample	EX sol'n µg/L	EX sed mg/kg	WAS sol'n µg/L	WAS sed mg/kg	ER sol'n µg/L	ER sed mg/kg	MR sol'n µg/L	MR sed mg/kg	OX1 sol'n µg/L	OX1 sed mg/kg	OX2 sol'n µg/L	OX2 sed mg/kg	Total sed mg/kg
C120-0.5	--	--	bd	bd	31.50	0.87	6.50	0.14	178.00	4.55	4.92	0.14	5.70
C121-1.5	--	--	bd	bd	10.10	0.25	29.90	0.59	4.10	0.09	3.00	0.07	1.00
C123-3.5	--	--	bd	bd	9.80	0.29	84.10	1.97	6.70	0.18	2.74	0.08	2.51
C140-0.5	--	--	51.30	0.61	320.00	9.44	120.00	2.83	495.00	13.44	24.00	0.71	27.03
C141-1.5	--	--	bd	bd	28.50	0.75	100.00	2.10	25.20	0.61	2.50	0.07	3.52
C143-3.5	--	--	12.80	0.15	18.50	0.52	160.00	3.63	4.80	0.13	4.36	0.12	4.55
C160-0.5	--	--	bd	bd	128.60	3.79	37.50	0.88	231.00	6.26	9.00	0.26	11.19
D50-0.5	--	--	bd	bd	40.20	0.98	8.70	0.17	227.00	5.08	6.38	0.16	6.39
D51-1.5	--	--	bd	bd	8.00	0.21	3.90	0.08	197.00	4.86	bd	bd	5.15
D53-3.5	--	--	8.10	0.09	24.80	0.71	145.10	3.32	203.00	5.34	3.00	0.09	9.55
D70-0.5	--	--	71.90	0.81	230.00	6.44	17.20	0.39	265.00	6.83	14.50	0.41	14.87
D71-1.5	--	--	bd	bd	235.30	5.70	10.00	0.19	189.00	4.22	1.50	0.04	10.15
D73-3.5	--	--	bd	bd	31.30	0.92	51.00	1.20	201.00	5.45	8.40	0.25	7.83
D90-0.5	--	--	bd	bd	25.50	0.66	4.30	0.09	190.00	4.50	1.00	0.03	5.27
D91-1.5	--	--	bd	bd	5.60	0.16	11.70	0.26	212.00	5.40	5.58	0.15	5.97
D93-3.5	--	--	bd	bd	31.5	0.9	52.6	1.2	205.7	5.4	2.3	0.1	7.5
D110-0.5	--	--	bd	bd	24.70	0.58	67.50	1.28	205.00	4.45	2.54	0.06	6.37
D111-1.5	--	--	6.10	0.06	20.40	0.53	160.00	3.32	184.00	4.39	0.50	0.01	8.31
D113-3.5	--	--	bd	bd	5.90	0.15	47.20	0.94	189.00	4.33	0.00	0.00	5.41
D130-0.5	--	--	bd	bd	60.50	1.59	13.70	0.29	45.50	1.10	3.08	0.08	3.07
D131-1.5	--	--	bd	bd	4.80	0.11	27.30	0.52	bd	bd	2.40	0.06	0.69
D133-3.5	--	--	bd	bd	12.10	0.34	65.30	1.46	bd	bd	3.82	0.11	1.90

Table I-1. Copper (continued)

Sample	EX sol'n µg/L	EX sed mg/kg	WAS sol'n µg/L	WAS sed mg/kg	ER sol'n µg/L	ER sed mg/kg	MR sol'n µg/L	MR sed mg/kg	OX1 sol'n µg/L	OX1 sed mg/kg	OX2 sol'n µg/L	OX2 sed mg/kg	Total sed mg/kg
D150-0.5	--	--	42.10	0.46	120.00	3.29	48.70	1.07	35.20	0.89	9.50	0.26	5.96
D151-1.5	--	--	166.50	1.66	240.00	5.98	150.00	2.99	10.50	0.24	11.50	0.29	11.16
D153-3.5	--	--	20.60	0.21	16.60	0.43	78.80	1.63	bd	bd	4.92	0.13	2.40
D170-0.5	--	--	232.10	3.61	500.00	19.42	410.00	12.74	2510.00	89.71	174.00	6.76	132.24
D171-1.5	--	--	90.30	1.32	160.00	5.86	240.00	7.03	2220.00	74.74	3.92	0.14	89.09
D173-3.5	--	--	20.00	0.24	47.70	1.42	30.30	0.72	47.10	1.29	21.00	0.62	4.29
D190-0.5	--	--	bd	bd	820.00	25.24	320.00	7.88	1070.00	30.31	65.00	2.00	65.43
D191-1.5	--	--	147.30	2.79	1100.00	52.13	1490.00	56.49	9880.00	430.80	1495.00	70.86	613.08
D193-3.5	--	--	bd	bd	470.00	13.98	81.70	1.94	900.00	24.64	43.00	1.28	41.84
E140-0.5	--	--	79.80	0.84	190.00	4.99	53.50	1.12	32.10	0.78	15.50	0.41	8.14
E141-1.5	--	--	bd	bd	23.80	0.68	11.10	0.25	bd	bd	3.16	0.09	1.02
E143-3.5	--	--	bd	bd	19.80	0.54	59.60	1.30	bd	bd	1.00	0.03	1.86
E160-0.5	--	--	21.00	0.32	66.90	2.52	17.10	0.52	400.00	13.86	17.00	0.64	17.86
E161-1.5	--	--	17.10	0.33	44.90	2.14	15.30	0.58	290.00	12.69	49.00	2.33	18.07
E163-3.5	--	--	115.10	2.74	501.80	29.89	11.50	0.55	360.00	19.73	17.50	1.04	53.94
E180-0.5	--	--	226.90	3.32	660.00	24.18	320.00	9.38	750.00	25.28	501.50	18.37	80.52
E181-1.5	--	--	1940.00	47.26	1050.00	63.95	110.00	5.36	1390.00	77.88	274.00	16.69	211.13
E200-0.5	--	--	bd	bd	240.00	6.82	20.80	0.47	240.00	6.28	21.50	0.61	14.18
E201-1.5	--	--	bd	bd	88.70	2.18	18.40	0.36	200.00	4.52	15.50	0.38	7.45
F130-0.5	--	--	9.70	0.10	38.20	0.94	6.00	0.12	6.00	0.14	5.50	0.13	1.42
F131-1.5	--	--	0.00	0.00	9.90	0.25	63.80	1.29	1.80	0.04	3.80	0.10	1.68

Table I-1. Copper (continued)

Sample	EX sol'n µg/L	EX sed mg/kg	WAS sol'n µg/L	WAS sed mg/kg	ER sol'n µg/L	ER sed mg/kg	MR sol'n µg/L	MR sed mg/kg	OX1 sol'n µg/L	OX1 sed mg/kg	OX2 sol'n µg/L	OX2 sed mg/kg	Total sed mg/kg
F133-3.5	--	--	29.00	0.31	23.30	0.63	220.00	4.76	3.10	0.08	3.16	0.09	5.86
F150-0.5	--	--	bd	bd	370.00	14.09	100.00	3.05	680.00	23.83	10.50	0.40	41.37
F151-1.5	--	--	54.70	0.54	290.00	7.14	36.50	0.72	250.00	5.66	1.00	0.02	14.09
F153-3.5	--	--	49.00	0.52	36.60	0.96	180.00	3.79	4.10	0.10	0.50	0.01	5.38
F170-0.5	--	--	97.50	1.22	470.00	14.72	220.00	5.51	590.00	17.00	5.90	0.18	38.64
F171-1.5	--	--	bd	bd	bd	bd	19.50	0.42	bd	bd	1.76	0.05	0.47
F173-3.5	--	--	bd	bd	16.0	0.5	69.9	1.6	bd	bd	1.4	0.0	2.1
F190-0.5	--	--	bd	bd	83.90	2.33	28.50	0.63	220.00	5.63	4.50	0.13	8.72
F191-1.5	--	--	bd	bd	10.80	0.28	35.60	0.75	0.00	0.00	0.50	0.01	1.04
F193-3.5	--	--	22.60	0.25	16.00	0.45	170.00	3.82	bd	bd	2.50	0.07	4.60
F210-0.5	--	--	bd	bd	21.40	0.60	74.70	1.68	bd	bd	4.32	0.12	2.40
F211-1.5	--	--	bd	bd	29.90	0.74	160.00	3.17	4.00	0.09	2.50	0.06	4.06
F213-3.5	--	--	bd	bd	45.30	1.13	100.00	2.00	13.80	0.32	5.04	0.13	3.58
G140-0.5	--	--	bd	bd	280.00	10.61	47.10	1.43	85.20	2.97	4.50	0.17	15.18
G141-1.5	--	--	bd	bd	130.00	5.36	33.10	1.09	410.00	15.55	24.50	1.01	23.01
G143-3.5	--	--	bd	bd	41.30	1.08	5.90	0.12	13.80	0.33	5.50	0.14	1.67
G160-0.5	--	--	bd	bd	15.00	2.27	28.20	3.41	390.00	54.20	5.50	0.83	60.71
G161-1.5	--	--	bd	bd	150.00	5.95	90.00	2.86	640.00	23.37	31.00	1.23	33.41
G163-3.5	--	--	bd	bd	3.10	0.11	36.20	1.03	420.00	13.79	23.00	0.82	15.76
G180-0.5	--	--	bd	bd	160.00	4.66	59.20	1.38	310.00	8.31	13.00	0.38	14.73
G181-1.5	--	--	bd	bd	bd	bd	190.00	4.20	11.40	0.29	4.00	0.11	4.60

Table I-1. Copper (continued)

Sample	EX µg/L	EX mg/kg	WAS µg/L	WAS sed	WAS mg/kg	ER µg/L	ER sed	ER mg/kg	MR µg/L	MR sed	MR mg/kg	OX1 µg/L	OX1 sed	OX1 mg/kg	OX2 µg/L	OX2 sed	OX2 mg/kg	Total sed	Total mg/kg
G183-3.5	--	--	bd	bd	bd	24.00	0.62	220.00	4.53	0.17	3.00	0.08	5.39						
G200-0.5	--	--	bd	bd	bd	31.90	0.96	10.80	0.26	16.50	0.46	3.54	0.11	1.78					
G201-1.5	--	--	bd	bd	bd	52.60	1.37	100.00	2.08	5.20	0.12	2.00	0.05	3.63					
G203-3.5	--	--	bd	bd	bd	13.00	0.35	100.00	2.15	4.30	0.11	1.56	0.04	2.65					
G220-0.5	--	--	bd	bd	bd	160.00	4.51	110.00	2.48	99.50	2.58	7.00	0.20	9.76					
G221-1.5	--	--	bd	bd	bd	100.00	2.71	43.80	0.95	45.20	1.13	8.50	0.23	5.02					
G223-3.5	--	--	bd	bd	bd	16.70	0.45	190.00	4.11	0.00	0.00	2.30	0.06	4.63					
H150-0.5	--	--	bd	bd	bd	400.00	18.84	130.00	4.90	440.00	19.07	5.00	0.24	43.04					
H151-1.5	--	--	bd	bd	bd	320.00	13.30	47.30	1.57	420.00	16.06	21.00	0.87	31.80					
H153-3.5	--	--	bd	bd	bd	110.00	5.05	5.50	0.20	640.00	27.03	23.00	1.06	33.34					
H170-0.5	--	--	4410.00	112.68	3440.00	219.73	220.00	11.24	710.00	41.72	15.50	0.99	386.36						
H171-1.5	--	--	bd	bd	bd	210.00	25.23	49.10	4.72	540.00	59.69	9.00	1.08	90.72					
H173-3.5	--	--	bd	bd	bd	45.80	1.48	43.50	1.12	360.00	10.69	13.00	0.42	13.71					
H190-0.5	--	--	bd	bd	bd	450.00	15.77	140.00	3.93	960.00	30.96	52.50	1.84	52.50					
H191-1.5	--	--	bd	bd	bd	800.00	42.07	310.00	13.04	1590.00	76.93	47.50	2.50	134.54					
H193-3.5	--	--	bd	bd	bd	220.00	26.56	120.00	11.59	690.00	76.63	19.50	2.35	117.12					
H210-0.5	--	--	bd	bd	bd	2.30	0.05	190.00	3.49	bd	bd	2.70	0.06	3.60					
H211-1.5	--	--	bd	bd	bd	160.00	7.36	100.00	3.68	400.00	16.92	7.50	0.34	28.30					
H213-3.5	--	--	bd	bd	bd	17.60	0.46	190.00	3.97	4.20	0.10	3.16	0.08	4.62					
H230-0.5	--	--	bd	bd	bd	76.0	2.2	32.4	0.8	0.8	29.8	11.7	0.3	4.1					
H233-3.5	--	--	bd	bd	bd	36.30	1.04	160.00	3.68	2.30	0.06	1.24	0.04	4.82					

Table I-1. Copper (continued)

Sample	EX sol'n µg/L	EX sed mg/kg	WAS sol'n µg/L	WAS sed mg/kg	ER sol'n µg/L	ER sed mg/kg	MR sol'n µg/L	MR sed mg/kg	OX1 sol'n µg/L	OX1 sed mg/kg	OX2 sol'n µg/L	OX2 sed mg/kg	Total sed mg/kg
I200-0.5	--	--	117.70	2.99	560.00	35.62	380.00	19.34	1020.00	59.69	38.50	2.45	120.08
I201-1.5	--	--	239.70	9.02	910.00	85.64	390.00	29.36	890.00	77.06	133.50	12.56	213.64
I203-3.5	--	--	bd	bd	13.90	2.13	4.40	0.54	460.00	65.00	34.00	5.22	72.90
I220-0.5	--	--	bd	bd	13.90	1.07	41.90	2.59	1370.00	97.22	69.00	5.32	106.20
I221-1.5	--	--	bd	bd	1.10	0.12	27.90	2.41	830.00	82.58	40.00	4.33	89.44
I223-3.5	--	--	18.50	0.23	12.40	0.38	17.80	0.44	5.70	0.16	1.24	0.04	1.25
I240-0.5	--	--	bd	bd	79.60	2.65	16.00	0.43	70.20	2.15	7.50	0.25	5.48
I241-1.5	--	--	bd	bd	43.30	1.33	120.00	2.94	17.80	0.50	5.12	0.16	4.93
I243-3.5	--	--	bd	bd	91.20	2.62	160.00	3.68	11.50	0.30	4.50	0.13	6.74
I260-0.5	--	--	bd	bd	260.00	7.43	130.00	2.97	730.00	19.19	49.00	1.40	30.99
I261-1.5	--	--	bd	bd	373.3	10.0	96.7	2.10	405.00	9.90	3.3	0.1	22.0
J190-0.5	--	--	bd	bd	136.7	11.4	176.7	11.8	510.00	39.20	36.0	3.0	65.8
J191-1.5	--	--	bd	bd	1070.00	91.38	120.00	8.20	1430.00	112.35	436.40	37.27	249.20
J193-3.5	--	--	bd	bd	48.80	4.15	0.90	0.06	1840.00	144.00	31.96	2.72	150.94
J210-0.5	--	--	bd	bd	110.00	3.34	0.00	0.00	330.00	9.23	5.50	0.17	12.74
J211-1.5	--	--	bd	bd	76.50	2.00	34.10	0.71	300.00	7.21	5.50	0.14	10.06
J230-0.5	--	--	bd	bd	68.70	11.04	54.50	7.01	1070.00	158.17	72.50	11.65	187.87
J231-1.5	--	--	bd	bd	3.40	0.40	bd	bd	3000.00	321.74	851.00	99.20	421.34
J233-3.5	--	--	42.10	0.44	51.20	1.33	20.70	0.43	300.00	7.18	3.14	0.08	9.46
J250-0.5	--	--	bd	bd	810.00	30.70	180.00	5.46	2233.10	77.86	51.00	1.93	115.95
J251-1.5	--	--	bd	bd	11.10	0.90	230.00	14.89	123.20	9.17	9.50	0.77	25.74

Table I-1. Copper (continued)

Sample	EX sol'n µg/L	EX sed mg/kg	WAS sol'n µg/L	WAS sed mg/kg	ER sol'n µg/L	ER sed mg/kg	MR sol'n µg/L	MR sed mg/kg	OX1 sol'n µg/L	OX1 sed mg/kg	OX2 sol'n µg/L	OX2 sed mg/kg	Total sed mg/kg
J253-3.5	--	--	bd	bd	40.30	1.05	0.80	0.02	59.20	1.42	4.50	0.12	2.61
J270-0.5	--	--	bd	bd	58.70	1.89	510.00	13.10	405.90	11.99	13.00	0.42	27.40
J271-1.5	--	--	bd	bd	45.80	1.26	60.50	1.33	10.90	0.28	0.50	0.01	2.88
K200-0.5	--	--	bd	bd	48.50	7.13	350.00	41.13	237.90	32.15	2.50	0.37	80.78
K203-3.5	--	--	bd	bd	63.50	2.05	250.00	6.46	144.30	4.29	11.50	0.37	13.17
K220-0.5	--	--	bd	bd	24.70	19.02	410.00	252.52	318.60	225.66	16.04	12.35	509.54
K221-1.5	--	--	10.50	0.50	101.10	11.95	240.00	22.70	143.60	15.62	7.00	0.83	51.60
K223-3.5	--	--	0.00	0.00	19.50	0.45	20.90	0.39	13.20	0.28	3.00	0.07	1.19
K240-0.5	--	--	15.90	0.65	200.00	20.49	170.00	13.93	840.40	79.20	20.50	2.10	116.37
K241-1.5	--	--	bd	bd	3.10	0.35	39.50	3.55	340.70	35.17	16.00	1.80	40.86
K243-3.5	--	--	43.80	0.47	33.20	0.89	32.90	0.71	17.20	0.42	4.00	0.11	2.60
K260-0.5	--	--	bd	bd	530.00	17.86	71.00	1.91	337.80	10.48	20.36	0.69	30.94
K261-1.5	--	--	bd	bd	25.80	2.94	280.00	25.54	192.30	20.17	5.20	0.59	49.24
K263-3.5	--	--	bd	bd	100.00	4.47	400.00	14.30	333.80	13.73	26.88	1.20	33.70
K280-0.5	--	--	bd	bd	31.00	1.75	390.00	17.65	314.00	16.34	17.56	0.99	36.73
K281-1.5	--	--	bd	bd	128.30	10.69	520.00	34.66	451.40	34.60	40.80	3.40	83.35
L210-0.5	--	--	495.20	5.23	790.00	20.86	640.00	13.52	360.00	8.74	29.80	0.79	49.13
L211-1.5	--	--	12.90	0.14	60.50	1.59	20.20	0.43	98.50	2.39	3.82	0.10	4.64
L230-0.5	--	--	5.60	0.38	62.60	10.66	14.40	1.96	159.60	25.02	5.36	0.91	38.94
L231-1.5	--	--	bd	bd	120.00	18.41	30.10	3.69	260.00	36.70	4.04	0.62	59.43
L233-3.5	--	--	bd	bd	70.20	1.89	0.00	0.00	24.10	0.60	10.80	0.29	2.78

Table I-1. Copper (continued)

Sample	EX sol'n µg/L	EX mg/kg sed	WAS sol'n µg/L	WAS mg/kg sed	ER sol'n µg/L	ER mg/kg sed	MR sol'n µg/L	MR mg/kg sed	OX1 sol'n µg/L	OX1 mg/kg sed	OX2 sol'n µg/L	OX2 mg/kg sed	Total sed mg/kg
L250-0.5	--	--	bd	bd	90.00	2.38	41.50	0.88	80.90	1.97	5.68	0.15	5.38
L251-1.5	--	--	bd	bd	31.70	3.07	15.80	1.23	350.00	31.21	4.20	0.41	35.91
L253-3.5	--	--	bd	bd	26.6	2.6	11.4	0.9	283.30	25.4	5.1	0.5	29.4
L270-0.5	--	--	bd	bd	30.50	3.88	5.30	0.54	280.00	32.73	4.24	0.54	37.68
L271-1.5	--	--	bd	bd	28.80	1.69	11.00	0.52	90.00	4.87	6.68	0.39	7.48
L273-3.5	--	--	bd	bd	16.56	0.44	237.60	5.10	46.50	1.15	38.04	1.02	7.71
M200-0.5	--	--	10.20	0.12	74.10	2.12	28.40	0.65	41.70	1.10	3.60	0.10	4.09
M201-1.5	--	--	bd	bd	25.80	1.41	4.50	0.20	75.30	3.79	6.10	0.33	5.73
M220-0.5	--	--	8.80	0.16	77.00	3.52	10.40	0.38	240.00	10.08	6.44	0.29	14.43
M221-1.5	--	--	6.40	0.09	97.90	3.59	83.00	2.43	270.00	9.10	5.88	0.22	15.43
M223-3.5	--	--	3.40	0.04	64.60	1.71	0.00	0.00	37.80	0.92	8.04	0.21	2.88
M240-0.5	--	--	23.50	0.56	100.00	5.91	35.50	1.68	720.00	39.16	25.44	1.50	48.81
M241-1.5	--	--	bd	bd	32.30	3.92	8.50	0.83	530.00	59.25	8.80	1.07	65.07
M243-3.5	--	--	bd	bd	12.90	0.36	18.80	0.42	bd	bd	2.40	0.07	0.86
M260-0.5	--	--	43.50	0.99	250.00	14.27	65.40	2.99	940.00	49.37	49.76	2.84	70.47
M261-1.5	--	--	bd	bd	86.30	5.99	28.10	1.56	470.00	30.00	16.16	1.12	38.66
M280-0.5	--	--	28.50	0.62	250.00	13.65	49.70	2.17	450.00	22.60	14.08	0.77	39.81
M281-1.5	--	--	13.40	0.26	90.00	4.31	15.80	0.61	87.60	3.86	20.20	0.97	10.01
M283-3.5	--	--	10.80	0.12	61.90	1.74	90.00	2.02	12.20	0.32	6.16	0.17	4.37
N210-0.5	--	--	bd	bd	50.10	4.50	34.60	2.48	400.00	33.02	15.84	1.42	41.42
N211-1.5	--	--	bd	bd	18.40	1.42	10.80	0.67	310.00	21.97	32.80	2.53	26.58

Table I-1. Copper (continued)

Sample	EX sol'n µg/L	EX sed mg/kg	WAS sol'n µg/L	WAS sed mg/kg	ER sol'n µg/L	ER sed mg/kg	MR sol'n µg/L	MR sed mg/kg	OX1 sol'n µg/L	OX1 sed mg/kg	OX2 sol'n µg/L	OX2 sed mg/kg	Total sed mg/kg
N230-0.5	--	--	8.90	0.51	72.40	10.39	28.60	3.28	380.00	50.16	5.48	0.79	65.13
N231-1.5	--	--	bd	bd	49.80	1.48	22.90	0.54	24.20	0.66	7.20	0.21	2.90
N233-3.5	--	--	bd	bd	42.00	1.34	24.30	0.62	37.30	1.09	8.88	0.28	3.33
N250-0.5	--	--	14.40	0.17	93.90	2.73	14.20	0.33	60.60	1.62	8.36	0.24	5.09
N251-1.5	--	--	bd	bd	20.40	1.19	3.30	0.15	82.70	4.43	4.00	0.23	6.00
N253-3.5	--	--	bd	bd	61.70	1.88	20.40	0.50	75.30	2.11	14.32	0.44	4.93
O220-0.5	--	--	5.90	0.21	140.00	12.20	130.00	9.06	610.00	48.89	7.28	0.63	70.99
O221-1.5	--	--	43.2	1.6	396.7	37.9	163.3	12.5	436.70	38.4	13.8	1.3	91.8
O223-3.5	--	--	bd	bd	36.90	1.21	46.80	1.23	310.00	9.38	22.80	0.75	12.57
O240-0.5	--	--	34.10	1.60	250.00	29.39	63.00	5.92	440.00	47.58	13.08	1.54	86.03
O241-1.5	--	--	17.90	0.38	110.00	5.91	110.00	4.73	440.00	21.76	13.80	0.74	33.54
O243-3.5	--	--	19.90	0.27	90.00	3.10	36.00	0.99	74.80	2.37	12.20	0.42	7.16
P230-0.5	--	--	36.50	1.93	450.00	59.61	150.00	15.90	620.00	75.56	13.52	1.79	154.79
P231-1.5	--	--	bd	bd	11.40	0.37	8.60	0.22	220.00	6.51	30.52	0.98	8.08
P233-3.5	--	--	--	--	42.1	1.5	32.1	0.9	330.00	10.60	22.3	0.8	13.7
P250-0.5	--	--	bd	bd	90.00	13.59	30.00	3.62	350.00	48.62	7.00	1.06	66.90
P251-1.5	--	--	5.60	0.26	75.40	8.84	12.80	1.20	320.00	34.52	7.96	0.93	45.76
P253-3.5	--	--	bd	bd	13.30	0.41	5.80	0.14	21.30	0.61	5.12	0.16	1.33
Q240-0.5	--	--	17.90	0.46	120.00	7.67	100.00	5.12	1120.00	65.90	26.72	1.71	80.85
Q241-1.5	--	--	12.2	0.3	120.0	8.2	45.2	2.5	320.00	20.00	12.1	0.8	31.8
Q243-3.5	--	--	bd	bd	54.50	3.47	28.80	1.47	470.00	27.55	20.16	1.28	33.77

Table I-1. Copper (continued)

Sample	EX sol'n µg/L	EX sed mg/kg	WAS sol'n µg/L	WAS sed mg/kg	ER sol'n µg/L	ER sed mg/kg	MR sol'n µg/L	MR sed mg/kg	OX1 sol'n µg/L	OX1 sed mg/kg	OX2 sol'n µg/L	OX2 sed mg/kg	Total sed mg/kg
Q260-0.5	--	--	bd	bd	610.00	18.68	32.00	0.78	2120.00	59.74	159.40	4.88	84.09
R250-0.5	--	--	bd	bd	170.00	15.07	90.00	6.38	410.00	33.43	7.64	0.68	56.27
R251-1.5	--	--	11.30	0.23	90.00	4.49	90.00	3.59	400.00	18.37	11.56	0.58	27.27
R253-3.5	--	--	10.30	0.12	90.00	2.73	42.80	1.04	250.00	6.98	21.80	0.66	11.53
R270-0.5	--	--	bd	bd	73.80	7.00	24.20	1.84	540.00	47.10	14.12	1.34	57.27
R271-1.5	--	--	bd	bd	53.20	7.17	49.70	5.36	450.00	55.80	15.16	2.04	70.37
R273-3.5	--	--	bd	bd	91.00	7.64	11.70	0.79	260.00	20.09	22.16	1.86	30.38
S260-0.5	--	--	34.40	0.91	280.00	18.44	140.00	7.37	830.00	50.28	17.60	1.16	78.16
S261-1.5	--	--	bd	bd	30.50	3.78	70.10	6.94	330.00	37.60	4.12	0.51	48.83
T270-0.5	--	--	26.50	0.67	180.00	11.33	130.00	6.55	550.00	31.86	24.04	1.51	51.92
T271-1.5	--	--	13.00	0.54	150.00	15.53	15.30	1.27	450.00	42.86	8.08	0.84	61.04
U260-0.5	--	--	38.10	0.40	82.50	2.14	100.00	2.08	16.60	0.40	7.52	0.20	5.21
U261-1.5	--	--	19.40	0.22	140.00	3.96	110.00	2.49	300.00	7.81	21.40	0.61	15.09
U263-3.5	--	--	bd	bd	84.80	2.41	90.00	2.05	92.70	2.42	19.16	0.54	7.43

Appendix I

Table I-2. Replicate Sample Analysis for Copper

sed indicates concentration in sediment (dry weight basis)
indicates the average of three replicate samples. RSD indicates the relative standard
deviation of the three replicates. SRM 2704 is NIST Buffalo River Sediment

Sample	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
B3a0-0.5	--	bd	0.8	0.2	bd	0.1	1.1
B3b0-0.5	--	bd	0.8	0.4	bd	0.0	1.3
B3c0-0.5	--	bd	0.6	0.7	bd	0.0	1.4
	--	--	0.7	0.5	--	0.0	1.2
RSD	--	--	13.9	55.3	--	30.0	14.0
B9a0-0.5	--	0.3	1.3	0.3	0.2	0.1	2.1
B9b0-0.5	--	0.2	1.2	0.3	0.2	0.1	1.8
B9c0-0.5	--	0.2	3.7	0.3	0.2	bd	4.4
	--	0.2	2.1	0.3	0.2	0.1	2.8
RSD	--	35.6	69.8	12.8	13.8	25.1	49.9
B13a1-1.5	--	bd	0.2	0.1	bd	0.3	0.6
B13b1-1.5	--	bd	0.1	0.1	bd	bd	0.3
B13c1-1.5	--	bd	0.1	0.1	bd	bd	0.3
	--	--	0.2	0.1	--	0.3	0.4
RSD	--	--	10.6	3.7	--	bd	50.4

Table I-2. Copper (continued)

Sample	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
D9a3-3.5	--	bd	1.0	1.1	5.3	0.1	7.5
D9b3-3.5	--	bd	0.9	1.1	5.4	0.1	7.5
D9c3-3.5	--	bd	0.8	1.3	5.4	0.1	7.6
	--	--	0.9	1.2	5.4	0.1	7.5
RSD	--	--	14.6	7.5	1.5	14.1	0.4
H23a0-0.5	--	bd	2.3	0.8	0.7	0.6	4.3
H23b0-0.5	--	bd	2.1	0.8	0.9	0.3	4.1
H23c0-0.5	--	bd	2.3	0.7	0.8	0.2	4.0
	--	--	2.2	0.8	0.8	0.3	4.1
RSD	--	--	4.1	7.0	9.9	57.9	4.2
I26a1-1.5	--	bd	10.2	2.1	10.8	0.1	23.2
I26b1-1.5	--	bd	9.6	2.1	10.0	0.1	21.8
I26c1-1.5	--	bd	10.2	2.0	8.9	0.1	21.1
	--	--	10.0	2.1	9.9	0.1	22.0
RSD	--	--	3.4	4.0	10.1	18.2	5.0

Table 1-2. Copper (continued)

Sample	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
J19a0-0.5	--	1.1	10.9	10.7	37.7	2.3	62.6
J19b0-0.5	--	bd	12.1	12.9	39.3	3.3	67.6
J19c0-0.5	--	bd	11.3	11.8	40.7	3.5	67.3
	--	--	11.4	11.8	39.2	3.0	65.8
RSD	--	--	5.4	9.3	3.9	21.6	4.2
L25a3-3.5	--	bd	2.9	0.8	27.0	0.3	31.0
L25b3-3.5	--	bd	1.9	0.7	23.6	1.0	27.3
L25c3-3.5	--	bd	2.9	1.1	25.5	0.3	29.7
	--	--	2.6	0.9	25.4	0.5	29.4
RSD	--	--	21.0	25.6	6.7	83.6	6.5
O22a1-1.5	--	1.7	35.7	12.4	38.2	1.5	89.5
O22b1-1.5	--	1.3	37.7	12.4	37.3	1.2	89.8
O22c1-1.5	--	2.0	40.4	12.8	39.8	1.2	96.1
	--	1.6	37.9	12.5	38.4	1.3	91.8
RSD	--	21.8	6.2	1.9	3.2	15.1	4.0

Table I-2. Copper (continued)

Sample	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
P23a3-3.5	--	bd	0.8	1.0	10.8	1.0	13.6
P23b3-3.5	--	bd	1.4	0.8	10.9	0.5	13.7
P23c3-3.5	--	bd	2.1	0.9	9.9	0.8	13.8
	--	--	1.5	0.9	10.6	0.8	13.7
RSD	--	--	43.9	7.1	5.3	31.5	0.4
Q24a1-1.5	--	0.4	8.2	2.6	20.2	1.1	32.6
Q24b1-1.5	--	0.3	8.0	2.1	20.3	0.8	31.5
Q24c1-1.5	--	0.2	8.2	2.7	19.6	0.6	31.3
	--	0.3	8.2	2.5	20.0	0.8	31.8
RSD	--	26.5	1.5	13.5	2.0	31.1	2.2
SRM27042/3/97	--	2.4	35.9	5.7	20.9	0.3	65.2
SRM27042/17/97	--	2.2	36.2	6.4	20.4	0.2	65.4
SRM27042/24/97	--	1.7	32.1	6.0	24.4	0.3	64.4
SRM27043/10/97	--	2.4	36.5	6.0	21.5	0.2	66.6
SRM27043/24/97	--	1.1	35.7	6.9	23.7	0.2	66.6
SRM27044/7/97	--	2.6	39.1	6.0	19.0	0.2	67.0
		2.1	35.9	6.2	21.6	0.2	65.9
RSD		28.0	6.2	6.4	9.4	16.4	1.5

Appendix J

Table J-1. Sequential Chemical Extraction Data for Zinc

sol'n indicates concentration detected in leachate solution, mg/L

sed indicates concentration in sediment, mg/kg (dry weight basis)

bd indicates below detection, -- indicates not measured

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
B3a0-0.5	0.03	0.34	0.01	0.10	bd	bd	0.44	8.85	0.00	0.00	0.13	3.27	12.66
B3b0-0.5	0.15	1.70	0.04	0.39	bd	bd	0.10	2.14	0.00	0.00	0.01	0.25	4.58
B3c0-0.5	1.33	12.81	0.01	0.10	bd	bd	0.16	3.01	0.00	0.00	0.01	0.22	16.13
B31-1.5	1.37	14.57	0.06	0.64	0.30	8.06	0.26	5.45	0.20	4.98	bd	bd	33.69
B33-3.5	0.01	0.14	0.01	0.10	bd	bd	0.16	3.19	0.05	1.26	0.02	0.48	5.17
B50-0.5	0.49	4.86	0.06	0.59	0.09	2.31	0.36	7.02	0.01	0.18	0.10	2.43	17.39
B51-1.5	bd	bd	bd	bd	0.09	2.55	0.23	4.92	bd	bd	0.05	1.33	8.79
B53-3.5	bd	bd	bd	bd	bd	bd	0.22	5.13	bd	bd	0.03	0.86	5.99
B70-0.5	0.09	0.90	0.19	1.77	bd	bd	0.04	0.71	0.01	0.18	bd	bd	3.55
B71-1.5	bd	bd	0.04	0.35	0.01	0.35	0.02	0.34	bd	bd	bd	bd	1.03
B73-3.5	0.13	1.47	0.11	1.20	bd	bd	bd	bd	bd	bd	bd	bd	2.67
B9a0-0.5	0.05	0.57	bd	bd	0.19	5.11	0.29	6.05	bd	bd	bd	bd	11.73
B9b0-0.5	bd	bd	bd	bd	0.19	5.36	0.26	5.68	0.03	0.71	bd	bd	11.75
B9c0-0.5	0.03	0.36	bd	bd	0.14	3.76	0.28	5.79	0.19	4.52	bd	bd	14.43
B91-1.5	0.11	1.22	0.04	0.38	0.03	0.91	0.66	14.10	bd	bd	bd	bd	16.61
B93-3.5	0.01	0.15	0.19	1.98	bd	bd	0.02	0.36	bd	bd	bd	bd	2.49
B110-0.5	1.57	19.30	0.36	4.41	0.23	7.17	bd	bd	0.11	3.21	0.04	1.20	35.29
B111-1.5	bd	bd	0.11	1.22	bd	bd	0.04	0.82	0.03	0.71	bd	bd	2.75

Table J-1. Zinc (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
B113-3.5	0.03	0.39	0.09	0.97	bd	bd	0.12	2.67	bd	bd	bd	bd	4.03
B130-0.5	bd	bd	0.14	1.45	0.05	1.45	0.09	1.86	0.16	4.04	bd	bd	8.80
B13a1-1.5	bd	bd	0.04	0.37	bd	bd	0.19	3.91	bd	bd	bd	bd	4.27
B13b1-1.5	bd	bd	0.09	0.95	bd	0.11	0.30	6.67	0.01	0.21	bd	bd	7.94
B13c1-1.5	bd	bd	0.04	0.40	bd	bd	0.25	5.71	bd	bd	bd	bd	6.11
B133-3.5	bd	bd	0.09	0.89	0.04	1.15	0.02	0.36	bd	bd	bd	bd	2.39
B150-0.5	0.33	3.61	0.22	2.38	0.49	13.36	0.33	7.08	bd	bd	bd	bd	26.43
B151-1.5	0.09	1.05	0.77	8.57	1.46	40.73	1.51	33.54	0.07	1.74	0.13	3.59	89.22
B153-3.5	1.75	27.68	32.12	506.84	22.74	896.91	17.95	566.42	0.84	30.63	0.11	4.30	2032.78
B170-0.5	1.23	13.14	1.75	18.59	1.71	45.64	1.70	36.15	0.13	3.28	0.05	1.30	118.11
B171-1.5	bd	bd	bd	bd	0.12	3.13	0.10	1.96	0.01	0.19	bd	bd	5.28
B173-3.5	0.19	4.07	bd	bd	0.21	11.22	0.15	6.16	0.05	2.31	bd	bd	23.76
C20-0.5	0.73	7.79	0.16	1.70	0.19	5.15	0.51	10.76	0.01	0.20	0.15	3.95	29.55
C21-1.5	bd	bd	bd	bd	bd	0.10	0.16	3.01	bd	bd	bd	bd	3.11
C23-3.5	bd	bd	0.19	1.87	0.04	1.11	0.14	2.77	bd	bd	bd	bd	5.75
C40-0.5	0.53	5.80	0.06	0.65	0.08	2.28	0.38	8.19	bd	bd	bd	bd	16.91
C41-1.5	0.31	3.25	bd	bd	0.09	2.43	0.13	2.63	bd	bd	bd	bd	8.31
C43-3.5	bd	bd	0.11	1.06	bd	0.10	0.03	0.52	bd	bd	bd	bd	1.67
C60-0.5	bd	bd	0.19	1.80	0.07	1.80	0.05	0.92	0.11	2.42	bd	bd	6.95
C61-1.5	0.27	2.65	0.09	0.82	0.03	0.82	0.27	5.17	0.01	0.18	bd	bd	9.65
C63-3.5	bd	bd	0.04	0.34	bd	bd	0.04	0.72	0.07	1.51	0.02	0.46	3.03
C80-0.5	4.85	52.86	3.51	38.23	1.34	36.59	12.91	281.15	1.93	48.44	1.74	47.35	504.62

Table J-1. Zinc (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
C81-1.5	0.01	0.16	0.06	0.70	0.04	1.29	0.03	0.63	bd	bd	bd	bd	2.79
C83-3.5	bd	bd	0.01	0.10	bd	bd	bd	bd	bd	bd	bd	bd	0.10
C100-0.5	0.23	2.67	0.21	2.40	0.07	2.11	0.37	8.38	0.21	5.62	0.01	0.26	21.43
C101-1.5	0.01	0.14	bd	bd	bd	bd	0.10	1.92	bd	bd	bd	bd	2.05
C103-3.5	0.03	0.36	0.06	0.64	bd	bd	bd	bd	bd	bd	bd	bd	1.01
C120-0.5	0.15	1.71	0.06	0.67	0.05	1.50	0.49	10.82	0.12	3.17	bd	bd	17.86
C121-1.5	0.09	0.92	0.04	0.34	bd	bd	0.43	8.38	0.01	0.18	bd	bd	9.83
C123-3.5	0.07	0.86	0.06	0.70	0.03	0.99	0.12	2.73	0.05	1.29	bd	bd	6.58
C140-0.5	0.07	0.87	2.24	26.38	1.43	42.32	2.40	56.59	0.13	3.64	0.07	2.04	131.83
C141-1.5	0.03	0.36	0.54	5.62	0.04	1.16	0.05	0.99	bd	bd	bd	bd	8.12
C143-3.5	bd	bd	0.54	6.07	0.04	1.25	0.12	2.65	bd	bd	bd	bd	9.96
C160-0.5	bd	bd	bd	bd	0.11	3.36	0.38	8.88	bd	bd	bd	bd	12.24
D50-0.5	0.11	1.11	0.01	0.10	0.11	2.77	0.29	5.59	0.03	0.63	bd	bd	10.20
D51-1.5	bd	bd	0.01	0.11	bd	bd	0.09	1.86	0.07	1.68	bd	bd	3.65
D53-3.5	bd	bd	0.01	0.11	bd	bd	0.14	3.13	0.03	0.74	bd	bd	3.99
D70-0.5	1.41	15.85	0.31	3.47	0.26	7.40	0.34	7.55	0.03	0.72	0.05	1.37	36.37
D71-1.5	bd	bd	0.04	0.34	0.03	0.82	0.04	0.72	0.05	1.07	0.01	0.22	3.17
D73-3.5	bd	bd	0.04	0.41	bd	bd	0.01	0.17	0.01	0.22	bd	bd	0.80
D90-0.5	0.23	2.41	0.19	1.90	0.14	3.71	0.12	2.41	0.05	1.14	0.04	1.00	12.57
D91-1.5	bd	bd	0.09	0.94	0.01	0.39	bd	bd	0.05	1.22	bd	bd	2.55
D9a3-3.5	0.13	1.49	0.04	0.39	0.01	0.39	0.03	0.60	0.01	0.21	0.01	0.25	3.33
D9b3-3.5	0.05	0.61	0.29	3.20	bd	bd	bd	bd	0.01	0.21	bd	bd	4.01

Table J-1. Zinc (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
D9c3-3.5	bd	bd	0.09	1.00	bd	bd	bd	bd	bd	bd	bd	bd	1.00
D110-0.5	bd	bd	0.06	0.57	0.02	0.57	0.27	5.04	0.05	1.04	bd	bd	7.22
D111-1.5	0.03	0.35	0.09	0.88	bd	bd	0.22	4.50	0.03	0.67	bd	bd	6.40
D113-3.5	bd	bd	0.06	0.60	0.06	1.59	0.05	0.94	0.03	0.64	0.01	0.22	3.99
D130-0.5	0.09	0.99	bd	bd	0.08	2.21	0.65	13.64	0.22	5.43	bd	bd	22.27
D131-1.5	0.19	1.86	0.06	0.57	bd	bd	0.27	5.11	0.03	0.62	bd	bd	8.15
D133-3.5	0.07	0.83	0.06	0.67	0.04	1.23	0.13	2.84	0.05	1.23	bd	bd	6.80
D150-0.5	0.05	0.59	0.36	3.94	0.22	6.13	0.26	5.63	0.01	0.20	bd	bd	16.50
D151-1.5	0.09	0.94	0.61	6.08	0.24	6.08	0.79	15.69	0.01	0.18	bd	bd	28.98
D153-3.5	0.07	0.76	0.41	4.23	0.03	0.88	0.27	5.52	0.01	0.19	bd	bd	11.58
D170-0.5	12.99	201.82	27.82	432.30	21.18	822.65	7.95	247.01	0.69	24.80	0.25	9.67	1738.27
D171-1.5	0.17	2.55	1.27	18.59	2.06	75.24	0.59	17.21	0.17	5.86	bd	bd	119.45
D173-3.5	0.29	3.50	2.40	28.47	1.40	41.73	1.31	31.08	0.01	0.22	bd	bd	104.99
D190-0.5	12.82	157.90	7.66	94.33	5.23	161.13	5.62	138.34	0.23	6.63	0.12	3.66	561.99
D191-1.5	4.37	82.92	3.59	67.96	2.86	135.36	0.89	33.63	0.23	10.20	bd	bd	330.08
D193-3.5	0.01	0.17	2.31	27.49	1.63	48.62	0.42	9.93	0.05	1.31	bd	bd	87.52
E140-0.5	bd	bd	bd	bd	0.15	4.05	0.38	7.92	0.03	0.68	0.01	0.24	12.88
E141-1.5	bd	bd	bd	bd	0.14	4.09	0.16	3.57	0.01	0.21	bd	bd	7.86
E143-3.5	0.01	0.15	0.02	0.22	0.04	1.20	0.11	2.33	0.09	2.20	bd	bd	6.09
E160-0.5	0.61	9.25	0.07	1.05	0.31	11.83	0.16	4.73	0.05	1.66	bd	bd	28.53
E161-1.5	0.41	7.88	bd	bd	0.17	8.28	0.14	5.21	0.12	5.43	bd	bd	26.80
E163-3.5	0.17	4.15	5.42	129.12	3.30	196.78	0.89	42.26	0.12	6.79	bd	bd	379.11
E180-0.5	bd	bd	2.15	31.43	1.92	70.48	2.79	81.67	1.51	51.02	0.33	12.05	246.65

Table J-1. Zinc (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/L	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
E181-1.5	0.09	2.29	0.30	7.19	0.21	13.03	0.56	27.14	0.17	9.75	0.04	2.38	61.77
E200-0.5	0.35	4.02	0.36	4.09	0.37	10.63	0.72	16.30	0.08	2.20	0.07	1.96	39.21
E201-1.5	0.07	0.73	0.19	1.82	0.10	2.56	0.18	3.48	0.07	1.67	0.05	1.20	11.47
F130-0.5	0.13	1.31	0.10	0.93	0.17	4.27	0.38	7.40	0.06	1.44	0.01	0.22	15.58
F131-1.5	0.01	0.14	bd	bd	0.04	1.11	0.10	1.97	0.07	1.72	bd	bd	4.95
F133-3.5	0.13	1.45	0.10	1.03	bd	bd	0.19	4.04	0.04	1.09	bd	bd	7.61
F150-0.5	0.25	3.87	3.93	59.88	6.22	236.79	3.83	116.63	3.08	108.08	0.27	10.25	535.49
F151-1.5	0.11	1.12	bd	bd	0.54	13.40	2.41	47.42	0.16	3.72	bd	bd	65.66
F153-3.5	bd	bd	bd	bd	0.04	1.16	0.30	6.25	0.03	0.68	bd	bd	8.09
F170-0.5	0.19	2.43	4.16	52.12	3.93	123.22	5.75	144.00	0.17	4.84	0.06	1.85	328.46
F171-1.5	1.57	16.91	0.09	0.91	bd	bd	0.40	8.53	0.11	2.67	bd	bd	29.02
F17a3-3.5	bd	bd	0.09	1.08	bd	bd	0.14	3.49	0.13	3.75	0.02	0.61	8.93
F17b3-3.5	bd	bd	0.06	0.66	bd	bd	0.08	1.68	0.17	4.23	0.03	0.79	7.36
F17c3-3.5	bd	bd	0.06	0.65	bd	bd	0.07	1.46	0.06	1.60	bd	bd	3.72
F190-0.5	7.31	81.26	1.74	19.29	0.94	26.24	0.78	17.28	0.08	2.15	0.07	1.92	148.13
F191-1.5	0.03	0.36	0.64	6.65	0.02	0.63	0.36	7.48	bd	bd	bd	bd	15.12
F193-3.5	bd	bd	0.61	6.86	0.03	0.96	0.19	4.20	bd	bd	bd	bd	12.02
F210-0.5	0.63	7.12	0.66	7.41	0.18	5.17	0.52	11.61	0.01	0.21	bd	bd	31.52
F211-1.5	bd	bd	0.66	6.53	0.05	1.34	0.19	3.70	0.01	0.18	bd	bd	11.75
F213-3.5	bd	bd	0.56	5.61	0.11	2.85	0.15	2.94	bd	bd	bd	bd	11.41
G140-0.5	bd	bd	0.99	14.94	3.96	150.27	0.61	18.41	0.15	5.16	0.03	1.10	189.88
G141-1.5	bd	bd	0.01	0.16	1.27	52.52	0.97	31.89	0.23	8.87	0.03	1.20	94.65

Table J-1. Zinc (continued)

Sample	EX sol'n	EX mg/kg sed	WAS sol'n	WAS mg/kg sed	ER sol'n	ER mg/kg sed	MR sol'n	MR mg/kg sed	OX1 sol'n	OX1 mg/kg sed	OX2 sol'n	OX2 mg/kg sed	Total sed mg/kg
G143-3.5	bd	bd	bd	bd	0.12	3.23	bd	bd	0.07	1.77	0.02	0.50	5.50
G160-0.5	bd	bd	bd	bd	2.73	413.01	0.00	0.00	1.43	199.30	0.02	2.87	615.17
G161-1.5	bd	bd	bd	bd	0.58	22.86	1.83	58.04	0.47	17.31	0.04	1.55	99.76
G163-3.5	bd	bd	bd	bd	0.42	14.85	0.43	12.22	0.20	6.70	0.11	3.89	37.66
G180-0.5	1.21	14.15	0.31	3.61	0.31	9.15	1.04	24.17	0.15	4.13	0.01	0.26	55.46
G181-1.5	bd	bd	0.01	0.11	bd	0.11	0.41	9.00	0.17	4.27	bd	bd	13.49
G183-3.5	0.01	0.14	0.04	0.36	0.04	1.13	0.16	3.23	0.23	5.39	bd	bd	10.26
G200-0.5	0.43	5.22	0.34	4.03	0.11	3.43	0.63	15.08	0.01	0.22	0.04	1.17	29.14
G201-1.5	bd	bd	0.14	1.41	0.08	2.19	0.11	2.23	0.15	3.55	bd	bd	9.37
G203-3.5	0.15	1.66	0.01	0.11	bd	bd	0.08	1.66	0.05	1.19	0.01	0.24	4.86
G220-0.5	0.43	4.89	1.06	11.94	0.37	10.53	1.06	23.81	0.01	0.21	bd	bd	51.38
G221-1.5	bd	bd	0.49	5.26	0.21	5.80	0.22	4.71	bd	bd	bd	bd	15.77
G223-3.5	bd	bd	0.81	8.77	0.03	0.92	0.20	4.27	bd	bd	bd	bd	13.96
H150-0.5	0.01	0.26	1.79	33.63	1.26	59.16	0.67	25.17	0.31	13.35	0.05	2.31	133.88
H151-1.5	0.03	0.57	0.34	5.57	1.10	45.55	0.23	7.58	0.31	11.78	0.01	0.37	71.41
H153-3.5	0.01	0.26	bd	bd	0.46	20.94	0.67	24.53	0.77	32.44	0.04	1.79	79.96
H170-0.5	0.23	5.98	3.37	86.10	2.65	169.53	1.63	83.19	0.07	4.00	0.00	0.00	348.80
H171-1.5	1.05	50.65	2.79	133.84	2.42	290.26	0.63	60.36	0.19	20.78	bd	bd	555.89
H173-3.5	bd	bd	bd	bd	0.40	13.04	0.51	13.12	0.17	4.99	0.02	0.61	31.76
H190-0.5	0.07	0.94	0.91	12.76	1.78	62.53	0.89	24.87	0.35	11.22	bd	bd	112.33
H191-1.5	bd	bd	bd	bd	1.40	73.84	0.64	26.80	0.15	7.16	0.02	1.00	108.79
H193-3.5	0.02	0.82	2.21	106.71	1.69	204.48	0.34	32.54	0.09	9.77	0.08	9.54	363.86

Table J-1. Zinc (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
H210-0.5	0.03	0.31	0.14	1.24	bd	bd	0.05	0.86	0.09	1.86	0.02	0.44	4.71
H211-1.5	3.33	61.32	1.04	19.03	0.80	36.97	0.72	26.37	0.31	13.03	bd	bd	156.72
H213-3.5	bd	bd	bd	bd	bd	bd	0.30	6.21	0.04	1.06	bd	bd	7.27
H23a0-0.5	0.06	0.69	0.01	0.12	0.04	1.32	0.64	15.33	0.11	2.99	0.05	1.47	21.92
H23b0-0.5	bd	bd	0.06	0.66	0.04	1.21	0.63	13.81	0.07	1.72	bd	bd	17.40
H23c0-0.5	0.05	0.57	0.04	0.43	0.10	3.16	0.54	13.04	0.03	0.78	bd	bd	17.98
H231-1.5	bd	bd	bd	bd	bd	bd	0.22	3.43	0.13	2.33	0.04	0.77	6.53
H233-3.5	0.24	2.72	bd	bd	bd	0.11	0.12	2.69	0.03	0.74	bd	bd	6.27
I200-0.5	bd	bd	0.49	12.34	0.48	30.78	bd	bd	1.73	101.11	0.19	12.02	156.26
I201-1.5	4.31	162.13	9.76	367.40	7.86	739.32	4.31	324.26	0.19	16.28	0.07	6.49	1615.88
I203-3.5	bd	bd	0.06	3.69	0.22	33.18	0.35	42.64	0.35	49.17	bd	bd	128.68
I220-0.5	bd	bd	0.31	9.56	2.02	156.12	2.02	124.46	0.61	43.15	0.09	6.86	340.16
I221-1.5	bd	bd	bd	bd	2.93	317.30	1.88	162.39	0.19	18.70	0.07	7.46	505.85
I223-3.5	0.14	1.69	0.09	1.05	bd	bd	0.05	1.16	0.07	2.10	bd	bd	5.99
I240-0.5	0.12	1.56	0.07	0.93	0.21	7.12	0.51	13.50	0.08	2.57	bd	bd	25.69
I241-1.5	bd	bd	0.02	0.25	bd	0.12	0.13	3.11	0.06	1.80	bd	bd	5.29
I243-3.5	bd	bd	bd	bd	0.03	0.98	0.19	4.30	0.03	0.90	bd	bd	6.18
I260-0.5	1.73	19.74	14.48	165.48	8.62	246.17	7.27	166.12	2.75	72.23	0.51	14.54	684.29
I26a1-1.5	0.05	0.58	0.32	3.43	1.12	30.12	1.28	27.38	0.05	1.18	0.04	1.05	63.74
I26b1-1.5	0.09	0.97	0.40	4.09	1.14	29.64	1.32	27.29	0.01	0.19	0.06	1.53	63.72
I26c1-1.5	0.09	1.03	0.37	4.07	0.98	27.07	1.12	24.58	0.03	0.71	0.04	1.07	58.54
J19a0-0.5	--	--	4.05	135.23	1.14	95.62	0.78	51.95	0.15	11.38	0.11	9.11	303.29

Table J-1.1. Zinc (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
J1960-0.5	7.15	230.36	4.77	153.72	1.50	121.17	0.83	53.30	0.13	9.49	0.09	7.17	575.22
J1960-0.5	6.79	235.75	4.07	141.35	1.32	114.96	0.77	53.28	0.13	10.22	0.15	12.94	568.50
J191-1.5	6.47	220.95	2.72	92.91	1.54	131.86	0.97	66.07	0.07	5.34	0.01	0.77	517.89
J193-3.5	0.01	0.48	bd	bd	bd	32.67	6.04	410.85	3.91	305.85	0.03	2.47	752.31
J210-0.5	0.55	6.74	bd	bd	0.32	9.85	1.48	35.91	0.03	0.78	0.06	1.79	55.07
J211-1.5	0.03	0.36	bd	bd	0.04	1.15	0.30	6.21	0.03	0.67	bd	bd	8.38
J230-0.5	0.03	2.19	bd	bd	0.69	111.51	0.78	99.88	0.21	30.75	0.06	9.48	253.80
J231-1.5	0.27	12.78	5.25	244.57	22.10	2575.79	22.43	2091.60	40.14	4304.90	1.01	117.62	9347.26
J233-3.5	bd	bd	bd	bd	bd	bd	0.13	2.64	0.01	0.19	bd	bd	2.83
J250-0.5	bd	bd	0.65	9.78	1.91	72.54	0.67	20.22	bd	bd	0.01	0.34	102.88
J251-1.5	bd	bd	bd	bd	0.25	20.56	0.05	3.04	bd	bd	0.03	2.35	25.95
J253-3.5	bd	bd	0.17	1.78	0.39	10.31	0.28	5.80	0.03	0.67	0.03	0.76	19.32
J270-0.5	bd	bd	0.10	1.22	2.08	66.93	2.13	54.65	0.47	13.83	0.08	2.54	139.16
J271-1.5	bd	bd	0.05	0.49	0.09	2.58	0.12	2.57	bd	bd	bd	bd	5.65
K200-0.5	0.01	0.82	1.04	60.82	2.30	338.47	0.97	113.65	0.09	11.89	bd	bd	525.66
K203-3.5	bd	bd	0.06	0.78	0.22	7.24	0.27	6.90	0.01	0.24	0.01	0.29	15.44
K220-0.5	bd	bd	0.07	21.56	3.55	2736.11	1.39	854.24	0.09	62.33	0.02	14.63	3688.86
K221-1.5	bd	bd	0.90	42.33	0.96	113.98	0.23	21.47	0.07	8.05	bd	bd	185.84
K223-3.5	bd	bd	bd	bd	0.03	0.79	0.07	1.24	0.01	0.17	bd	bd	2.19
K240-0.5	0.19	7.95	0.90	36.67	3.29	337.43	2.48	202.99	0.93	87.46	0.13	13.21	685.72
K241-1.5	bd	bd	0.32	14.36	7.18	805.14	2.58	231.31	0.31	31.79	0.02	2.13	1084.73
K243-3.5	bd	bd	0.10	1.02	0.13	3.59	0.14	2.94	0.01	0.20	0.01	0.24	7.99

Table J-1. Zinc (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
K260-0.5	bd	bd	0.17	2.29	0.60	20.36	0.26	6.93	0.05	1.49	0.02	0.64	31.71
K261-1.5	bd	bd	bd	bd	0.41	47.20	0.11	9.76	0.11	11.33	0.06	6.73	75.02
K263-3.5	0.17	3.11	bd	bd	0.64	28.79	0.38	13.48	0.03	1.15	0.10	4.43	50.95
K280-0.5	0.09	2.13	bd	bd	bd	bd	1.04	46.92	0.37	19.15	0.05	2.77	70.97
K281-1.5	bd	bd	bd	bd	0.78	65.32	0.46	30.46	0.11	8.28	bd	bd	104.05
L210-0.5	bd	bd	1.57	16.58	2.06	54.49	2.65	55.91	0.03	0.68	0.03	0.77	128.42
L211-1.5	0.27	2.89	bd	bd	0.09	2.48	0.33	6.89	0.03	0.68	bd	bd	12.93
L230-0.5	0.21	14.58	0.07	4.77	0.53	90.97	0.23	30.94	0.09	13.79	0.01	1.53	156.59
L231-1.5	0.15	9.45	0.27	16.57	0.45	69.66	0.13	15.59	0.11	15.25	bd	bd	126.52
L233-3.5	0.01	0.15	0.07	0.75	0.10	2.80	0.18	3.81	bd	bd	bd	bd	7.52
L250-0.5	bd	bd	bd	bd	0.13	3.54	0.40	8.40	0.01	0.19	bd	bd	12.14
L251-1.5	bd	bd	bd	bd	0.47	45.94	0.15	11.40	0.15	13.20	bd	bd	70.53
L25a3-3.5	bd	bd	bd	bd	0.66	62.93	0.28	21.00	0.15	12.90	bd	bd	96.84
L25b3-3.5	bd	bd	bd	bd	0.49	55.18	0.30	26.54	0.23	23.43	0.00	0.00	105.15
L25c3-3.5	bd	bd	bd	bd	0.68	61.12	0.32	22.66	0.23	18.74	0.00	0.00	102.53
L270-0.5	bd	bd	bd	bd	0.57	72.93	0.24	24.09	bd	bd	0.04	4.96	101.97
L271-1.5	bd	bd	bd	bd	0.29	17.30	0.11	5.04	0.01	0.43	0.10	5.83	28.60
L273-3.5	bd	bd	bd	bd	0.06	1.72	0.15	3.15	bd	bd	bd	bd	4.87
M200-0.5	0.29	3.37	bd	bd	0.18	5.27	0.30	6.81	bd	bd	bd	bd	15.45
M201-1.5	0.01	0.31	bd	bd	0.12	6.79	0.07	2.93	bd	bd	bd	bd	10.03
M220-0.5	0.29	5.37	bd	bd	0.54	24.84	0.33	11.94	bd	bd	0.02	0.87	43.02
M221-1.5	0.05	0.79	bd	bd	0.50	18.47	0.34	9.88	bd	bd	bd	bd	29.14

Table J-1. Zinc (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
M223-3.5	0.13	1.42	bd	bd	0.09	2.49	0.18	3.75	bd	bd	0.01	0.24	7.90
M240-0.5	bd	bd	bd	bd	0.98	58.17	0.61	28.71	0.09	4.79	0.02	1.12	92.79
M241-1.5	0.17	8.46	bd	bd	0.81	98.90	0.40	38.59	0.09	9.84	bd	bd	155.79
M243-3.5	0.03	0.38	0.12	1.35	0.01	0.39	0.05	1.06	bd	bd	0.01	0.25	3.45
M260-0.5	0.05	1.23	bd	bd	0.79	45.33	0.50	22.70	0.01	0.42	0.03	1.66	71.34
M261-1.5	bd	bd	bd	bd	0.60	41.90	0.34	18.70	0.03	1.79	0.02	1.32	63.71
M280-0.5	0.15	3.36	0.52	11.35	1.15	62.99	0.71	30.87	0.05	2.41	0.07	3.77	114.76
M281-1.5	bd	bd	0.05	0.86	0.21	10.26	0.10	3.72	0.01	0.35	0.03	1.39	16.58
M283-3.5	0.11	1.28	bd	bd	0.08	2.36	0.16	3.53	bd	bd	bd	bd	7.17
N210-0.5	0.73	26.34	0.45	15.97	2.30	206.74	1.01	72.29	0.09	7.26	0.03	2.60	331.21
N211-1.5	0.23	7.21	bd	bd	1.36	105.09	0.54	33.10	0.61	43.09	0.05	3.78	192.26
N230-0.5	bd	bd	0.30	16.93	1.61	231.57	0.71	81.15	0.05	6.34	bd	bd	335.99
N231-1.5	0.05	0.64	0.17	2.02	0.13	3.98	0.06	1.35	bd	bd	0.01	0.27	8.26
N233-3.5	0.03	0.43	0.12	1.53	0.19	6.18	0.15	3.75	bd	bd	0.02	0.61	12.50
N250-0.5	bd	bd	0.02	0.23	0.18	5.35	0.22	5.05	bd	bd	bd	bd	10.63
N251-1.5	0.09	2.19	bd	bd	0.37	21.78	0.17	7.78	0.01	0.43	0.01	0.52	32.70
N253-3.5	0.01	0.17	bd	bd	0.20	6.22	0.21	5.05	bd	bd	0.02	0.58	12.02
O220-0.5	0.41	14.43	bd	bd	0.99	86.59	0.53	36.73	0.03	2.24	0.05	4.27	144.26
O22a1-1.5	0.57	22.17	5.35	206.47	4.37	422.40	2.90	223.81	0.01	0.71	0.07	6.66	882.23
O22b1-1.5	0.45	17.54	4.62	178.46	3.84	371.22	2.77	213.77	0.01	0.71	0.06	5.70	787.40
O22c1-1.5	0.59	22.32	5.47	205.54	4.33	407.13	3.07	230.49	0.25	21.43	0.07	6.48	893.38
O223-3.5	bd	bd	bd	bd	0.52	17.23	0.58	15.18	0.85	25.66	0.16	5.23	63.30

Table J-1. Zinc (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
O240-0.5	0.73	34.51	1.99	93.33	1.44	169.73	0.43	40.15	0.03	3.03	0.09	10.46	351.21
O241-1.5	bd	bd	0.41	8.82	0.40	21.72	1.85	79.44	bd	bd	0.03	1.56	111.54
O243-3.5	0.09	1.30	0.51	7.03	0.19	6.69	0.22	5.98	bd	bd	0.08	2.72	23.72
P230-0.5	1.45	77.04	6.80	360.04	4.70	623.12	2.93	310.18	0.15	18.04	0.15	19.74	1408.16
P231-1.5	0.07	0.95	0.10	1.22	0.95	30.70	0.59	15.11	1.09	32.21	0.17	5.44	85.63
P23a3-3.5	bd	bd	bd	bd	0.30	11.18	0.35	10.21	bd	bd	0.06	2.17	23.57
P23b3-3.5	0.05	0.71	bd	bd	0.30	10.02	0.32	8.36	bd	bd	bd	bd	19.09
P23c3-3.5	0.13	1.86	bd	bd	0.31	10.92	0.33	9.10	bd	bd	0.02	0.66	22.54
P250-0.5	0.11	6.89	0.71	42.89	0.81	122.92	0.76	91.45	0.71	98.36	0.04	5.89	368.39
P251-1.5	bd	bd	0.61	28.61	0.40	47.37	0.32	29.74	bd	bd	0.02	2.23	107.94
P253-3.5	0.05	0.67	0.17	2.12	0.17	5.43	0.10	2.42	bd	bd	bd	bd	10.64
Q240-0.5	1.77	45.38	2.92	74.70	7.02	448.69	4.22	215.75	1.67	98.14	0.19	12.09	894.75
Q24a1-1.5	0.03	0.93	0.50	13.58	0.76	52.39	0.99	54.15	0.15	9.34	0.08	5.42	135.81
Q24b1-1.5	bd	bd	0.55	14.56	0.73	49.04	0.96	51.15	0.15	9.10	0.03	1.94	125.78
Q24c1-1.5	0.01	0.38	0.42	11.52	0.67	46.22	0.95	51.96	0.11	6.81	0.07	4.73	121.63
Q243-3.5	bd	bd	0.02	0.51	0.76	48.68	0.73	37.06	2.11	123.57	0.08	5.03	214.84
Q260-0.5	bd	bd	1.46	17.89	0.83	25.55	0.35	8.50	0.06	1.80	bd	bd	53.74
R250-0.5	1.05	37.36	3.21	113.79	1.55	137.72	1.09	77.06	0.25	20.22	0.01	0.80	386.95
R251-1.5	0.01	0.28	0.46	9.19	0.59	29.66	0.51	20.25	bd	bd	bd	bd	59.38
R253-3.5	0.00	0.00	0.89	10.74	0.14	4.37	0.13	3.08	bd	bd	0.01	0.27	18.46
R270-0.5	bd	bd	0.46	17.45	1.03	98.04	1.01	76.38	0.45	39.08	0.02	1.80	232.74
R271-1.5	bd	bd	0.46	24.80	0.92	124.54	0.69	74.08	1.31	162.19	0.05	6.60	392.22

Table J-1. Zinc (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
R273-3.5	bd	bd	0.74	24.69	0.43	36.45	0.26	17.27	0.11	8.34	0.01	0.76	87.51
S260-0.5	0.91	24.07	1.47	38.72	2.61	172.13	1.15	60.42	0.15	8.97	0.01	0.59	304.90
S261-1.5	bd	bd	bd	bd	0.52	64.89	0.27	26.45	bd	bd	0.04	4.83	96.17
T270-0.5	2.67	67.34	1.82	45.83	2.32	146.31	0.99	49.71	0.09	5.10	0.10	6.23	320.53
T271-1.5	bd	bd	1.77	73.30	1.97	204.38	1.05	86.72	0.11	10.29	0.14	14.39	389.08
U260-0.5	0.11	1.19	1.01	10.50	0.29	7.64	0.24	4.93	0.27	6.41	0.03	0.75	31.42
U261-1.5	bd	bd	1.44	16.25	1.37	38.89	1.15	25.97	bd	bd	0.09	2.52	83.62
U263-3.5	bd	bd	0.76	8.64	0.55	15.75	0.45	10.16	bd	bd	0.03	0.82	35.38

Appendix J

Table J-2. Replicate Sample Analysis for Zinc

sed indicates concentration in sediment (dry weight basis)

avg indicates the average of three replicate samples. RSD indicates the relative standard deviation of the three replicates. SRM 2704 is NIST Buffalo River Sediment

Sample	EX sed (mg/kg)	WAS sed (mg/kg)	ER sed (mg/kg)	MR sed (mg/kg)	OX1s ed (mg/kg)	OX2 sed (mg/kg)	Total sed (mg/kg)
B3a0-0.5	bdl	bdl	bdl	8.8	bdl	3.3	12.1
B3b0-0.5	1.7	bdl	bdl	2.1	bdl	bdl	3.8
B3c0-0.5	12.8	bdl	bdl	3.0	bdl	bdl	15.8
AVG	7.25	bdl	bdl	4.7	bdl	bdl	10.6
RSD	108.31	--	--	78.1	--	--	57.9
B9a0-0.5	bdl	bdl	5.1	6.0	bdl	bdl	11.2
B9b0-0.5	bdl	bdl	5.4	5.7	bdl	bdl	11.0
B9c0-0.5	bdl	bdl	3.8	5.8	4.5	bdl	14.1
AVG	bdl	bdl	4.74	5.8	bdl	bdl	12.1
RSD	--	--	18.1	3.2	--	--	14.2
B13a1-1.5	bdl	bdl	bdl	3.9	bdl	bdl	3.9
B13b1-1.5	bdl	bdl	bdl	6.7	bdl	bdl	6.7
B13c1-1.5	bdl	bdl	bdl	5.7	bdl	bdl	5.7
AVG	bdl	bdl	bdl	5.4	bdl	bdl	5.4
RSD	--	--	--	25.9	--	--	25.9

Table J-2. Zinc (continued)

Sample	EX sed (mg/kg)	WAS sed (mg/kg)	ER sed (mg/kg)	MR sed (mg/kg)	OX1s ed (mg/kg)	OX2 sed (mg/kg)	Total sed (mg/kg)
D9a3-3.5	1.5	bdl	bdl	bdl	bdl	bdl	1.5
D9b3-3.5	bdl	3.2	bdl	bdl	bdl	bdl	3.2
D9c3-3.5	bdl	1.0	bdl	bdl	bdl	bdl	1.0
AVG	bdl	bdl	bdl	bdl	bdl	bdl	1.9
RSD	--	--	--	--	--	--	60.9
F17a3-3.5	bdl	1.1	bdl	3.5	3.8	bdl	8.3
F17b3-3.5	bdl	bdl	bdl	1.7	4.2	bdl	5.9
F17c3-3.5	bdl	bdl	bdl	1.5	1.6	bdl	3.1
AVG	bdl	bdl	bdl	2.2	bdl	bdl	5.8
RSD	--	--	--	50.4	--	--	45.7
H23a0-0.5	bdl	bdl	1.3	15.3	3.0	1.5	21.1
H23b0-0.5	bdl	bdl	1.2	13.8	1.7	bdl	16.7
H23c0-0.5	bdl	bdl	3.2	13.0	bdl	bdl	16.2
AVG	bdl	bdl	1.90	14.1	bdl	bdl	18.0
RSD	--	--	57.59	8.3	--	--	15.0
I26a1-1.5	bdl	3.4	30.1	27.4	1.2	1.0	63.2
I26b1-1.5	1.0	4.1	29.6	27.3	bdl	1.5	63.5
I26c1-1.5	1.0	4.1	27.1	24.6	bdl	1.1	57.8
AVG	bdl	3.87	28.94	26.4	bdl	bdl	61.5
RSD	--	9.7	5.7	6.0	--	--	5.2

Table J-2. Zinc (continued)

Sample	EX sed (mg/kg)	WAS sed (mg/kg)	ER sed (mg/kg)	MR sed (mg/kg)	OX1s ed (mg/kg)	OX2 sed (mg/kg)	Total sed (mg/kg)
J19a0-0.5	--	135.2	95.6	52.0	11.4	9.1	--
J19b0-0.5	230.4	153.7	121.2	53.3	9.5	7.2	575.2
J19c0-0.5	235.7	141.4	115.0	53.3	10.2	12.9	568.5
AVG	233.05	143.44	110.58	52.8	bdl	bdl	571.9
RSD	1.64	6.57	12.05	1.5	--	--	0.8
L25a3-3.5	bdl	bdl	62.9	21.0	12.9	bdl	96.8
L25b3-3.5	bdl	bdl	55.2	26.5	23.4	bdl	105.1
L25c3-3.5	bdl	bdl	61.1	22.7	18.7	bdl	102.5
AVG	bdl	bdl	59.74	23.4	18.4	bdl	101.5
RSD	--	--	6.79	12.1	28.7	--	4.2
O22a1-1.5	22.2	206.5	422.4	223.8	bdl	6.7	881.5
O22b1-1.5	17.5	178.5	371.2	213.8	bdl	5.7	786.7
O22c1-1.5	22.3	205.5	407.1	230.5	21.4	6.5	893.4
AVG	20.68	196.82	400.25	222.7	bdl	6.3	853.9
RSD	13.15	8.08	6.56	3.8	--	8.2	6.8
P23a3-3.5	bdl	bdl	11.2	10.2	bdl	2.2	23.6
P23b3-3.5	bdl	bdl	10.0	8.4	bdl	bdl	18.4
P23c3-3.5	1.9	bdl	10.9	9.1	bdl	bdl	21.9
AVG	bdl	bdl	10.71	9.2	bdl	bdl	21.3
RSD	--	--	5.71	10.1	--	--	12.5

Table J-2. Zinc (continued)

Sample	EX sed (mg/kg)	WAS sed (mg/kg)	ER sed (mg/kg)	MR sed (mg/kg)	OX1s ed (mg/kg)	OX2 sed (mg/kg)	Total sed (mg/kg)
Q24a1-1.5	bd1	13.6	52.4	54.2	9.3	5.4	134.9
Q24b1-1.5	bd1	14.6	49.0	51.1	9.1	1.9	125.8
Q24c1-1.5	bd1	11.5	46.2	52.0	6.8	4.7	121.2
AVG	bd1	13.22	49.22	52.4	8.4	4.0	127.3
RSD	--	11.74	6.28	3.0	16.5	45.8	5.5
SRM27042/3/97	22.4	51.9	71.9	65.7	15.9	bd1	227.8
SRM27042/17/97	22.7	54.3	71.8	66.9	14.1	2.7	232.4
SRM27042/24/97	22.1	51.4	66.4	73.8	14.8	1.6	230.1
SRM27043/10/97	21.7	50.6	72.8	72.6	12.7	1.2	231.5
SRM27043/24/97	21.7	48.0	75.1	53.8	12.0	1.9	212.5
SRM27044/7/97	--	--	--	--	--	--	--
AVG	22.09	51.27	71.59	66.55	13.90	1.84	226.87
RSD	2.1	4.4	4.5	11.9	11.4	32.5	3.6

Appendix K

Table K-1. Sequential Chemical Extraction Data for Manganese

sol'n indicates concentration detected in leachate solution, mg/L

sed indicates concentration in sediment, mg/kg (dry weight basis)

bd indicates below detection, -- indicates not measured

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
B3a0-0.5	bd	bd	bd	bd	0.210	5.315	0.840	17.009	bd	bd	bd	bd	22.325
B3b0-0.5	bd	bd	bd	bd	0.160	4.411	0.640	14.114	bd	bd	bd	bd	18.525
B3c0-0.5	bd	bd	bd	bd	0.150	3.600	0.760	14.594	bd	bd	bd	bd	18.194
B31-1.5	bd	bd	bd	bd	bd	bd	0.120	2.545	bd	bd	bd	bd	2.545
B33-3.5	bd	bd	bd	bd	0.130	3.298	0.680	13.802	bd	bd	bd	bd	17.101
B50-0.5	bd	bd	bd	bd	1.680	41.293	0.600	11.798	bd	bd	bd	bd	53.091
B51-1.5	bd	bd	bd	bd	0.040	1.083	0.560	12.135	bd	bd	bd	bd	13.219
B53-3.5	bd	bd	bd	bd	0.040	1.182	0.840	19.858	bd	bd	bd	bd	21.040
B70-0.5	bd	bd	bd	bd	0.060	1.435	0.210	4.018	bd	bd	bd	bd	5.453
B71-1.5	bd	bd	bd	bd	0.060	1.488	0.190	3.768	bd	bd	bd	bd	5.267
B73-3.5	bd	bd	bd	bd	bd	bd	0.120	2.627	bd	bd	bd	bd	2.627
B9a0-0.5	bd	bd	0.480	5.059	2.880	75.879	1.600	33.724	bd	bd	bd	bd	114.662
B9b0-0.5	bd	bd	0.520	5.746	2.520	69.617	1.600	35.361	bd	bd	bd	bd	110.725
B9c0-0.5	bd	bd	0.480	5.017	2.720	71.073	1.640	34.282	bd	bd	bd	bd	110.372
B91-1.5	bd	bd	bd	bd	0.110	2.951	0.440	9.444	bd	bd	bd	bd	12.395
B93-3.5	bd	bd	bd	bd	bd	bd	0.240	5.128	bd	bd	bd	bd	5.128
B110-0.5	bd	bd	1.120	13.731	1.470	45.056	bd	bd	bd	bd	bd	bd	58.788
B111-1.5	bd	bd	bd	bd	0.040	1.106	0.230	5.087	bd	bd	bd	bd	6.193
B113-3.5	bd	bd	bd	bd	bd	bd	0.320	7.308	bd	bd	bd	bd	7.308
B130-0.5	bd	bd	bd	bd	0.410	10.981	0.400	8.570	bd	bd	bd	bd	19.551
B13a1-1.5	bd	bd	bd	bd	0.210	5.482	0.440	9.188	bd	bd	bd	bd	14.670

Table K-1. Manganese (continued)

Sample	EX sol'n	EX mg/L	WAS sol'n	WAS mg/L	ER sol'n	ER mg/kg	MR sol'n	MR mg/kg	OX1 sol'n	OX1 mg/kg	OX2 sol'n	OX2 mg/L	OX2 mg/kg	Total sed
B13bl-1.5	bd	bd	bd	bd	0.180	5.053	0.440	9.882	bd	bd	bd	bd	bd	14.935
B13cl-1.5	bd	bd	bd	bd	0.170	4.911	0.480	11.094	bd	bd	bd	bd	bd	16.006
B133-3.5	bd	bd	bd	bd	bd	bd	0.600	12.530	bd	bd	bd	bd	bd	12.530
B150-0.5	bd	bd	1.280	13.849	2.250	60.858	0.800	17.311	bd	bd	bd	bd	bd	92.018
B151-1.5	bd	bd	3.160	35.166	6.000	166.929	2.360	52.527	bd	bd	bd	bd	bd	254.623
B153-3.5	bd	bd	4.040	63.749	2.930	115.585	1.200	37.871	bd	bd	bd	bd	bd	217.205
B170-0.5	bd	bd	0.520	5.539	3.350	89.206	0.960	20.451	bd	bd	bd	bd	bd	115.195
B171-1.5	bd	bd	bd	bd	0.280	7.072	0.560	11.315	bd	bd	bd	bd	bd	18.387
B173-3.5	bd	bd	bd	bd	bd	bd	0.320	13.419	bd	bd	bd	bd	bd	13.419
C20-0.5	bd	bd	bd	bd	1.810	48.039	3.440	73.040	bd	bd	bd	bd	bd	121.079
C21-1.5	bd	bd	bd	bd	0.170	4.075	1.120	21.476	bd	bd	bd	bd	bd	25.551
C23-3.5	bd	bd	bd	bd	0.050	1.264	0.840	16.985	bd	bd	bd	bd	bd	18.249
C40-0.5	bd	bd	bd	bd	2.110	57.266	2.960	64.269	bd	bd	bd	bd	bd	121.535
C41-1.5	bd	bd	bd	bd	0.340	8.794	1.120	23.176	bd	bd	bd	bd	bd	31.970
C43-3.5	bd	bd	bd	bd	6.280	150.862	6.560	126.071	bd	bd	bd	bd	bd	276.933
C60-0.5	bd	bd	bd	bd	0.140	3.414	0.170	3.317	bd	bd	bd	bd	bd	6.731
C61-1.5	bd	bd	bd	bd	0.280	6.780	0.600	11.622	bd	bd	bd	bd	bd	18.402
C63-3.5	bd	bd	bd	bd	bd	bd	0.400	7.738	bd	bd	bd	bd	bd	7.738
C80-0.5	bd	bd	3.040	33.107	1.750	47.646	0.640	13.940	bd	bd	bd	bd	bd	94.693
C81-1.5	bd	bd	bd	bd	0.020	0.587	0.480	11.264	bd	bd	bd	bd	bd	11.850
C83-3.5	bd	bd	bd	bd	0.030	0.774	0.360	7.430	bd	bd	bd	bd	bd	8.204
C100-0.5	bd	bd	bd	bd	0.830	23.684	0.720	16.436	bd	bd	bd	bd	bd	40.121
C101-1.5	bd	bd	bd	bd	0.070	1.728	0.600	11.848	bd	bd	bd	bd	bd	13.576
C103-3.5	bd	bd	bd	bd	0.040	1.072	0.360	7.717	bd	bd	bd	bd	bd	8.789
C120-0.5	bd	bd	0.480	5.332	1.000	27.770	0.960	21.328	bd	bd	bd	bd	bd	54.430

Table K-1. Manganese (continued)

Sample	EX Sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 Sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
C121-1.5	bd	bd	bd	bd	0.080	1.963	1.000	19.629	bd	bd	bd	bd	21.592
C123-3.5	bd	bd	bd	bd	0.160	4.674	0.800	18.695	bd	bd	bd	bd	23.369
C140-0.5	bd	bd	1.800	21.247	2.280	67.282	1.480	34.940	bd	bd	bd	bd	123.469
C141-1.5	bd	bd	bd	bd	0.030	0.788	0.560	11.765	bd	bd	bd	bd	12.553
C143-3.5	bd	bd	bd	bd	0.050	1.417	1.960	44.440	bd	bd	bd	bd	45.857
C160-0.5	bd	bd	0.760	8.950	1.210	35.624	1.200	28.264	bd	bd	bd	bd	72.838
D50-0.5	bd	bd	bd	bd	4.280	104.183	1.800	35.052	bd	bd	bd	bd	139.235
D51-1.5	bd	bd	bd	bd	0.590	15.806	1.880	40.293	bd	bd	bd	bd	56.099
D53-3.5	bd	bd	bd	bd	bd	bd	1.040	23.794	bd	bd	bd	bd	23.794
D70-0.5	bd	bd	0.840	9.414	1.520	42.588	0.520	11.656	bd	bd	bd	bd	63.658
D71-1.5	bd	bd	bd	bd	0.030	0.727	0.180	3.491	bd	bd	bd	bd	4.218
D73-3.5	bd	bd	bd	bd	bd	bd	0.090	2.124	bd	bd	bd	bd	2.124
D90-0.5	bd	bd	bd	bd	0.800	20.585	0.920	18.939	bd	bd	bd	bd	39.524
D91-1.5	bd	bd	bd	bd	0.020	0.554	0.210	4.653	bd	bd	bd	bd	5.207
D93-3.5	bd	bd	bd	bd	bd	bd	0.400	8.914	bd	bd	bd	bd	8.914
D963-3.5	bd	bd	bd	bd	bd	bd	0.400	8.973	bd	bd	bd	bd	8.973
D9c3-3.5	bd	bd	bd	bd	bd	bd	0.400	9.369	bd	bd	bd	bd	9.369
D110-0.5	bd	bd	bd	bd	0.430	10.154	0.920	17.381	bd	bd	bd	bd	27.535
D111-1.5	bd	bd	bd	bd	0.030	0.777	0.640	13.268	bd	bd	bd	bd	14.045
D113-3.5	bd	bd	bd	bd	0.050	1.244	0.440	8.761	bd	bd	bd	bd	10.005
D130-0.5	bd	bd	1.440	15.173	4.150	109.322	2.960	62.380	bd	bd	bd	bd	186.876
D131-1.5	bd	bd	bd	bd	0.470	11.239	0.880	16.835	bd	bd	bd	bd	28.075
D133-3.5	bd	bd	bd	bd	0.150	4.192	1.560	34.878	bd	bd	bd	bd	39.070
D150-0.5	bd	bd	0.840	9.202	1.090	29.851	1.000	21.909	bd	bd	bd	bd	60.961
D151-1.5	bd	bd	bd	bd	0.560	13.958	3.680	73.378	bd	bd	bd	bd	87.336

Table K-1. Manganese (continued)

Sample	EX sol'n	EX mg/L	WAS sed	WAS mg/L	WAS sed	ER sol'n	ER mg/L	ER sed	MR sol'n	MR mg/L	MR sed	OX1 Sol'n	OX1 mg/L	OX1 sed	OX2 mg/L	OX2 sed	Total sed
D153-3.5	bd	bd	0.400	4.131	0.750	19.366	123.538	1.200	24.788	bd	bd	bd	bd	bd	bd	bd	48.286
D170-0.5	bd	bd	1.520	23.620	3.180	19.366	123.538	1.320	41.024	bd	bd	bd	bd	bd	bd	bd	188.181
D171-1.5	bd	bd	4.560	66.747	6.920	253.230	0.840	24.591	bd	bd	bd	bd	bd	bd	bd	bd	344.568
D173-3.5	bd	bd	0.680	8.084	0.120	3.567	0.480	11.413	bd	bd	bd	bd	bd	bd	bd	bd	23.064
D190-0.5	bd	bd	bd	bd	1.010	31.094	0.640	15.762	bd	bd	bd	bd	bd	bd	bd	bd	46.856
D191-1.5	bd	bd	3.120	59.149	bd	bd	0.760	28.816	bd	bd	bd	bd	bd	bd	bd	bd	87.965
D193-3.5	bd	bd	58.100	691.468	5.390	160.371	1.200	28.563	bd	bd	bd	bd	bd	bd	bd	bd	880.401
E140-0.5	bd	bd	0.640	6.726	1.480	38.882	0.800	16.814	bd	bd	bd	bd	bd	bd	bd	bd	62.421
E141-1.5	bd	bd	0.640	7.269	2.390	67.863	2.160	49.066	bd	bd	bd	bd	bd	bd	bd	bd	124.198
E143-3.5	bd	bd	0.800	8.695	2.050	55.704	1.720	37.390	bd	bd	bd	bd	bd	bd	bd	bd	101.789
E160-0.5	bd	bd	1.720	25.921	2.570	96.827	0.320	9.645	bd	bd	bd	bd	bd	bd	bd	bd	132.393
E161-1.5	bd	bd	1.600	30.451	1.690	80.409	0.140	5.329	bd	bd	bd	bd	bd	bd	bd	bd	116.189
E163-3.5	bd	bd	1.320	31.447	0.330	19.654	0.130	6.194	bd	bd	bd	bd	bd	bd	bd	bd	57.296
E180-0.5	bd	bd	0.560	8.205	2.460	90.113	0.920	26.960	bd	bd	bd	bd	bd	bd	bd	bd	125.278
E181-1.5	bd	bd	bd	bd	bd	bd	0.080	3.898	bd	bd	bd	bd	bd	bd	bd	bd	3.898
E200-0.5	bd	bd	0.480	5.457	4.540	129.045	1.200	14.553	bd	bd	bd	bd	bd	bd	bd	bd	149.056
E201-1.5	bd	bd	0.680	6.688	1.090	26.802	1.200	23.606	bd	bd	bd	bd	bd	bd	bd	bd	57.096
F130-0.5	bd	bd	bd	bd	0.110	2.699	0.320	6.280	bd	bd	bd	bd	bd	bd	bd	bd	8.979
F131-1.5	bd	bd	bd	bd	0.480	12.160	4.720	95.662	bd	bd	bd	bd	bd	bd	bd	bd	107.822
F133-3.5	bd	bd	bd	bd	0.080	2.162	0.640	13.838	bd	bd	bd	bd	bd	bd	bd	bd	16.000
F150-0.5	bd	bd	3.200	48.759	4.130	157.324	1.840	56.073	bd	bd	bd	bd	bd	bd	bd	bd	262.156
F151-1.5	bd	bd	0.440	4.334	2.930	72.154	1.560	30.733	bd	bd	bd	bd	bd	bd	bd	bd	107.222
F153-3.5	bd	bd	bd	bd	0.560	14.739	0.720	15.160	bd	bd	bd	bd	bd	bd	bd	bd	29.900
F170-0.5	bd	bd	1.160	14.533	2.690	84.256	1.120	28.064	bd	bd	bd	bd	bd	bd	bd	bd	126.853
F171-1.5	bd	bd	bd	bd	0.050	1.343	0.400	8.594	bd	bd	bd	bd	bd	bd	bd	bd	9.937

Table K-1. Manganese (continued)

Sample	EX sol'n	EX mg/kg sed	WAS sol'n	WAS mg/L	ER sol'n	ER mg/kg sed	MR sol'n	MR mg/kg sed	OX1 Sol'n	OX1 mg/L	OX2 sol'n	OX2 mg/L	OX2 mg/kg sed	Total sed mg/kg
F17a3-3.5	bd	bd	bd	bd	0.100	3.186	0.440	11.216	bd	bd	bd	bd	bd	14.403
F17b3-3.5	bd	bd	bd	bd	0.100	2.735	0.520	11.378	bd	bd	bd	bd	bd	14.113
F17c3-3.5	bd	bd	bd	bd	0.130	3.541	0.480	10.459	bd	bd	bd	bd	bd	14.000
F190-0.5	bd	bd	0.800	8.895	5.070	140.93	4.080	90.731	bd	bd	bd	bd	bd	240.558
F191-1.5	bd	bd	bd	bd	0.350	9.169	1.480	31.018	bd	bd	bd	bd	bd	40.187
F193-3.5	bd	bd	bd	bd	0.100	2.811	1.680	37.774	bd	bd	bd	bd	bd	40.585
F210-0.5	bd	bd	bd	bd	0.420	11.793	1.480	33.244	bd	bd	bd	bd	bd	45.037
F211-1.5	bd	bd	bd	bd	0.180	4.451	2.320	45.898	bd	bd	bd	bd	bd	50.350
F213-3.5	bd	bd	bd	bd	0.090	2.253	1.080	21.633	bd	bd	bd	bd	bd	23.886
G140-0.5	bd	bd	8.560	129.799	2.060	78.092	1.120	33.966	bd	bd	bd	bd	bd	241.857
G141-1.5	bd	bd	2.600	42.874	1.560	64.311	0.440	14.511	bd	bd	bd	bd	bd	121.697
G143-3.5	bd	bd	0.560	5.840	0.120	3.129	0.290	6.049	bd	bd	bd	bd	bd	15.017
G160-0.5	bd	bd	0.480	29.004	0.130	19.638	0.040	4.834	bd	bd	bd	bd	bd	53.477
G161-1.5	bd	bd	4.200	66.678	2.380	94.460	0.330	10.478	bd	bd	bd	bd	bd	171.616
G163-3.5	bd	bd	7.320	104.518	0.750	26.772	0.090	2.570	bd	bd	bd	bd	bd	133.860
G180-0.5	bd	bd	0.440	5.127	3.260	94.964	1.080	25.168	bd	bd	bd	bd	bd	125.260
G181-1.5	bd	bd	bd	bd	1.200	33.152	2.120	46.854	bd	bd	bd	bd	bd	80.006
G183-3.5	bd	bd	bd	bd	0.160	4.114	0.600	12.342	bd	bd	bd	bd	bd	16.456
G200-0.5	bd	bd	bd	bd	0.100	3.006	0.440	10.579	bd	bd	bd	bd	bd	13.585
G201-1.5	bd	bd	bd	bd	bd	bd	1.560	32.496	bd	bd	bd	bd	bd	32.496
G203-3.5	bd	bd	bd	bd	0.190	5.115	0.760	16.369	bd	bd	bd	bd	bd	21.484
G220-0.5	bd	bd	0.560	6.308	1.380	38.859	0.800	18.022	bd	bd	bd	bd	bd	63.188
G221-1.5	bd	bd	0.440	4.771	1.770	47.982	0.680	14.747	bd	bd	bd	bd	bd	67.500
G223-3.5	bd	bd	bd	bd	1.550	41.961	0.760	16.459	bd	bd	bd	bd	bd	58.420
H150-0.5	bd	bd	3.640	68.582	1.040	48.987	0.380	14.319	bd	bd	bd	bd	bd	131.889

Table K-1. Manganese (continued)

Sample	EX sol'n	EX sed	WAS sol'n	WAS sed	ER sol'n	ER sed	MR sol'n	MR sed	OX1 sol'n	OX1 sed	OX2 sol'n	OX2 sed	Total sed
H151-1.5	bd	bd	2.440	40.561	1.500	62.337	0.310	10.306	bd	bd	bd	bd	113.204
H153-3.5	bd	bd	4.240	77.864	1.800	82.639	0.350	12.855	bd	bd	bd	bd	173.358
H170-0.5	bd	bd	0.640	16.352	0.610	38.964	0.100	5.110	bd	bd	bd	bd	60.426
H171-1.5	bd	bd	0.880	42.289	0.200	24.028	bd	bd	bd	bd	bd	bd	66.318
H173-3.5	bd	bd	2.200	28.406	0.450	14.526	0.310	8.005	bd	bd	bd	bd	50.938
H190-0.5	bd	bd	2.120	29.724	29.400	1030.5	2.720	76.273	bd	bd	bd	bd	1136.531
H191-1.5	bd	bd	20.880	439.225	74.800	3933.7	4.520	190.163	bd	bd	bd	bd	4563.062
H193-3.5	2.480	119.742	3.520	169.956	0.310	37.419	0.165	15.933	bd	bd	bd	bd	343.051
H210-0.5	bd	bd	0.400	3.669	0.960	22.017	0.640	11.742	bd	bd	bd	bd	37.429
H211-1.5	bd	bd	0.920	16.920	8.080	371.50	0.960	35.311	bd	bd	bd	bd	423.734
H213-3.5	bd	bd	bd	bd	0.920	24.057	0.520	10.878	bd	bd	bd	bd	34.935
H23a0-0.5	bd	bd	0.400	4.812	0.450	13.535	0.640	15.399	bd	bd	bd	bd	33.747
H23b0-0.5	bd	bd	0.360	3.964	0.540	14.865	0.760	16.737	bd	bd	bd	bd	35.566
H23c0-0.5	bd	bd	0.480	5.829	0.650	19.733	0.760	18.458	bd	bd	bd	bd	44.019
H231-1.5	1.600	12.651	bd	bd	0.150	2.965	0.800	12.651	bd	bd	bd	bd	28.267
H233-3.5	bd	bd	bd	bd	0.420	12.070	0.840	19.312	bd	bd	bd	bd	31.382
I200-0.5	bd	bd	bd	bd	0.110	6.996	0.200	10.177	bd	bd	bd	bd	17.173
I201-1.5	bd	bd	bd	bd	0.040	3.764	0.200	15.057	bd	bd	bd	bd	18.822
I203-3.5	0.200	12.288	bd	bd	0.070	10.752	0.070	8.601	bd	bd	bd	bd	31.640
I220-0.5	0.080	2.468	bd	bd	0.060	4.628	bd	bd	bd	bd	bd	bd	7.096
I221-1.5	0.080	3.461	bd	bd	0.050	5.407	bd	bd	bd	bd	bd	bd	8.868
I223-3.5	bd	bd	bd	bd	0.160	4.926	0.270	6.650	bd	bd	bd	bd	11.575
I240-0.5	0.880	11.717	bd	bd	0.260	8.655	0.800	21.304	bd	bd	bd	bd	41.675
I241-1.5	bd	bd	bd	bd	0.090	2.758	0.380	9.316	bd	bd	bd	bd	12.074
I243-3.5	0.040	0.460	bd	bd	0.120	3.452	0.440	10.125	bd	bd	bd	bd	14.037
I260-0.5	bd	bd	2.520	28.800	8.000	228.57	2.120	48.456	bd	bd	bd	bd	305.824

Table K-1. Manganese (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 Sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
J26a1-1.5	bd	bd	1.680	18.009	10.560	283.005	1.800	38.592	bd	bd	bd	bd	339.606
J26b1-1.5	bd	bd	3.080	31.917	10.720	277.716	1.960	40.621	bd	bd	bd	bd	350.254
J26c1-1.5	bd	bd	3.400	37.415	9.880	271.811	2.440	53.702	bd	bd	bd	bd	362.928
J19a0-0.5	bd	bd	bd	bd	0.050	4.179	0.200	13.373	bd	bd	bd	bd	17.552
J19b0-0.5	bd	bd	bd	bd	bd	bd	0.230	14.824	bd	bd	bd	bd	14.824
J19c0-0.5	bd	bd	bd	bd	bd	bd	0.210	14.587	bd	bd	bd	bd	14.587
J191-1.5	bd	bd	bd	bd	0.280	23.912	0.420	28.694	bd	bd	bd	bd	52.606
J193-3.5	0.380	12.930	bd	bd	0.060	5.104	0.040	2.722	bd	bd	bd	bd	20.757
J210-0.5	0.960	11.672	0.600	7.295	0.430	13.070	0.780	18.966	bd	bd	bd	bd	51.003
J211-1.5	1.260	13.166	bd	bd	0.190	4.963	0.690	14.420	bd	bd	bd	bd	32.549
J230-0.5	bd	bd	bd	bd	0.050	8.034	bd	bd	bd	bd	bd	bd	8.034
J231-1.5	bd	bd	bd	bd	0.050	5.829	0.060	5.595	bd	bd	bd	bd	11.424
J233-3.5	bd	bd	bd	bd	0.160	4.160	0.450	9.360	bd	bd	bd	bd	13.521
J250-0.5	0.340	5.154	13.280	201.327	53.100	2012.51	3.120	94.599	bd	bd	bd	bd	2313.591
J251-1.5	0.520	16.836	bd	bd	0.070	5.666	bd	bd	bd	bd	bd	bd	22.503
J253-3.5	bd	bd	bd	bd	0.520	13.603	0.360	7.534	bd	bd	bd	bd	21.138
J270-0.5	bd	bd	bd	bd	0.070	2.248	0.270	6.937	bd	bd	bd	bd	9.185
J271-1.5	bd	bd	bd	bd	0.070	1.922	0.270	5.932	bd	bd	bd	bd	7.854
K200-0.5	5.280	310.269	0.720	42.309	0.190	27.912	0.090	10.577	bd	bd	bd	bd	391.068
K203-3.5	1.920	24.808	1.080	13.955	0.450	14.536	0.810	20.932	bd	bd	bd	bd	74.231
K220-0.5	0.760	234.040	bd	bd	0.190	146.275	0.120	73.907	bd	bd	bd	bd	454.222
K221-1.5	0.220	10.405	2.160	102.161	1.130	133.613	0.480	45.405	bd	bd	bd	bd	291.583
K223-3.5	bd	bd	bd	bd	0.080	1.849	0.260	4.808	bd	bd	bd	bd	6.657
K240-0.5	2.200	90.146	0.400	16.390	0.120	12.293	0.330	27.044	bd	bd	bd	bd	145.873
K241-1.5	1.340	60.138	bd	bd	0.040	4.488	0.030	2.693	bd	bd	bd	bd	67.319
K243-3.5	bd	bd	bd	bd	0.150	4.022	0.420	9.008	bd	bd	bd	bd	13.030

Table K-1. Manganese (continued)

Sample	EX sol'n	EX sed	WAS sol'n	WAS mg/kg	WAS sed	ER sol'n	ER mg/kg	MR sol'n	MR sed	OX1 Sol'n	OX1 mg/kg sed	OX2 sol'n	OX2 mg/L	OX2 sed	Total sed
K260-0.5	1.220	16.449	8.000	107.860	16.800	566.27	4.350	117.298	bd	bd	bd	bd	bd	bd	807.872
K261-1.5	0.960	43.781	0.960	43.781	0.410	46.745	0.090	8.209	bd	bd	bd	bd	bd	bd	142.515
K263-3.5	2.220	39.693	0.640	11.443	0.560	25.031	0.750	26.819	bd	bd	bd	bd	bd	bd	102.986
K280-0.5	1.260	28.508	bd	bd	bd	0.090	5.091	0.300	13.575	bd	bd	bd	bd	bd	47.174
K281-1.5	bd	bd	bd	bd	bd	0.140	11.664	0.190	12.664	bd	bd	bd	bd	bd	24.327
L210-0.5	bd	bd	135.600	1431.98	122.400	3231.5	24.700	521.681	bd	bd	bd	bd	bd	bd	5185.13
L211-1.5	0.980	10.324	1.080	11.378	1.450	38.190	1.110	23.388	bd	bd	bd	bd	bd	bd	83.280
L230-0.5	0.460	31.347	1.480	100.856	1.500	255.55	0.060	8.178	bd	bd	bd	bd	bd	bd	395.928
L231-1.5	0.320	19.640	2.800	171.847	6.640	1018.8	2.220	272.501	bd	bd	bd	bd	bd	bd	1482.80
L233-3.5	0.240	2.585	bd	bd	bd	0.130	3.500	0.540	11.631	bd	bd	bd	bd	bd	17.715
L250-0.5	1.600	16.929	1.840	19.469	1.170	30.949	1.440	30.473	bd	bd	bd	bd	bd	bd	97.821
L251-1.5	6.800	263.621	0.560	21.710	0.140	13.569	0.280	21.710	bd	bd	bd	bd	bd	bd	320.610
L253-3.5	1.580	59.897	bd	bd	bd	0.110	10.425	0.390	29.569	bd	bd	bd	bd	bd	99.891
L253-3.5	1.420	63.444	bd	bd	bd	0.150	16.755	0.330	29.488	bd	bd	bd	bd	bd	109.687
L253-3.5	1.640	58.619	bd	bd	bd	0.110	9.829	0.420	30.024	bd	bd	bd	bd	bd	98.472
L270-0.5	2.200	111.806	0.600	30.492	0.130	16.517	0.060	6.098	bd	bd	bd	bd	bd	bd	164.913
L271-1.5	1.000	23.540	0.440	10.358	0.110	6.474	0.280	13.182	bd	bd	bd	bd	bd	bd	53.554
L273-3.5	0.560	6.007	bd	bd	bd	0.180	4.827	0.570	12.229	bd	bd	bd	bd	bd	23.064
M200-0.5	0.380	4.357	0.840	9.631	1.350	38.694	0.660	15.134	bd	bd	bd	bd	bd	bd	67.815
M201-1.5	0.240	5.254	bd	bd	bd	1.350	73.883	0.170	7.443	bd	bd	bd	bd	bd	86.580
M220-0.5	10.460	191.040	0.760	13.881	0.130	5.936	0.330	12.054	bd	bd	bd	bd	bd	bd	222.911
M221-1.5	1.980	29.019	bd	bd	bd	0.080	2.931	0.330	9.673	bd	bd	bd	bd	bd	41.623
M223-3.5	1.220	12.931	bd	bd	bd	0.190	5.035	0.600	12.719	bd	bd	bd	bd	bd	30.686
M240-0.5	1.340	31.687	0.400	9.459	0.530	31.333	0.960	45.403	bd	bd	bd	bd	bd	bd	117.881
M241-1.5	74.000	3596.50	bd	bd	bd	0.050	6.075	bd	bd	bd	bd	bd	bd	bd	3602.58
M243-3.5	bd	bd	bd	bd	bd	0.050	1.410	0.200	4.511	bd	bd	bd	bd	bd	5.921

Table K-1. Manganese (continued)

Sample	EX sol'n	EX mg/kg	WAS sol'n	WAS mg/L	ER sed	ER sol'n	ER mg/kg	MR sol'n	MR mg/kg	OX1 Sol'n	OX1 sed	OX2 sol'n	OX2 sed	Total sed
M260-0.5	1.500	34.256	0.360	17.699	0.310	0.310	17.699	0.360	16.443	bd	bd	bd	bd	76.619
M261-1.5	1.140	31.634	bd	0.090	0.090	0.090	6.244	0.090	4.995	bd	bd	bd	bd	42.872
M280-0.5	8.560	186.906	1.400	30.569	0.640	0.640	34.936	0.930	40.613	bd	bd	bd	bd	293.023
M281-1.5	1.360	26.069	bd	bd	0.180	0.180	8.626	0.390	14.951	bd	bd	bd	bd	49.646
M283-3.5	0.320	3.595	bd	bd	0.230	0.230	6.459	0.750	16.850	bd	bd	bd	bd	26.904
N210-0.5	4.100	147.158	0.520	18.664	0.130	0.130	11.665	0.130	9.332	bd	bd	bd	bd	186.818
N211-1.5	1.520	46.842	bd	bd	0.100	0.100	7.704	0.130	8.012	bd	bd	bd	bd	62.558
N230-0.5	2.440	140.034	bd	bd	0.060	0.060	8.609	0.090	10.330	bd	bd	bd	bd	158.973
N231-1.5	bd	bd	bd	bd	0.050	0.050	1.484	0.170	4.036	bd	bd	bd	bd	5.520
N233-3.5	0.300	3.824	bd	bd	0.120	0.120	3.824	0.360	9.178	bd	bd	bd	bd	16.826
N250-0.5	1.440	16.750	bd	bd	0.130	0.130	3.780	0.480	11.167	bd	bd	bd	bd	31.697
N251-1.5	2.040	47.514	bd	bd	0.070	0.070	4.076	0.210	9.782	bd	bd	bd	bd	61.372
N253-3.5	0.300	3.660	bd	bd	0.150	0.150	4.575	0.570	13.908	bd	bd	bd	bd	22.142
O220-0.5	bd	bd	bd	bd	0.530	0.530	46.171	0.450	31.362	bd	bd	bd	bd	77.533
O22a1-1.5	2.200	84.983	1.040	40.174	0.190	0.190	18.349	0.420	32.448	bd	bd	bd	bd	175.953
O22b1-1.5	1.940	74.939	0.960	37.083	0.170	0.170	16.417	0.360	27.813	bd	bd	bd	bd	156.252
O22c1-1.5	2.200	82.665	1.040	39.078	0.200	0.200	18.788	0.390	29.309	bd	bd	bd	bd	169.839
O223-3.5	0.400	5.262	4.960	65.246	0.300	0.300	9.866	0.450	11.839	bd	bd	bd	bd	92.212
O240-0.5	3.420	160.798	0.440	20.687	0.110	0.110	12.930	0.270	25.389	bd	bd	bd	bd	219.804
O241-1.5	1.060	22.796	bd	bd	0.070	0.070	3.763	0.480	20.645	bd	bd	bd	bd	47.205
O243-3.5	0.920	12.684	0.680	9.375	0.250	0.250	8.617	0.570	15.717	bd	bd	bd	bd	46.392
P230-0.5	1.560	82.659	1.000	52.986	0.340	0.340	45.038	0.300	31.792	bd	bd	bd	bd	212.475
P231-1.5	0.220	2.832	1.160	14.931	0.180	0.180	5.792	0.330	8.495	bd	bd	bd	bd	32.050
P23a3-3.5	0.200	2.943	bd	bd	0.250	0.250	9.198	0.720	21.192	bd	bd	bd	bd	33.334
P23b3-3.5	0.220	2.900	bd	bd	0.260	0.260	8.568	0.750	19.772	bd	bd	bd	bd	31.240
P23c3-3.5	0.240	3.338	bd	bd	0.250	0.250	8.692	0.750	20.860	bd	bd	bd	bd	32.890

Table K-1. Manganese (continued)

Sample	EX sol'n mg/L	EX sed mg/kg	WAS sol'n mg/L	WAS sed mg/kg	ER sol'n mg/L	ER sed mg/kg	MR sol'n mg/L	MR sed mg/kg	OX1 sol'n mg/L	OX1 sed mg/kg	OX2 sol'n mg/L	OX2 sed mg/kg	Total sed mg/kg
P250-0.5	1.680	101.478	bd	bd	0.070	10.571	0.140	16.913	bd	bd	bd	bd	128.961
P251-1.5	1.420	66.600	bd	bd	0.070	8.208	0.190	17.823	bd	bd	bd	bd	92.630
P253-3.5	0.280	3.493	bd	bd	0.050	1.559	0.150	3.742	bd	bd	bd	bd	8.794
Q240-0.5	bd	bd	0.880	22.511	1.840	117.673	0.600	30.697	bd	bd	bd	bd	170.882
Q244-1.5	0.320	8.778	0.960	26.335	0.180	12.344	0.390	21.397	bd	bd	bd	bd	68.854
Q246-1.5	0.340	9.086	0.800	21.378	0.170	11.357	0.390	20.843	bd	bd	bd	bd	62.664
Q246-1.5	0.320	8.778	0.920	25.237	0.160	10.973	0.360	19.751	bd	bd	bd	bd	64.739
Q243-3.5	0.840	21.408	2.280	58.107	0.210	13.380	0.300	15.291	bd	bd	bd	bd	108.187
Q260-0.5	6.440	78.904	69.200	847.848	1bd	306.303	9.630	235.976	bd	bd	bd	bd	1469.031
R250-0.5	8.340	295.640	1.120	39.702	0.190	16.838	0.390	27.650	bd	bd	bd	bd	379.830
R251-1.5	1.880	37.547	bd	bd	0.110	5.492	0.420	16.776	bd	bd	bd	bd	59.815
R253-3.5	0.600	7.281	bd	bd	0.130	3.944	0.360	8.738	bd	bd	bd	bd	19.963
R270-0.5	1.960	74.333	bd	bd	0.090	8.533	0.300	22.755	bd	bd	bd	bd	105.620
R271-1.5	1.120	60.383	bd	bd	0.100	13.478	0.230	24.800	bd	bd	bd	bd	98.662
R273-3.5	0.840	28.219	bd	bd	0.130	10.918	0.420	28.219	bd	bd	bd	bd	67.356
S260-0.5	1.980	52.151	5.360	141.177	24.500	1613.26	2.580	135.909	bd	bd	bd	bd	1942.501
S261-1.5	7.000	346.734	0.680	33.683	0.190	23.528	0.240	23.776	bd	bd	bd	bd	427.721
T270-0.5	0.180	4.533	1.800	45.330	5.860	368.932	1.050	52.885	bd	bd	bd	bd	471.680
T271-1.5	2.780	115.132	0.440	18.222	0.140	14.495	0.360	29.818	bd	bd	bd	bd	177.668
U260-0.5	0.520	5.406	0.600	6.238	0.160	4.158	0.330	6.861	bd	bd	bd	bd	22.664
U261-1.5	0.400	4.528	bd	bd	0.140	3.962	0.450	10.189	bd	bd	bd	bd	18.680
U263-3.5	0.460	5.230	bd	bd	0.140	3.979	0.330	7.504	bd	bd	bd	bd	16.713

Appendix K

Table K-2. Replicate Sample Analysis for Manganese

sed indicates concentration in sediment (dry weight basis)

AVG indicates the average of three replicate samples. RSD indicates the relative standard deviation of the three replicates. SRM 2704 is NIST Buffalo River Sediment

Sample Replicate	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1 sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
B3a0-0.5	bd	bd	5.315	17.009	bd	bd	22.325
B3b0-0.5	bd	bd	4.411	14.114	bd	bd	18.525
B3c0-0.5	bd	bd	3.600	14.594	bd	bd	18.194
AVG	--	--	4.44	15.24	--	--	19.68
RSD	--	--	19.31	10.18	--	--	11.66
B9a0-0.5	bd	5.059	75.879	33.724	bd	bd	114.662
B9b0-0.5	bd	5.746	69.617	35.361	bd	bd	110.725
B9c0-0.5	bd	5.017	71.073	34.282	bd	bd	110.372
AVG	--	5.27	72.19	34.46	--	--	111.92
RSD	--	7.77	4.54	2.42	--	--	2.13
B13a1-1.5	bd	bd	5.482	9.188	bd	bd	14.670
B13b1-1.5	bd	bd	5.053	9.882	bd	bd	14.935
B13c1-1.5	bd	bd	4.911	11.094	bd	bd	16.006
AVG	--	--	5.15	10.05	--	--	15.20
RSD	--	--	5.77	9.59	--	--	4.65

Table K-2. Manganese (continued)

Sample Replicate	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1 sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
D9a3-3.5	bd	bd	bd	8.914	bd	bd	8.914
D9b3-3.5	bd	bd	bd	8.973	bd	bd	8.973
D9c3-3.5	bd	bd	bd	9.369	bd	bd	9.369
AVG	--	--	--	9.09	--	--	9.09
RSD	--	--	--	2.72	--	--	2.72
F17a3-3.5	bd	bd	3.186	11.216	bd	bd	14.403
F17b3-3.5	bd	bd	2.735	11.378	bd	bd	14.113
F17c3-3.5	bd	bd	3.541	10.459	bd	bd	14.000
AVG	--	--	3.15	11.02	--	--	14.17
RSD	--	--	12.81	4.45	--	--	1.47
I26a1-1.5	bd	18.009	283.005	38.592	bd	bd	339.606
I26b1-1.5	bd	31.917	277.716	40.621	bd	bd	350.254
I26c1-1.5	bd	37.415	271.811	53.702	bd	bd	362.928
AVG	--	29.11	277.51	44.30	--	--	350.93
RSD	--	34.35	2.02	18.51	--	--	3.33
J19a0-0.5	bd	bd	4.179	13.373	bd	bd	17.552
J19b0-0.5	bd	bd	bd	14.824	bd	bd	14.824
J19c0-0.5	bd	bd	bd	14.587	bd	bd	14.587
AVG	--	--	1.39	14.26	--	--	15.65
RSD	--	--	173.21	5.46	--	--	10.52

Table K-2. Manganese (continued)

Sample Replicate	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1 sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
L25a3-3.5	59.897	bd	10.425	29.569	bd	bd	99.891
L25b3-3.5	63.444	bd	16.755	29.488	bd	bd	109.687
L25c3-3.5	58.619	bd	9.829	30.024	bd	bd	98.472
AVG	60.65	--	12.34	29.69	--	--	102.68
RSD	4.12	--	31.11	0.97	--	--	5.95
O22a1-1.5	84.983	40.174	18.349	32.448	bd	bd	175.953
O22b1-1.5	74.939	37.083	16.417	27.813	bd	bd	156.252
O22c1-1.5	82.665	39.078	18.788	29.309	bd	bd	169.839
AVG	80.86	38.78	17.85	29.86	--	--	167.35
RSD	6.50	4.04	7.06	7.92	--	--	6.03
P23a3-3.5	2.943	bd	9.198	21.192	bd	bd	33.334
P23b3-3.5	2.900	bd	8.568	19.772	bd	bd	31.240
P23c3-3.5	3.338	bd	8.692	20.860	bd	bd	32.890
AVG	3.06	--	8.82	20.61	--	--	32.49
RSD	7.88	--	3.79	3.61	--	--	3.40
Q24a1-1.5	8.778	26.335	12.344	21.397	bd	bd	68.854
Q24b1-1.5	9.086	21.378	11.357	20.843	bd	bd	62.664
Q24c1-1.5	8.778	25.237	10.973	19.751	bd	bd	64.739
AVG	8.88	24.32	11.56	20.66	--	--	65.42
RSD	2.00	10.71	6.12	4.05	--	--	4.82

Table K-2. Manganese (continued)

Sample Replicate	EX sed mg/kg	WAS sed mg/kg	ER sed mg/kg	MR sed mg/kg	OX1 sed mg/kg	OX2 sed mg/kg	Total sed mg/kg
SRM2704 2/3/97	bd	10bd	111.574	67.407	bd	bd	278.981
SRM2704 2/17/97	bd	114.786	109.679	64.591	bd	bd	289.056
SRM2704 2/24/97	bd	115.464	95.127	69.728	bd	bd	280.319
SRM2704 3/10/97	bd	108.217	112.893	64.367	bd	bd	285.477
SRM2704 3/24/97	bd	112.735	102.357	63.985	bd	bd	279.076
SRM2704 4/7/97	bd	104.134	115.642	66.145	bd	bd	285.922
AVG	--	109.22	107.88	66.04	--	--	283.14
RSD	--	5.71	7.13	3.36	--	--	1.50

Appendix L

Table L-1. Chemical Compositions of the Treatment Water

Compound or Element	Concentration from Galloway et al., (1976) (μM)	Microcosms Acidic Conditions (μM)	Microcosms 'Natural' Conditions (μM)
H^+ (as pH)	3.84	3.86 **	5.61 **
Na^+	1.2	1.2	135.8
K^+ *	0.26	23.3	23.3
Ca^+	6.5	6.5	6.5
Mg^{2+}	1.5	1.5	1.5
NH_4^+	29.4	29.4	29.4
Cl^-	19.2	19.2	19.2
Br^- *	0.0	142.7	142.7
NO_3^-	45.2	45.2	45.2
SO_4^{2-}	58.4	58.4	58.4

* KBr was added to the exchange solution to serve as a tracer.

** These pHs are the average of all pH values for the actual exchange solutions.

Appendix M Microcosm Data

Table M-1. Acid Rain Microcosm Data -- pH

Two dashes (--) indicates a parameter that was not measured.

Day x	0	7	14	21	27	34	41	48	55	62	69	76	82	112	144	171
Sample																
K22 Acid	7.23	7.42	7.17	7.14	7.20	7.12	7.27	7.17	7.11	7.01	6.97	--	7.05	6.92	6.95	6.81
N23 Acid	7.09	7.14	6.90	6.88	6.91	6.78	6.98	6.87	6.74	6.66	6.58	6.68	6.66	6.25	6.6	6.11
P25 Acid	7.16	7.42	7.01	6.94	6.87	6.8	7.11	6.82	7.01	6.79	6.84	6.9	6.71	6.34	6.64	6.46
J23 Acid	7.81	7.74	7.31	7.11	7.28	7.11	7.17	7.23	7.2	7.12	7.18	7.12	7.08	6.97	6.77	6.62
O22 Acid	8.28	8.11	7.70	7.58	7.75	7.41	7.63	7.64	7.4	7.37	7.65	8.18	8.01	7.88	7.69	7.48
J19 Acid	7.81	7.62	7.09	6.87	6.98	6.84	7.04	6.94	6.99	7.02	6.99	6.85	7.06	6.74	6.92	6.65
K22 Control	7.86	7.95	7.24	7.45	7.29	7.15	7.46	7.33	7.3	7.09	7.09	--	7.14	7.05	7.1	6.99
N23 Control	7.69	7.43	7.08	6.92	6.98	6.93	7.16	6.89	6.85	6.81	6.66	6.84	6.84	6.47	6.6	6.5
P25 Control	7.78	7.06	7.00	6.86	6.78	6.71	7	6.83	6.94	6.69	6.69	6.91	6.77	6.56	6.76	6.71
J23 Control	7.75	7.38	6.90	6.68	6.88	6.66	7.03	6.95	7	6.91	6.98	6.98	6.89	6.91	6.84	6.8
O22 Control	8.24	8.01	8.13	7.99	8.15	7.78	8.28	8.25	8.25	8.21	8.29	8.31	8.33	7.52	8.06	7.91
J19 Control	7.6	6.81	6.75	6.70	6.74	6.66	6.89	6.79	6.9	6.84	6.82	6.77	6.96	6.71	6.82	6.93

Table M-2. Acid Rain Microcosm Data – Chromium (µg/L)

Day x Sample	0	7	14	21	27	34	41	48	55	62	69	76	82	112	144	171
K22 Acid	13.45	53	44.2	42.25	36.05	23.6	21.2	12.55	11.15	4.3512	33.7	15.29	14.58	12.68	23.22	29.24
N23 Acid	21.75	89.4	91.7	143.4	88.1	70.95	53	40	29.6	32.45	42.9	46.96	41.42	44.32	49.2	49.86
P25 Acid	89.25	233.1	176.4	151.55	130.95	105.2	89.6	69.45	58.85	60.1	67.35	73.7	66.28	78.44	107.3	93.7
J23 Acid	31.7	47.6	40.6	54.65	35.5	37.4	26.6	26.23	21.25	21.35	30.45	25.92	27.92	34.26	37.89	44.15
O22 Acid	10.55	21.1	33.4	18.05	13.2	17.3	11.3	9.42	8.76	9.4	9.85	11.47	8.38	9.48	7.88	7.19
J19 Acid	207	1681	1317	1273	983	919	620	589	509	377	447	416.8	377.4	547.4	764.25	471.71
K22 Control	25.05	96.4	65.7	58.1	53.25	50.1	38.1	34.75	35	23.55	13.85	31.85	33.96	40.82	49.42	54.99
N23 Control	43.65	102.3	85.6	89.35	128.75	72.75	56.55	47.25	49.6	33.95	45	48.32	45.08	52.3	64.48	65.23
P25 Control	65.95	206.2	132.7	117.8	108.5	93.55	76	67.8	87.85	48	66.1	58.9	68.3	100.24	120.92	117.61
J23 Control	22.9	45.5	40.3	42.5	43.25	42.55	33.85	32.15	39.95	37.95	35.1	32.84	33.32	37.3	47.82	45.44
O22 Control	16.25	37.7	39.6	29.8	33.15	42.25	25.7	21.5	24.45	20.95	21.55	18.28	20.5	12	9.42	9.14
J19 Control	152.7	913	889	1006	826	667	386.1	308	312.8	283.8	272.6	280	255.8	383	505.5	597.1

Table M-3. Acid Rain Microcosm Data – Dissolved Organic Carbon (mg/L C)

Two dashes (--) indicates a parameter that was not measured.

Day x Sample	0	7	14	21	27	34	41	48	55	62	69	76	82	112	144	171
K22 Acid	--	3.272	9.66	9.29	6.058	5.8	4.77	2.812	2.154	2.846	2.844	2.634	5.892	4.242	4.424	--
N23 Acid	--	10.948	11.802	10.586	8.488	7.816	6.32	3.72	3.038	2.658	1.822	1.56	2.774	2.572	2.33	--
P25 Acid	--	17.106	18.324	15.986	12.862	11.24	10.808	6.038	6.14	5.438	5.88	3.656	4.12	5.378	4.58	--
J23 Acid	--	15.378	11.408	8.452	8.206	8.786	4.616	3.816	4.258	3.722	3.64	2.962	2.99	5.388	4.1	--
O22 Acid	--	15.702	17.138	19.21	26	8.908	10.022	7.106	5.544	4.108	5.012	3.266	4.244	5.068	4.256	--
J19 Acid	--	60.42	62.12	61.86	39.88	36.86	31.6	25.9	22.38	19.784	19.37	18.174	14.194	36.96	20.04	--
K22 Control	--	27.7	17.166	12.434	10.238	8.46	7.27	5.754	5.05	3.672	8.042	4.732	5.618	6.656	7.966	--
N23 Control	--	14.632	11.87	12.134	7.904	7.98	6.488	5.144	3.142	3.692	2.542	2.49	2.34	3.426	3.072	--
P25 Control	--	26.36	19.284	15.71	15.254	11.706	9.856	6.946	7.33	5.598	6.222	5.726	4.936	8.904	7.39	--
J23 Control	--	100.54	58.64	50.7	35.9	25.28	17.918	12.646	10.852	9.244	7.858	6.11	10.282	10.046	10.002	--
O22 Control	--	--	16.96	47.88	11.758	7.804	7.35	5.77	4.262	3.61	4.61	3.638	3.554	4.62	4.404	--
J19 Control	--	30.63	27.64	30.44	23.1	17.394	19.302	19.324	15.118	11.378	12.696	10.974	11.186	22.82	17.716	--

Table M-4. Nutrient Microcosm Data – Chromium (µg/L)

Day x Sample	1	7	14	22	29	36	43	50	57	64	71	107
O22 N	13	9.27	7.21	5.02	4.7	4.57	5.96	5.12	4.58	4.63	4.01	5.6
J19 N	176.79	309.67	363.46	356.24	321.15	295.33	340.07	294.28	285.92	229.97	250.83	677.63
P25 N	93.62	214.97	203.17	190.21	174.76	165.57	211.29	181.08	179.12	160.01	142.19	138.74
N23 N	59.19	97.53	115.76	141.02	156.48	158.31	168.62	181.74	177.75	167.75	168.44	281.93
J23 N	39.56	59.32	55.31	54	53.41	54.21	61.29	64.37	62.09	86.86	64.15	78.54
K22 N	43.96	62.59	82.23	94.06	103.23	58.83	87.01	88.46	107.58	91.12	79.92	88.89
O22 N&P	27.43	8.94	6.35	5.74	4.69	12	8.87	7.96	8.09	7.22	8.81	4.95
J19 N&P	310.02	515.59	585.96	531.06	480.28	426.56	425.76	400.72	366.23	336.4	333.09	613
P25 N&P	106.09	132.7	115.8	93.17	114.16	109.98	118.5	119.35	127.03	110.93	100.29	122.9
N23 N&P	24.34	40.39	42.05	53.88	66.38	50.74	55.26	68.04	60.88	55.7	60.51	69.75
J23 N&P	28.95	47.15	50.47	51.02	54.25	55.51	71.1	62.19	56.81	53.57	53.12	52.21
K22 N&P	5.72	18.21	14.18	12.24	10.33	9.89	13.48	14.21	42.36	16.56	18.78	26
O22 Control	66.03	35.68	29	33.69	33.65	36.92	39.13	40.09	43.55	45.13	33.39	12.75
J19 Control	170.39	303.46	332.02	352.16	338.67	315.73	315.5	277.95	250.2	233.4	246.84	401.42
P25 Control	90.81	141.06	33.09	97.04	85.74	92.16	101.55	114.72	103.81	106.46	90.63	75.77
N23 Control	6.77	10.1	120.46	42.54	28.14	60.32	65.5	27.14	35.26	43.48	46.11	49.91
J23 Control	23.02	31.7	27.49	29.43	24.51	24.75	27.94	28.85	29.54	53.11	49.74	39.96
K22 Control	40	57.95	55.18	53.82	46.02	52.2	45.62	42.96	43.53	48.98	48.46	70.39

Table M-5. Nutrient Microcosm Data – Dissolved Organic Carbon (mg/L C)

Day *	1	7	14	22	29	36	43	50	57	64	71	107
Sample												
O22 N	22.56	13.818	11.068	6	4.684	5.835	6.234	3.522	4.466	2.906	3.276	4.39
J19 N	14.946	23.58	20.34	20.82	18.548	15.868	18.288	16.34	12.214	10.746	11.368	24.654
P25 N	18.036	20.54	15.894	12.912	10.232	8.932	12.058	10.952	9.618	7.976	8.01	6.776
N23 N	79.56	41.71	21.72	19.406	18.578	13.06	12.714	13.26	11.036	10.97	10.214	20.3
J23 N	34.94	12.56	10.084	8.332	5.992	5.328	6.39	4.08	3.916	3.722	3.444	7.81
K22 N	121.6	49.8	29.64	29.5	20.16	23.8	29.915	20.676	14.698	14.78	12.862	18.862
O22 N&P	18.42	9.872	10.032	10.954	5.844	6.256	8.12	5.217	4.078	2.888	2.764	6.178
J19 N&P	32.91	44.52	45.1	36.42	34.66	28.52	31.78	32.874	24.68	25.986	21.72	45.48
P25 N&P	--	27.98	21.984	16.338	16.106	13.72	26.37	22.827	11.584	11.28	11.964	14.908
N23 N&P	17.474	17.158	19.498	9.658	10.358	8.648	10.094	10.29	6.892	8.218	7.186	11.186
J23 N&P	8.86	8.086	8.306	8.434	6.294	5.728	5.806	4.875	4.91	4.154	3.986	5.464
K22 N&P	3.33	4.33	7.234	7.534	4.584	4.886	6.39	6.339	6.028	6.804	6.498	5.002
O22 Control	32.7	--	13.04	10.174	9.644	7.282	10.012	9.842	3.912	8.208	5.242	17.99
J19 Control	99.4	--	99.7	128.3	112.12	95.72	98.6	82.1	35.41	56.08	44.88	103.92
P25 Control	28.36	--	11.558	13.43	12.5	10.414	13.776	14.806	5.486	8.92	8.698	11.28
N23 Control	5.25	--	15.272	10.968	8.174	8.876	11.326	5.81	3.018	7.294	7.136	7.208
J23 Control	46.86	--	11.964	7.52	7.288	6.318	13.958	6.552	3.727	7.558	7.762	9.864
K22 Control	32.04	--	9.795	11.988	7.236	6.754	7.99	8.164	3.141	6.148	4.802	8.776

Table M-6. Nutrient Microcosm Data – Nitrate (mg/L NO₃)

Day x Sample	1	7	14	22	29	36	43	50	57	64	71	107
O22 N	35.87	31.46	32.31	34.30	32.56	31.75	30.90	31.17	34.95	34.53	3.22	2.12
J19 N	76.04	32.50	33.47	33.75	39.34	41.51	36.98	40.95	39.09	45.12	9.88	1.44
P25 N	32.13	24.65	24.15	21.36	25.10	30.56	25.80	27.91	27.72	28.74	3.21	2.52
N23 N	19.14	13.74	18.13	18.04	20.59	22.64	25.69	18.81	25.00	29.82	0.46	0.69
J23 N	8.69	9.86	23.12	22.41	30.06	30.84	25.06	30.03	31.66	36.95	23.85	bd
K22 N	28.41	23.90	27.04	18.43	19.88	32.24	21.56	22.66	24.52	26.74	3.54	1.05
O22 N&P	12.40	11.20	12.11	8.47	11.71	4.89	4.89	6.45	6.83	7.48	1.46	1.46
J19 N&P	10.57	1.68	1.43	1.04	1.03	0.68	0.56	0.62	bd	1.17	--	0.14
P25 N&P	--	0.44	0.65	0.37	0.89	0.85	0.41	0.82	1.61	0.92	bd	0.14
N23 N&P	14.51	10.65	11.35	9.34	9.54	11.22	9.89	9.53	11.01	11.09	3.40	2.06
J23 N&P	1.36	1.44	1.92	2.73	1.88	1.71	1.59	1.53	2.66	2.53	bd	0.22
K22 N&P	16.43	13.73	13.67	12.70	13.76	15.36	14.90	13.84	16.48	13.79	3.52	2.60
O22 Control	0.42	0.31	0.55	0.40	0.55	0.39	0.31	0.17	2.36	0.21	0.23	0.65
J19 Control	1.37	0.35	0.35	0.29	0.26	0.31	0.04	0.17	bd	0.33	0.75	0.26
P25 Control	bd	bd	1.61	0.24	0.26	0.37	bd	0.11	1.53	0.23	0.36	0.14
N23 Control	2.38	1.74	0.24	0.98	1.55	1.25	0.72	1.69	3.52	1.36	1.83	1.07
J23 Control	0.05	0.02	0.38	1.26	0.54	0.66	0.51	0.56	0.81	0.30	1.44	bd
K22 Control	0.16	0.24	0.22	0.15	0.36	0.63	0.51	0.71	0.90	1.06	0.78	0.40

Table M-7. Nutrient Microcosm Data – Sulfate (mg/L SO₄²⁻)

Day x Sample	1	7	14	22	29	36	43	50	57	64	71	107
O22 N	26.75	36.33	28.69	35.78	47.25	56.03	58.73	60.50	66.31	66.90	83.96	221.49
J19 N	13.53	14.87	12.90	9.65	7.12	6.83	6.43	6.82	6.05	8.04	25.42	51.42
P25 N	2.19	2.65	4.72	6.18	6.69	8.29	8.90	9.20	7.62	9.25	30.21	102.22
N23 N	1.29	2.43	3.65	4.30	5.74	7.02	7.94	7.76	8.01	10.26	32.02	2.11
J23 N	2.97	5.82	9.60	10.27	10.49	11.91	11.29	10.71	9.75	11.99	17.65	48.55
K22 N	2.00	3.14	3.74	4.41	4.44	6.11	5.04	4.97	7.10	6.81	32.46	47.50
O22 N&P	17.69	14.65	12.05	11.90	11.75	15.38	12.39	12.87	13.27	13.45	19.51	47.30
J19 N&P	27.71	15.70	8.70	4.26	2.79	2.45	2.07	2.15	1.91	2.62	--	3.78
P25 N&P	--	1.20	1.53	1.41	1.45	1.95	1.63	1.84	2.57	2.09	4.66	5.23
N23 N&P	4.53	3.90	4.17	3.40	3.42	3.96	4.65	3.79	4.30	4.10	11.52	13.80
J23 N&P	4.09	5.01	4.45	4.78	3.73	3.94	3.32	3.16	3.52	3.52	5.09	4.13
K22 N&P	5.23	4.36	4.30	4.03	4.36	5.33	5.12	4.74	4.39	4.62	15.43	15.35
O22 Control	21.55	7.81	6.86	7.94	7.89	8.28	9.12	8.67	9.30	7.99	7.15	39.07
J19 Control	14.16	6.87	4.68	3.76	3.29	2.45	2.33	2.40	2.08	2.34	1.89	1.17
P25 Control	1.09	1.60	3.32	2.21	2.06	2.08	2.20	1.52	1.54	1.92	1.02	2.03
N23 Control	5.36	4.15	1.74	3.04	3.93	3.12	3.25	4.53	4.69	4.21	2.78	3.33
J23 Control	1.56	2.65	2.41	2.53	2.89	2.67	2.61	2.21	2.20	1.56	0.66	1.53
K22 Control	2.47	2.65	2.23	2.57	2.88	2.97	3.71	3.84	3.71	3.78	3.00	2.59

