MICROBIAL REDUCTION OF HEXAVALENT CHROMIUM UNDER VADOSE ZONE CONDITIONS

by

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ABSTRACT

Improper disposal of hexavalent chromium [Cr(VI)] in arid and semi-arid regions has led to contamination of underlying vadose zones and aquifers. To remediate Cr(VI) contamination, soluble Cr(VI) can be reduced to insoluble Cr(III). The objectives of this study were to assess the potential for immobilizing Cr(VI) contamination using a native microbial community to reduce Cr(VI) to Cr(III) under conditions similar to those found in the vadose zone, and to evaluate the potential for enhancing biological reduction of Cr(VI) through the addition of nutrients. Batch microcosm and unsaturated flow column experiments were performed. Native microbial communities in subsurface sediments with no prior Cr(VI) exposure were shown to be capable of Cr(VI) reduction. In both the batch and column experiments, Cr(VI) reduction and loss from the aqueous phase were enhanced by adding both nitrate (NO_3^-) and organic carbon (molasses). These results suggest that biostimulation of microbial Cr(VI) reduction by nutrient amendment is a promising strategy for remediation of Cr(VI)-contaminated vadose zones. This thesis presents a journal article, submitted to ***Environmental Science & Technology***, that describes the experiments performed and discusses the results of these experiments. Supporting data for the journal article are provided in the thesis appendices.

ACKNOWLEDGMENTS

I would like to thank the U.S. Department of Energy Natural and Accelerated Bioremediation (NABIR) Program for funding this project. I thank my advisors Dr. Robert Bowman and Dr. Thomas Kieft and committee members Dr. Jan Hendrickx and Dr. John Wilson for all of their support and assistance. I also would like to thank collaborators on the project, Dr. Fred Brockman at Pacific Northwest National Laboratory and Dr. David Balkwill at Florida State University.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This thesis includes a journal article and supporting appendices for a study conducted in order to better understand the effects of native microbial populations on reduction of hexavalent chromium [Cr(VI)] to trivalent forms [Cr(III)] under vadose zone conditions. Batch and column experiments were performed to evaluate the potential for enhancing bioremediation of Cr(VI) in contaminated vadose zones. Various combinations of nutrients were tested including organic carbon (in the form of molasses), nitrogen [in the form of nitrate (NO_3^-)], and combinations of both. An additional objective of the study was to assess the effects that Cr(VI) and the nutrient additions have on microbial community activity and structure. The journal article is entitled "Microbial Reduction of Hexavalent Chromium Under Vadose Zone Conditions" and has been submitted to the journal ***Environmental Science & Technology***.

This study was part of a larger project entitled "Vadose zone microbial community structure and activity in radionuclide/metals contaminated sediments," funded by the U.S. Department of Energy Natural and Accelerated Bioremediation Research (NABIR) Program. The principal investigator and co-principal investigators of this NABIR project are Dr. Fred J. Brockman (Environmental Microbiology Group, Battelle-Pacific Northwest National Laboratory), Dr. Thomas L. Kieft (Department of Biology, New Mexico Institute of Mining and Technology), and Dr. David L. Balkwill (Department of Biological Sciences, Florida State University).

Supporting data for the article are provided in the appendices. Physical and chemical characteristics of the vadose zone sediment used in the experiments are provided in Appendix A. These include grain size analyses, chemical analyses, soil moisture characteristic curves, batch sorption data for Cr(VI), and mineralogical analyses. Data from the batch microcosm experiments are provided in Appendix B, including soil water content data that was used to correct the initial and final aqueous Cr(VI) concentrations for variations in water content. Data and results from the column experiments are provided in Appendix C. These data include water content data, flow rate data, soil water tension data, influent and effluent Cr, NO_3^-, and pH data, results from x-ray fluorescence (XRF) spectroscopy and X-ray absorption near edge structure (XANES) spectroscopy of sediments from the columns, and tritium tracer test data. Procedures to correct flow data and effluent Cr data for evaporation are also described.

PAPER ENTITLED

"MICROBIAL REDUCTION OF HEXAVALENT CHROMIUM UNDER VADOSE ZONE CONDITIONS"

By Douglas S. Oliver, Fred J. Brockman, Thomas L. Kieft, Robert S. Bowman

ABSTRACT

Hexavalent chromium [Cr(VI)] is a common constituent of wastes associated with nuclear reactor operation and fuel processing. Improper disposal at facilities in arid and semi-arid regions has led to contamination of underlying vadose zones and aquifers. The objectives of this study were to assess the potential for immobilizing Cr(VI) contamination using a native microbial community to reduce soluble Cr(VI) to insoluble Cr(III) under conditions similar to those found in the vadose zone, and to evaluate the potential for enhancing biological reduction of Cr(VI) through the addition of nutrients. Batch microcosm and unsaturated flow column experiments were performed. Native microbial communities in subsurface sediments with no prior Cr(VI) exposure were shown to be capable of Cr(VI) reduction. In both the batch and column experiments, Cr(VI) reduction and loss from the aqueous phase were enhanced by adding high levels of both nitrate (NO_3^-) and organic carbon (molasses). Nutrient amendments resulted in up to 87% Cr(VI) reduction in unsaturated batch experiments. Molasses and nitrate additions to 15-cm length unsaturated flow columns receiving 65 mg L^{-1} Cr(VI) resulted in microbially mediated reduction and immobilization of 10% of the Cr during a 45-day experiment. First-order decay constants calculated for Cr(VI) loss from these columns ranged from 0.07 to 0.10 d^{-1}. All of the immobilized Cr was in the form of Cr (III), as shown by XANES analysis. This suggests that biostimulation of microbial Cr(VI) reduction in vadose zones by nutrient amendment is a promising strategy; and that immobilization of close to 100% of Cr contamination could be achieved in a thick vadose zone with longer flow paths and longer contact times than in this experiment.

INTRODUCTION

Past methods for disposing of industrial wastes in arid to semi-arid regions included placement in ponds, trenches, landfills, leach fields, or injection wells, and were based on the mistaken belief that potential contaminants would remain in the thick vadose zones and not migrate to underlying aquifers. At Department of Energy (DOE) facilities in the western United States one of the most common contaminants is hexavalent chromium [Cr(VI)], a common constituent of wastes associated with nuclear reactor operation, irradiated fuel processing, and fuel fabrication (*1*). The DOE's Hanford Site in eastern Washington state is typical of these facilities: it is located in a semi-arid region, has a thick vadose zone and due to improper disposal of industrial wastes, is contaminated with a variety of compounds including Cr(VI). Methods to remediate Cr(VI)-contaminated vadose zones are needed to prevent further contamination of groundwater.

Within the range of pH and Eh encountered in most natural waters, chromium occurs as Cr(III) and Cr(VI) (*2*). The trivalent form is far less toxic than the hexavalent form, and is far less mobile in groundwater, being found either as cationic species that sorb to solids or as relatively insoluble precipitates such as $Cr(OH)_3^0$ (*3*). The hexavalent form typically occurs as anionic species such as chromate (CrO_4^{2-}) that tend to be mobile in groundwater.

To remediate chromium-contaminated groundwater and soil *in situ*, Cr(VI) can be reduced to Cr(III) (*4-6*). A variety of bacteria have been shown to reduce Cr(VI) to Cr(III) under either aerobic conditions (*7-14*) or anaerobic conditions (*15-17*). Bacteria used in these studies generally were isolated from sewage sludge or chromium-contaminated soil and water. Most studies of microbial Cr(VI) reduction have involved pure cultures, although a few have examined Cr(VI) reduction by native communities in soil and aquifer materials (*18-20*). Cifuentes et al. (*18*) and Bader et al. (*20*) examined microbial reduction of Cr(VI) in surface soil samples by indigenous microorganisms with and without organic amendments. However, little research has been concerned specifically with microbial reduction of Cr(VI) in vadose zone subsoils or sediment materials.

Tolerance of bacteria to Cr(VI) is very important when considering the effectiveness of microbial reduction for site remediation. If concentrations in the soil or groundwater are too high, even chromium-tolerant bacteria will be inhibited, thus eliminating bioremediation as a feasible approach. Within soil or water contaminated with Cr(VI), bacteria that are resistant to and reduce Cr(VI) will have a selective advantage (*21*). However, the ability of bacteria to tolerate Cr(VI) and reduce Cr(VI) are not necessarily related (*11*). Bacteria reduce Cr(VI) to Cr(III) either as a detoxification process, in which no energy is gained, or as a terminal-electron accepting process that is coupled to organic carbon oxidation (*19, 21*).

The primary goal of this study was to assess the effects of a native microbial community on reduction of Cr(VI) to Cr(III) under conditions similar to those found in the vadose zone. A related goal was to evaluate the potential for enhancing biological reduction of Cr(VI) through the addition of nutrients. Batch microcosm experiments were performed to assess whether native populations were capable of Cr(VI) reduction and to evaluate treatments for enhancing Cr(VI) reduction. Treatments included addition of organic carbon (molasses) and/or nitrate (NO_3^-). Based on the results of the batch experiments, column experiments were used to assess Cr(VI) reduction under unsaturated flow conditions.

MATERIALS AND METHODS

Porous Medium. The porous medium used in the batch and column experiments was a subsurface sediment collected in Richland, WA, approximately 2 km from the Hanford Site 300 Area (former reactor fuel fabrication facility, now contaminated with Cr(VI)). The selected site was uncontaminated but is similar to contaminated areas in that it had been subjected to artificial recharge, although by irrigation rather than by contaminated wastewater. Microbial populations at this site were expected to be similar to those of contaminated areas at the Hanford Site, except that native Cr-tolerant microbes were not expected to be abundant.

The sediment was collected beneath the root zone at a depth interval of 1 to 2 m below the ground surface. Overlying soil was removed with a backhoe. Samples were collected with flame-sterilized shovels. Samples were composited in the field and sealed in five-gallon buckets that had been sterilized with a 10% bleach solution and rinsed with sterile deionized water. Samples were stored at 5°C. Prior to use in the experiments, the sediment was homogenized using a sample splitter. The field gravimetric soil water content of the samples was 3.3 %; drying was minimized during handling in order to sustain the bacteria and to minimize particle sorting by grain size during column packing. The sediment was primarily medium to coarse sand with minor amounts of silt (1-3 %)

and clay (5-6 %) and trace gravel. Most of the sand was quartz with some feldspar, volcanic glass, and a minor amount of mafic minerals including biotite and magnetite. The pH of the sediment was 8.04 (determined in a saturated paste). Total organic carbon was 0.34%. Background Cr(III) and Cr(VI) concentrations for the sediment were 37 $\mu g\ g^{-1}$ [determined using x-ray fluorescence (XRF) spectroscopy] and $< 5\ \mu g\ g^{-1}$ [determined using X-ray absorption near edge structure (XANES) spectroscopy], respectively.

Synthetic Pore Water. The synthetic pore water composition was based upon water collected from Well 600-S3-25 at the Hanford Site (*22*). The well water is dominated by calcium, bicarbonate, and sulfate and is saturated with respect to calcite. To avoid precipitation problems, the dominant anion used in the synthetic pore water was sulfate rather than bicarbonate. The synthetic pore water consisted of 0.087 g $NaHCO_3$, 0.086 g $MgSO_4{\cdot}7H_2O$, 0.051 g $MgCl_2{\cdot}6H_2O$, 0.293 g $CaSO_4{\cdot}2H_2O$, and 0.014 g KCl L^{-1} of deionized water.

Cr(VI) was added to the synthetic pore water in varied amounts in the form of K_2CrO_4. KNO_3 and molasses (Grandma's Molasses, Mott's USA, Stamford, CT or Brer Rabbit, Nabisco, Inc., East Hanover, NJ) were added to the synthetic pore water for the nutrient additions of NO_3^- and organic carbon. NO_3^- was selected because it is a common co-contaminant with Cr(VI) and is present at high concentrations in contaminated regions of the vadose zone at the Hanford Site (*1*), provides nitrogen for microbial growth, and may be used as an electron acceptor in dissimilatory NO_3^- reduction. Molasses was selected because it is an inexpensive source of organic carbon suitable for remediation schemes (*23*). All solutions were filter-sterilized (0.22-µm pore-size) before use.

Batch Microcosm Experiments. The batch microcosm experiment consisted of nine treatments, each in triplicate, representing all combinations of control, low, and high concentrations of NO_3^- (0, 346 mg L^{-1}, and 34600 mg L^{-1}) and molasses (0, 200 mg L^{-1}, and 2000 mg L^{-1}; Brer Rabbit). Samples of 225 g of the sediment (with gravimetric water content of 3.3%) were spread onto trays and sprayed with 22.5 ml of the appropriate solutions containing nutrients and 67 mg L^{-1} Cr(VI) until gravimetric water contents of approximately 13% were achieved. The sediment was then placed into sealed bottles and incubated statically in the dark at room temperature for 35 days. Following incubation, samples were centrifuged in Maxi-Spin nylon centrifuge filters with 0.45-µm pore size (Alltech Associates, Inc., Deerfield, IL) to extract the water from the sediment for chemical analysis.

A separate batch microcosm experiment was conducted with sediment (containing its native microbial community) and abiotic controls to assess the relative contribution of microbial reduction and abiotic reduction on the loss of Cr(VI) from solution. Sterile synthetic pore water (2 mL containing 250 mg Cr(VI) L^{-1}) was added to sediment samples of 20.6 g in glass vials to achieve gravimetric water contents of 13.3%. Abiotic controls consisted of 1) an autoclaved set (autoclaved at 121°C for 20 minutes on three successive days) and 2) a $HgCl_2$-poisoned set (200 mg Hg L^{-1}). A second set of samples was prepared in which 2000 mg L^{-1} molasses (Grandma's Molasses) was added to the Cr(VI) solution. Samples were prepared in duplicate. The samples were incubated statically at room temperature in the dark for 35 days followed by pore water extraction as described above.

Column Experiments. Plexiglas columns (15 cm long by 5 cm I.D.) from Soil Measurement Systems (Tucson, AZ) were used in these experiments. Each column had a nylon mesh screen at the top (inlet) of the column and a nylon filter membrane, with 1.2-μm pore size and bubbling (air entry) pressure of 600 mbar, located at the bottom (outlet) of the column. The nylon screen and membranes were held in place by perforated aluminum plates. Tensiometers with 1-cm diameter ceramic porous cups in contact with the sediment were installed through the column wall 4 cm from each end.

Prior to packing, the empty columns were sterilized with a 1% sodium hypochlorite (NaOCl) solution and rinsed with filter-sterilized, deionized water. The sediment was packed into the columns to a bulk density of approximately 1.5 g cm^{-3}.

The fluid delivery system was comprised of a Harvard Apparatus PHD 2000 programmable syringe pump (Holliston, MA), Tygon tubing (formulation B-44-4X), 5-mL sterile plastic syringes, and plastic check valves. A drip chamber, which provided free fall of feed solution, was installed immediately above each column to reduce the likelihood of microbial contamination of the reservoirs. The fluid delivery system was sterilized with 1% NaOCl and rinsed with filter-sterilized deionized water prior to the experiments.

The column outlets were connected to vacuum chambers to maintain unsaturated conditions. Chamber vacuums were regulated with Moore model 43 sub-atmospheric pressure regulators (Spring House, PA) connected to vacuum and pressure sources.

Effluent samples were collected in 20-mL glass vials with ISCO Retriever II fraction collectors (Lincoln, NE) situated in the vacuum chambers. Vials in the fraction collectors were removed and weighed periodically to determine flow rates. Sample evaporation within the vacuum chambers was determined by monitoring water loss from test vials. Columns were weighed daily to monitor gravimetric water contents. Soil water tensions were measured daily at the tensiometers to monitor hydraulic gradients.

The columns were initially leached for five days with synthetic pore water, during which time they attained steady discharge rates, developed unit hydraulic gradients (indicated by tensiometer measurements), and had nearly achieved steady-state water contents. The flow rate to each column was approximately 50 mL d^{-1}. Following the equilibration period, the feed solutions were spiked with tritiated water (0.02 μCi mL^{-1}) to determine hydraulic properties of each column. Following this initial tracer test, the inlet solutions were switched to solutions of synthetic pore water containing Cr(VI) and nutrient additives (Table 1) and run for 45 days. Treatment columns received solutions of synthetic pore water that contained approximately 65 mg Cr(VI) L^{-1} and additions of organic carbon (Grandma's Molasses) and/or NO_3^-. Columns B1 and B2, which served as controls, received only Cr(VI) solution. Effluent samples were analyzed for total Cr concentrations, which were then corrected for evaporation. A second tritium tracer test was performed after 38 days of nutrient addition to assess the effects that the nutrient additions and resulting increase in biomass had on the hydraulic properties.

Immediately following the column experiment, sediment from the top (0-5 cm), middle (5-10 cm), and bottom (10-15 cm) of each column was collected into separate Ziplock bags and homogenized.

Table 1. Column experiment feed solution compositions. All solutions were prepared in synthetic pore water.

Column ID	Cr(VI) (mg L^{-1})	NO_3^- (mg L^{-1})	Molasses (mg L^{-1})
NC1 and NC2	65	3500	2000
C1 and C2	65	0	2000
N1 and N2	65	3500	0
B1 and B2	65	0	0

Analytical Methods. Aqueous Cr concentrations were measured by several methods. For the batch microcosm experiment, inductively-coupled plasma mass spectrometry (EPA method 200.8) was employed to measure total Cr in the aqueous phase. To measure Cr(VI) from the abiotic batch experiments, the high-performance liquid chromatography method described by Li and Bowman (*24*) was used. For the column experiment, influent and effluent samples were analyzed with flame atomic absorption (AA) spectroscopy for total Cr (EPA method 218.1) and with ion chromatography (IC) with a Dionex AS14 analytical column (EPA method 300.0) for NO_3^-. Prior to Cr analysis with the AA, a small amount (15 µL) of concentrated sulfuric acid was added to the samples to dissolve any Cr precipitates that may have formed in the sample vials.

Unsieved and sieved sediment was analyzed for total Cr using x-ray fluorescence (XRF) spectroscopy. Sieved fractions [in millimeters (mm) diameter] were <0.125, 0.125-0.25, 0.25-0.5, 0.5-1.0, and >1.0. To determine solid phase Cr speciation, sediment was analyzed with X-ray absorption near edge structure (XANES) spectroscopy at the Advanced Photon Source at Argonne National Laboratory.

Tritium was quantified in Scintiverse universal liquid scintillation cocktail (Fisher) with a Beckman LS6500 scintillation counter (Beckman Instruments, Inc., Palo Alto, CA). The resulting breakthrough curves were analyzed with the transport parameter estimation software package CXTFIT2 (*25*) and fit using a two-region non-equilibrium deterministic convection-dispersion model (MODE 2 in CXTFIT2) with a pulse input (MODB 3 in CXTFIT2).

Statistical Analyses. The effects that NO_3^- and organic carbon concentrations had on aqueous Cr concentrations in the batch microcosm experiments were assessed with single-factor and two-factor analyses of variance (ANOVA) methods with replicates. Two-factor ANOVA was used to determine the significance of interactions between factors and Tukey's procedure was used to identify significant differences between factor levels (*26*). Single-factor ANOVA was performed to compare individual treatments. Single-factor ANOVA was used to assess differences between sterile and live treatments that were performed to assess microbial reduction and abiotic reduction. One-factor ANOVA and the T method using the Studentized range distribution were used to assess the differences in effluent Cr(VI) concentrations from the column experiments (*26*). Results were considered statistically significance if $P < 0.05$ for these tests.

RESULTS

Batch Microcosm Experiments. The greatest Cr loss from solution (87%) was exhibited for batch microcosms that were treated with high concentrations of both NO_3^- and organic carbon (Table 2). Significantly less Cr loss (66% - 69%) was observed for microcosms that received high concentrations of either NO_3^- or organic carbon alone. The amount of Cr lost from solution in the control, low organic carbon only, low NO_3^- only, and combined low organic carbon and low NO_3^- treatments ranged from 13% to 26%. The two-factor ANOVA indicated that the addition of NO_3^- and/or carbon led to significant increases in Cr loss ($P < 0.05$); however, the interaction between organic carbon and NO_3^- was not significant.

Table 2. Percent of total Cr lost from solution after 35 days in batch microcosms with initial Cr(VI) concentration of 67 mg L^{-1}. Values in parentheses are standard deviations for triplicate samples. Mean percentages followed by different letters are significantly different at the 95% confidence level ($P < 0.05$).

	NO_3^- Concentration (mg L^{-1})		
Molasses Conc.(mg L^{-1})	0	346	34600
0	26 (14)a	13 (2)a	66 (6)b
200	22 (20)a	22 (8)a	68 (2)b
2000	69 (2)b	69 (3)b	87 (1)c

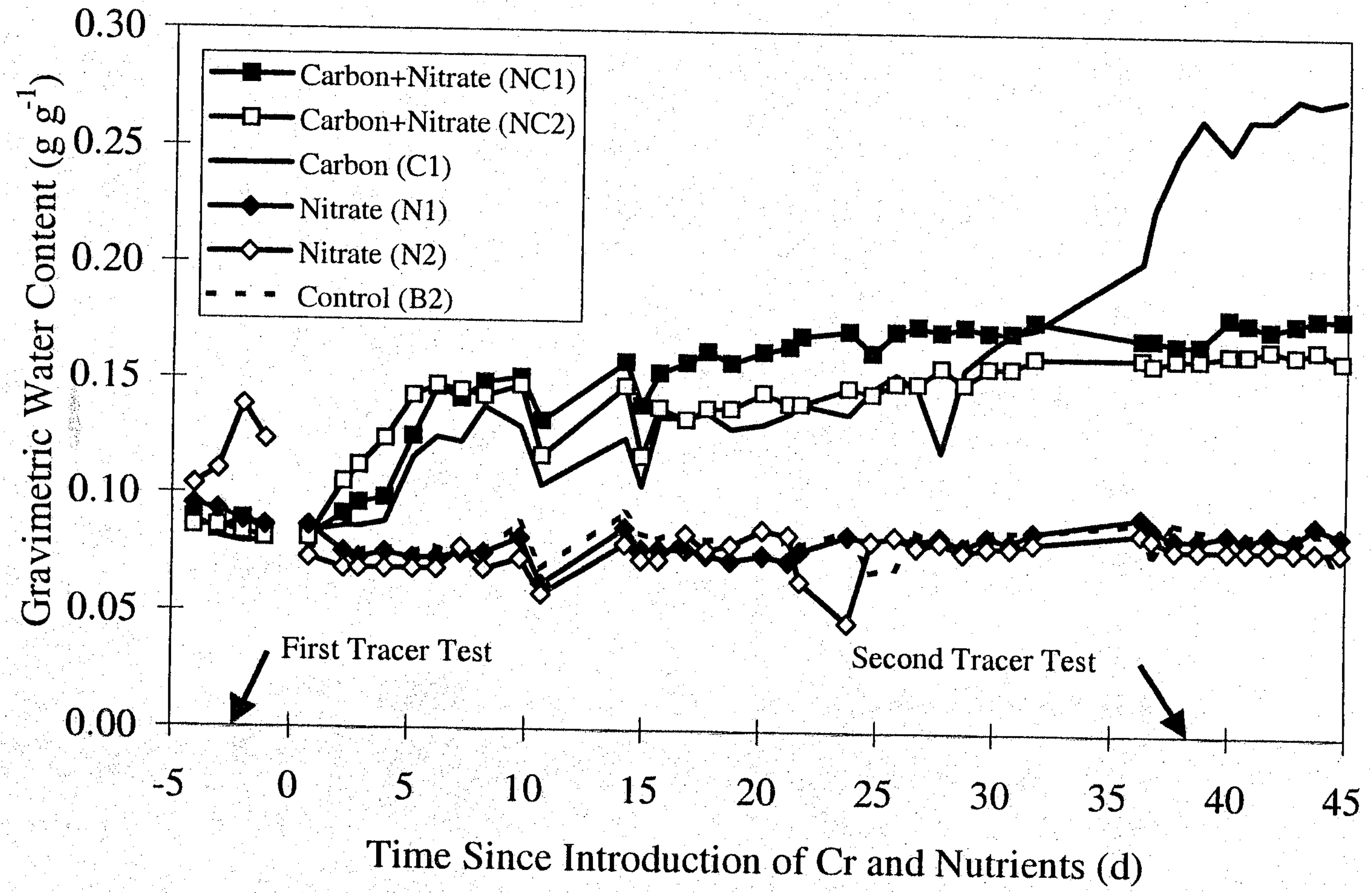
Microbially mediated removal of Cr(VI) was greater than abiotic Cr(VI) loss from the aqueous phase in the batch microcosms for the range of Cr(VI) concentrations used in the experiments (Table 3). Aqueous Cr loss was significantly ($P < 0.05$) greater in the live samples that were amended with molasses than it was in the abiotically treated samples with or without molasses.

Table 3. Percent of total Cr lost from solution after 35 days in batch microcosms with initial Cr(VI) concentration of 250 mg L^{-1}. Values in parentheses are standard deviations for duplicate samples. Mean percentages followed by different letters are significantly different at the 95% confidence level ($P < 0.05$).

	Nutrient Addition	
Sterilization Treatment	None	Molasses (2000 mg L^{-1})
None (live)	9.3 (3.5)a	21.1 (0.3)b
Autoclaved	-0.1 (4.6)a	3.9 (1.6)a
Hg-poisoned	2.2 (0.8)a	7.9 (1.1)a

Column Experiments. Within three days of starting water flow through the columns, gravimetric soil water contents within all but one column (N2) had stabilized at 7% to 11%. Water contents remained constant through the initial tracer test in all but column N2, which stabilized at 7% following the initial tracer test (Figure 1). Following the introduction of Cr(VI) and nutrients, the water contents of the columns receiving

Figure 1. Gravimetric water contents of columns through time. Cr(VI) and nutrients were added to influent on day 0.



organic carbon additions (NC1, NC2, C1, and C2) began increasing, eventually stabilizing at 13% to 15% after ten days. In the meantime, the gravimetric water contents of the other columns remained between 7% and 9%. Approximately 28 days into the test, the water content began increasing again in column C1, and it became fully saturated after 38 days. Water contents dropped in the columns on day 10 because the syringe pump was inoperable for approximately 6 hours while the vacuum pump maintained tension on the soil water in the columns, allowing water to continue discharging from the columns.

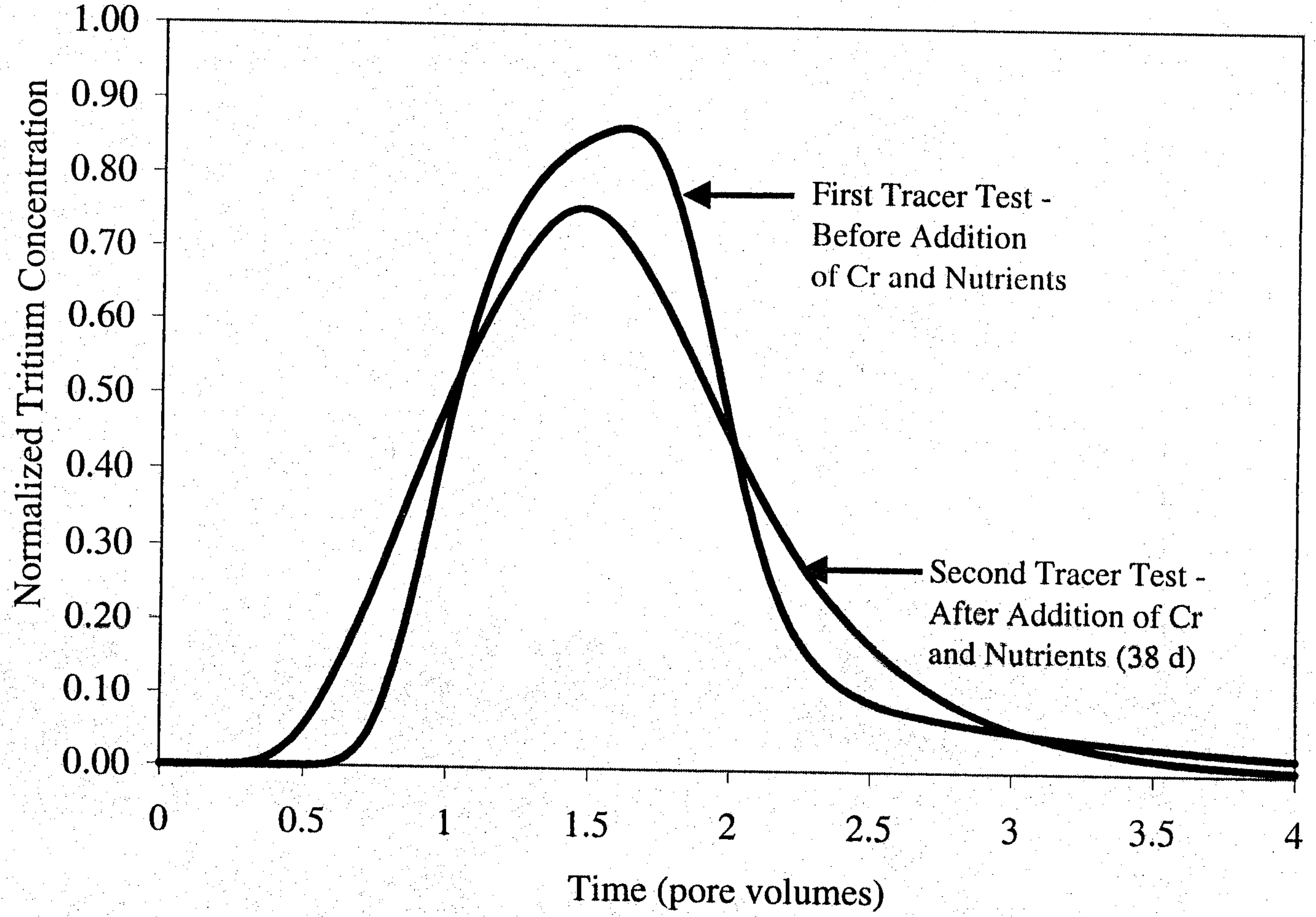
Column flow rates generally ranged between 47 and 53 mL d^{-1}, with the exception of columns C2 and B1, which had flow rates of 35 mL d^{-1} due to syringe and column malfunctions; data from these two columns were not considered further. The flow rate in column C1 averaged 50 mL d^{-1}, prior to its becoming fully saturated near the end of the test (at day 37) at which time Cr analyses were discontinued. Darcy velocities ranged from 2.4 to 2.6 cm d^{-1} for all columns except C2 and B1. Total flow volumes for the columns ranged from 2100 to 2400 mL, excluding columns C2 and B1.

Comparing results for the two tracer tests, the water contents for columns NC1 and NC2 approximately doubled, whereas the water contents for columns N1, N2, and B2 remained fairly constant (Table 4). As a result, the average linear velocities (pore water velocities) declined by a factor of two for columns NC1 and NC2, whereas the velocities increased slightly for columns N1 and B2. Dispersion coefficients increased by a factor of approximately three for all columns. The fraction of mobile water increased for all columns, but most significantly for the columns that exhibited large increases in water contents. Break through curves (BTCs) for tritium tracer tests performed before and after addition of nutrients for column NC2 illustrate the effects that the nutrient addition had on the shape of the BTCs by affecting velocity, dispersion, fraction of mobile water, and mass transfer coefficients (Figure 2). The general shapes of the BTCs for columns not receiving organic carbon additions also broadened, but were otherwise unchanged through time (not shown).

Table 4. Hydraulic parameters measured for the two tritium tracer tests (first test/second test). The first tracer test was performed prior to the addition of Cr(VI) and nutrients; the second tracer test was performed near the end of the Cr reduction experiment. Dispersion coefficients, mobile water fractions, and mass transfer coefficients were estimated using CXTFIT2 (*25*).

Column	Volumetric water content (%)	Average linear velocity (cm d^{-1})	Dispersion coefficient (cm^2 d^{-1})	Mobile water fraction	Mass transfer coefficient
NC1	11.9 / 24.3	20.3 / 10.9	4.6 / 13.9	0.77 / 0.99	0.45 / 0.0002
NC2	11.5 / 22.9	22.1 / 12.1	5.9 / 19.6	0.81 / 0.95	0.25 / 0.0002
C1	11.6 / 38.6	17.8 / n.a.	5.4 / n.a.	0.66 / n.a.	0.66 / n.a.
N1	13.2 / 13.0	18.8 / 21.4	3.6 / 10.1	0.87 / 0.92	0.28 / 0.06
N2	n.a. / 12.1	n.a. / 24.3	n.a. / 9.9	n.a. / 0.91	n.a. / 0.19
B2	12.6 / 13.2	18.7 / 23.3	3.2 / 10.1	0.78 / 0.82	0.81 / 0.79

Figure 2. Normalized tritium breakthrough curves for column NC2 for the two tracer tests before and after 38 days of Cr(VI) and nutrient addition.



Effluent Cr Concentrations Through Time. Column effluent Cr concentrations were normalized to influent concentrations, adjusted for evaporation, and plotted against time (Figure 3). The average effluent Cr concentration for columns NC1 and NC2 (NO_3^- plus organic carbon treatment), was approximately 90% of the influent Cr concentration for the duration of the test, indicating that 10% of added Cr was retained in the sediment. The other three treatments (organic carbon only, NO_3^- only, and the control) exhibited no significant Cr loss, i.e., effluent concentrations were not statistically different from influent concentrations.

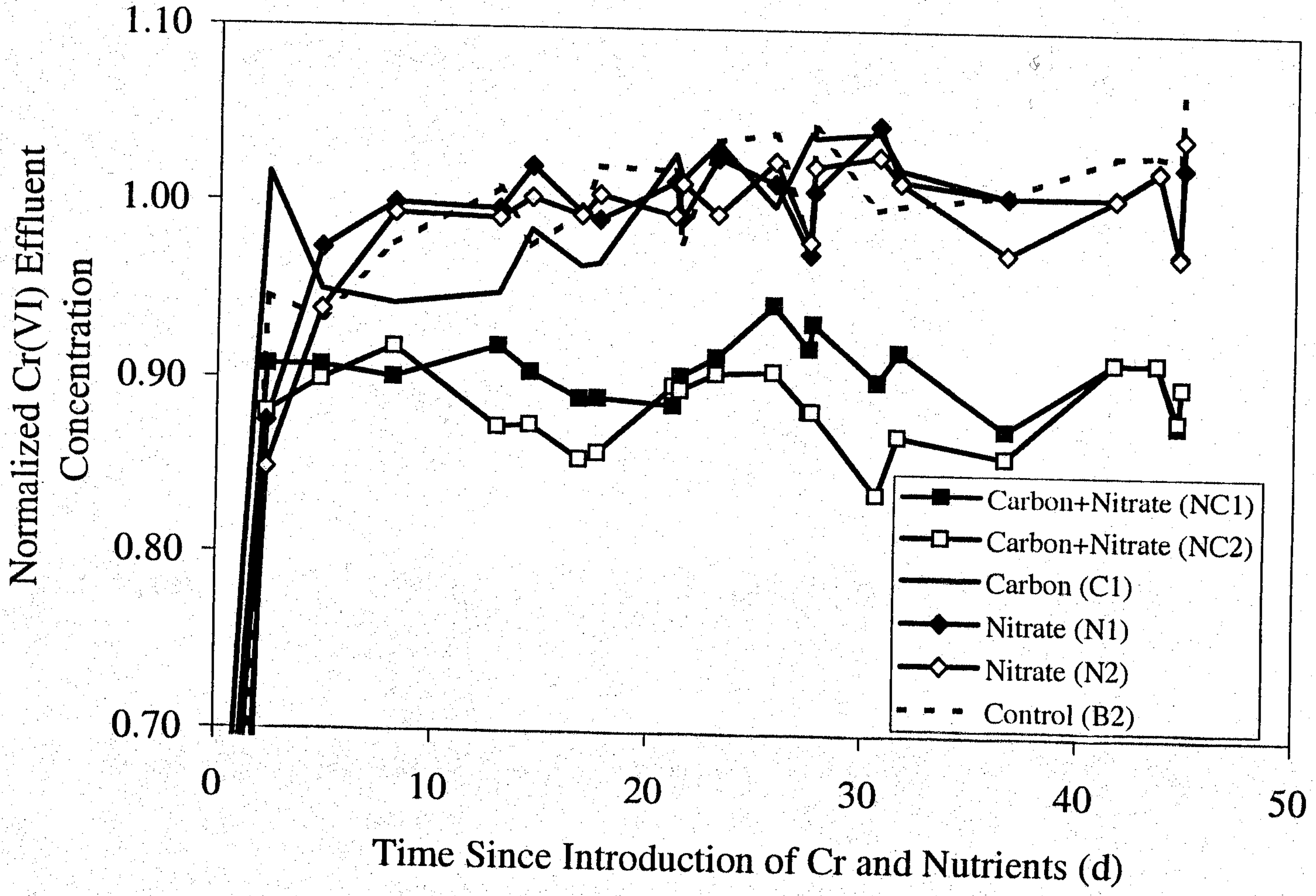
Microbial reduction and subsequent loss of aqueous phase Cr in the columns can be described with first-order kinetics. First order decay constants were calculated for Cr loss in columns NC1 and NC2 using the following equation and the average effluent Cr concentrations as well as average residence time in the columns:

$$C_{eff} = C_o e^{-kt}$$

where C_o is the initial Cr concentration in solution, C_{eff} is the effluent Cr concentration, k is the first order decay rate, and t is the residence time in the column. Effluent concentrations reported are normalized to influent concentrations (i.e., $C = C_{eff}/C_o$). Using the average normalized effluent concentrations (0.91 for column NC1 and 0.88 for column NC2) and average residence times in the columns (1.38 d in column NC1 and 1.24 d in column NC2), first-order decay constants for Cr loss of 0.07 d^{-1} and 0.10 d^{-1} were calculated for columns NC1 and NC2, respectively.

Cumulative Cr Loss Through Time. Aqueous phase Cr loss was calculated starting 5 days into the test, the point at which the effluent Cr concentration theoretically would be

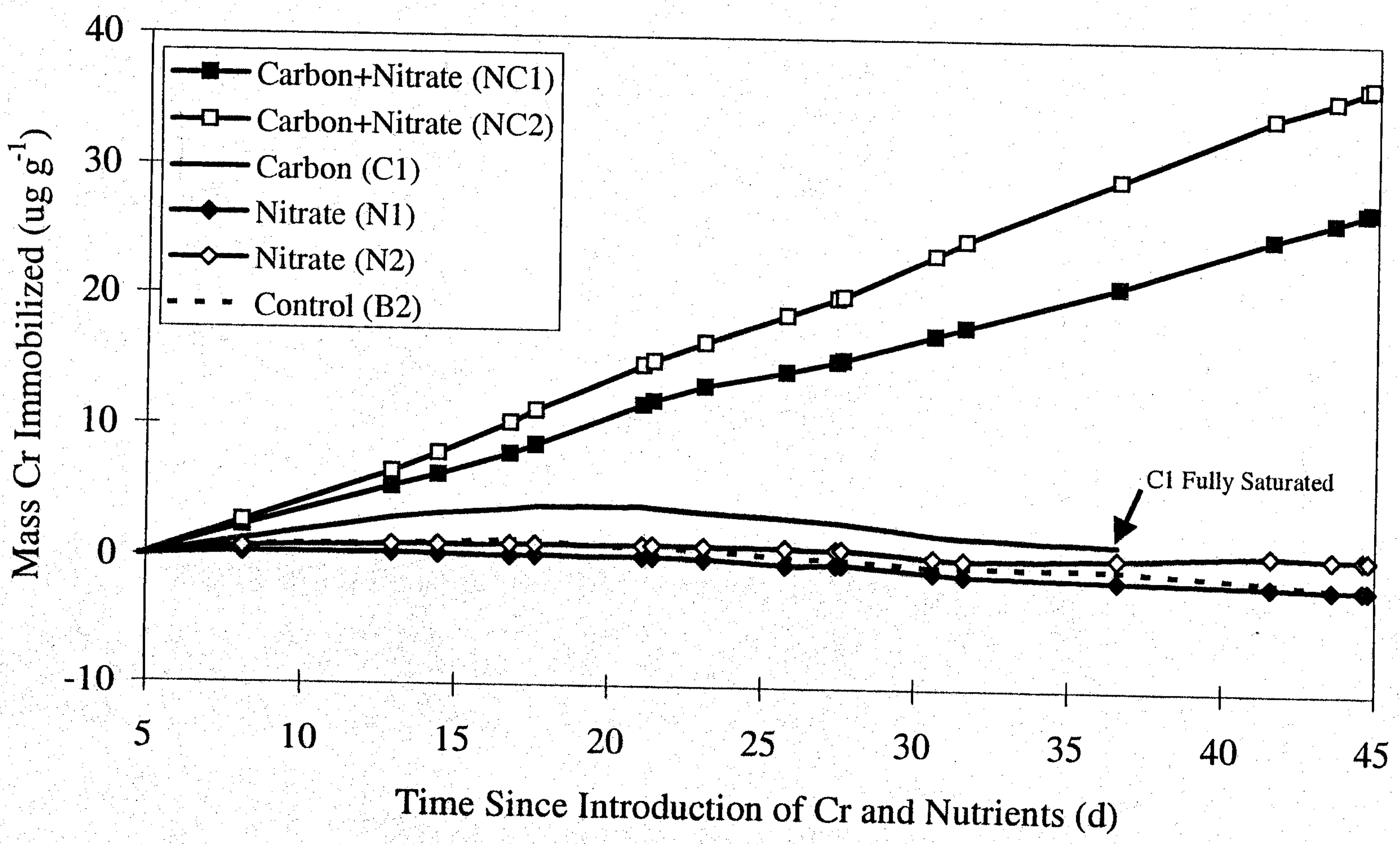
Figure 3. Cr concentrations in the column effluents normalized to influent concentration. Influent C concentrations were approximately 65 mg L^{-1}.



99% of the influent Cr concentration (based on tritium tracer results) if Cr were not reduced, sorbed, or otherwise lost from the aqueous phase. Over the course of the 45-day experiment, the amount of Cr immobilized in columns NC1 and NC2 averaged approximately 13.5 mg per column, or 32 $\mu g\ g^{-1}$ dry sediment (Figure 4). Cumulative Cr loss from the aqueous phase for the other treatments including the controls was not statistically significant; analytical variations rather than actual Cr concentrations are probably responsible for the changes seen, particularly where the values became slightly negative, implying Cr mobilization.

Total Cr measured with XRF for the sediments after completion of the column experiment corroborates the values calculated for Cr immobilized (shown in Figure 4). The calculated values included background Cr in the sediment (37 $\mu g\ g^{-1}$), Cr remaining in the pore water at the end of the experiment (5-24 $\mu g\ g^{-1}$, depending on the water content), sorbed Cr (approximately 2 $\mu g\ g^{-1}$), and the calculated amount of Cr immobilized in the sediments (27 $\mu g\ g^{-1}$ for column NC1, 37 $\mu g\ g^{-1}$ for column NC2, and 0 for all other columns). For columns NC1 and NC2, total Cr measured with XRF was 93 $\mu g\ g^{-1}$ and 96 $\mu g\ g^{-1}$, respectively. For all other columns, total Cr measured with XRF was between 35 and 44 $\mu g\ g^{-1}$, except for column C1 with 70 $\mu g\ g^{-1}$. Mass balance errors were minor ($\leq 22\%$) considering the spatial variability of background Cr levels in replicate untreated subsamples by XRF (95% confidence interval is from 23 to 51 $\mu g\ g^{-1}$). Total sediment Cr concentrations were measured at the top, middle, and bottom of each column. However, no systematic pattern was evident in Cr distribution with respect to location in the column, so a mean concentration was calculated.

Figure 4. Cumulative Cr immobilized in the columns. Full breakthrough of Cr is expected after 5 days : no Cr loss mechanisms are operative.



To determine the size fractions in which microbial reduction occurred, sediment from columns B2 and NC2 and from untreated sediment were sieved and analyzed for total Cr with XRF. Similar values were obtained for the B2 column sediment and the original untreated sediment, as expected. In all three sediments, the greatest total mass of Cr was in the 0.125-0.25 mm or 0.25-0.5 mm size fractions and the highest Cr concentration was in the <0.125 mm fraction. The greatest difference in sediment Cr concentrations resulting from organic carbon and nitrate amendment (NC2 column) was observed in the larger size fractions (>0.25 mm), which contained 2-4 fold more Cr than in the unamended column (B2).

XANES results confirmed that the Cr present in sediments from columns NC2 and B2 was in the form of Cr(III); Cr(VI) was below the detection limit of 5 $\mu g\ g^{-1}$. These spectroscopic analyses confirm that the Cr(VI) in column NC2 was not merely sorbed as Cr(VI), but rather was reduced to Cr(III) as hypothesized.

DISCUSSION

Native microbial communities in vadose zone sediments with no prior Cr(VI) exposure were shown to be capable of reducing Cr(VI) to Cr(III). XANES spectroscopy confirmed that the Cr(VI) that was removed from the aqueous phase and immobilized on the sediments was reduced to Cr(III). Microbial reduction of Cr(VI) has been shown previously (7-*21*); the current study demonstrates the potential for microbial Cr(VI) reduction under unsaturated conditions such as those found in vadose zone sediments.

In both the batch and column experiments, Cr(VI) reduction and loss from the aqueous phase was found to be enhanced when high levels of both NO_3^- and organic carbon were added to the aqueous phase. In the batch experiments, additions of a high level of either NO_3^- or organic carbon alone led to significantly greater amounts of Cr loss than was observed in the control and in samples with additions of low levels of these nutrients. In the column experiment, however, simultaneous addition of both NO_3^- and organic carbon was required for significant Cr reduction. Neither significant aqueous Cr loss nor insoluble Cr accumulation was observed either in the column receiving organic carbon alone or in the columns receiving NO_3^- alone. However, note that the nitrate level in the column experiment was intermediate to the high and low levels of nitrate in the batch experiment. Also, the lack of Cr reduction in the nitrate-alone columns was similar to the low levels of Cr reduction observed in the zero molasses-low nitrate batch experiment treatment.

The column that received high levels of carbon alone (C1) became clogged, probably due to extracellular polysaccharide production (a slime was observed) caused by unbalanced growth (response to excess carbon relative to other nutrients). The 2:1 C:N ratio in the NC1 and NC2 provided nitrogen at 10 times the level required for balanced growth. NO_3^- was used as an electron acceptor for dissimilatory NO_3^- reduction in the two batch treatments containing NO_3^- without molasses (Table 2; nitrate-nitrite data not shown). Thus, it is probable that some dissimilatory NO_3^- reduction occurred in the NC1 and NC2 columns. Cr(VI) reduction under anaerobic conditions has been found to be induced by NO_3^- when linked with benzoate catabolism (*19*). In contrast, aerobic Cr(VI) reduction by *Pseudomonas putida* and *Bacillus subtilus* has been shown to be unaffected by additions of NO_3^- (*8, 14*).

The total aqueous Cr loss in the batch microcosm and column experiments can be attributed to the combined effects of microbial reduction, abiotic reduction, and sorption. Sorption of Cr(VI) is expected to have been negligible because it is an anion that will not adsorb to the mostly negatively charged surfaces of the sediment. Furthermore, batch sorption experiments indicated that only about 1 to 3 $\mu g\ g^{-1}$ will sorb to the sediment at the aqueous concentrations used in the experiments (data not shown). This is below detection limits for XANES analysis. The abiotic batch microcosm experiment demonstrated that abiotic reduction of Cr(VI) was minor relative to microbial reduction. The addition of organic carbon led to increased microbial Cr(VI) reduction, but did little to stimulate abiotic reduction (Table 3). This is to be expected at the alkaline pH of this sediment. Thus, microbially mediated Cr(VI) reduction is responsible for the bulk of the Cr loss from solution.

The XRF analyses of sieved fractions from columns NC2 and B2 provide evidence that abiotic reduction is primarily associated with the <0.125 mm fraction. The amounts of Cr measured in the <0.125 mm fractions were nearly identical and were considerably more than the amount measured in the same fraction of the untreated sediment. The <0.125 mm fraction contains a much higher proportion of mafic minerals, many of which contain ferrous iron, which is capable of reducing Cr(VI) (*27*). Abiotic reduction in the bulk sediment was minimal in all experiments because the <0.125 mm fraction is only 1-2% of the total sediment mass. Elevated Cr concentrations in the fractions from 0.25 to >1 mm in column NC2 compared to column B2 are due to microbial reduction stimulated by the additions of organic carbon and NO_3^-.

The differences in Cr(VI) reduction between the two batch experiments (Tables 2 and 3) was likely due to increased microbial inhibition encountered at the higher initial Cr(VI) concentration. Cr loss for the live samples with no additives was only 9% for the batch microcosm experiment with initial Cr(VI) concentration of 250 mg L^{-1} compared to 26% in the other batch microcosm experiment that had an initial Cr(VI) concentration of 67 mg L^{-1}. Likewise, reduction in the live sample with organic carbon additives was only 21% for the batch microcosm experiment with initial Cr(VI) concentration of 250 mg L^{-1} compared to 69% in the other batch microcosm experiment. A number of studies have examined Cr(VI) tolerance and concentrations inhibitory to microbial growth. Chirwa and Wang (*13*) found that microbial reduction by *Bacillus* sp., a chromium-tolerant species, was not inhibited by Cr(VI) concentrations of 200 mg L^{-1} but was nearly completely inhibited at 500 mg L^{-1}. Garbisu et al. (*14*) found that Cr(VI) reduction by *Bacillus subtilis*, a chromium-tolerant gram-positive species, was partially inhibited at a concentration of 52 mg L^{-1} Cr(VI) and was completely inhibited at 104 mg L^{-1} Cr(VI). Ross et al. (*28*) studied the chromium tolerance of bacteria in soil and found that aqueous Cr(VI) concentrations of 12 mg L^{-1} were inhibitory to most bacteria. Bacterial growth was not inhibited when similar concentrations of Cr(III) were added, indicating that Cr(III) is less toxic than Cr(VI) to bacteria.

Differences in hydraulic parameters between the two tracer tests are attributable to microbial processes. This is evident because the first tracer test was run after 5 days of unsaturated flow, which would have accounted for any flow-induced changes in packing and hydraulic parameters. The lack of added phosphate likely minimized growth; however, small increases in cell numbers, increased cell size, relocation of cells, and/or exopolysaccharide production could account for changes in hydraulic parameters observed between the two tests, especially in the two treatments receiving carbon. Background volumetric water contents of the sediment prior to the column experiments were 5%; however, during the experiments volumetric water contents increased to greater than 10% in all columns. This led to increases in dispersion as microbial processes clogged pores within the sediment and caused water to follow more tortuous pathways. The addition of organic carbon (columns NC1, NC2, and C1) led to the greatest changes in hydraulic parameters. Unbalanced growth in column C1 caused production of extracellular polysaccharide, whereas nitrate alone did not alter hydraulic properties appreciably.

Environmental Significance. Although the columns receiving additions of both NO_3^- and organic carbon showed only 10% Cr reduction and immobilization, the columns were very short (15 cm), as were the residence times (30-33 hours). The resulting Cr(VI) loss could be very significant in a thick vadose zone where the flow path may be tens to hundreds of meters before water reaches the water table and where the residence times may be years rather than hours. Microbially-mediated Cr(VI) reduction in thick vadose zones of arid and semi-arid regions could approach 100%. Assuming a first-order degradation constant of 0.07 d^{-1} (as was calculated for column NC1), the aqueous Cr concentration could be reduced to below the regulatory maximum contaminant level of 0.1 mg L^{-1} in less than 100 days. For enhanced in situ bioremediation strategies, the addition of organic carbon alone may be sufficient for enhancing microbial reduction of Cr(VI) if NO_3^- is present in adequate concentrations as a co-contaminant. Otherwise, NO_3^- addition may also be required for enhancing microbial reduction of Cr(VI). Proper nutrient balance (20:1 C:N ratio) should limit microbial production of extracellular polysaccharides that can reduce hydraulic conductivity. Enhanced microbial reduction appears to be a promising technique for remediating Cr(VI)-contaminated sites.

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CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Native microbial populations from vadose zone sediments were shown to be capable of reducing Cr(VI) to Cr(III) under unsaturated conditions. The batch microcosm and unsaturated flow column experiments further demonstrated that microbial reduction could be enhanced with the addition of organic carbon and NO_3^-. This could be a promising method for remediating Cr(VI)-contaminated vadose zones. Analysis of water and sediment from the column experiment showed that Cr(VI) lost from the aqueous phase was immobilized in the sediment and was reduced to Cr(III). Although the amount of aqueous Cr(VI) loss from the columns treated with organic carbon and NO_3^- was only 10%, Cr immobilization could be significant in thick vadose zones found in arid to semi-arid regions. Assuming a first-order degradation constant of 0.07 d^{-1} (as was calculated for column NC1), the aqueous Cr concentration could be reduced to below the regulatory maximum contaminant level of 0.1 mg L^{-1} in less than 100 days. The results of these studies also have implications for use in remedial strategies. NO_3^- must be present with Cr(VI) for enhanced Cr reduction to be successful. Also, the addition of organic carbon alone in the absence of NO_3^- may lead to clogging of the vadose zone sediments.

Additional laboratory experiments should be performed to determine the optimal combination of nutrients for enhanced microbial Cr reduction under unsaturated conditions. Phosphate should be included in these experiments as it is likely a limiting nutrient for microbial growth. Organic carbon sources other than molasses could also be tested to determine if higher reduction rates could be obtained.

The experiments presented in this thesis were performed with disturbed sediment packed in the columns. To obtain results that are more representative of field conditions, experiments with intact cores should be performed. Intact cores preserve physical, chemical, and biological heterogeneities present in the soil, and reduce the effects of disturbance of soils caused by repacking (*29*).

Similar experiments could be performed with additional co-contaminants such as lead or radionuclides. Common combinations of contaminants (metals, inorganic compounds, and radionuclides) found in soil and groundwater at DOE sites were identified by Riley and Zachara (1). In addition to studying contaminants, other vadose zone materials representative of different geologic settings could also be included in batch and column experiments. Jardine et al. (*30*) performed column experiments using a fractured shale found at Oak Ridge National Laboratory, where there also is Cr(VI) contamination.

If additional column experiments are to be performed, several improvements could be made to the experimental design that could improve data quality. Two primary problem areas were identified with the equipment and methodology that was used. The primary equipment problem was associated with the operation of the syringe pump. Specifically, the syringe pump used in the experiments (Harvard PHD 2000) did not have the power necessary to overcome all of the friction and back pressure that was encountered. Although the syringe pump can hold up to ten syringes, it can not produce the driving force required for operation of this many syringes continuously. Ideally, a more powerful syringe pump should be used or multiple syringe pumps should be used with two syringes per pump.

The other major source of errors in the experiment was related to sample evaporation. Evaporation within the vacuum chambers led to increased effluent aqueous solute concentrations and reduced measured effluent discharge rates. Although this problem was overcome by correcting for evaporation, this approach was tedious and crude; more accurate results could be obtained if evaporation were eliminated. Attempts were made to minimize evaporation due to air leaks. However this was not adequate; evaporation remained significant. To further minimize sample evaporation, a relative humidity of near 100% could be maintained in the vacuum chambers (e.g., by placing an open container of water in the vacuum chamber). Another approach to minimize evaporation would be to remove the sample vials or cap the vials at more frequent intervals. To minimize disturbances to flow in the columns, this either would need to be automated or some other method to maintain a vacuum on the column would have to be devised while removing the vials.

There is a need for additional research before this technology can be applied for site remediation. A series of experiments with increasing scales should be performed. The first experiment may be as simple as additional column experiments with longer columns. These experiments will help assess whether more Cr(VI) reduction occurs in a longer column. Because this technology involves adding water to the vadose zone, the potential exists for flushing Cr(VI) contamination to the water table. A pilot scale treatability study should be conducted in a setting in which Cr(VI) can be recovered if the experiment fails, such as in a sand-filled swimming pool or in a sheet pile cell with a low-permeability bottom. As part of this experiment, methods for applying nutrients would have to be developed and tested. Finally, a field scale demonstration is needed before this technology will be readily accepted by regulatory agencies as an option for remediation.

APPENDIX A

SEDIMENT CHARACTERISTICS

This appendix provides the data and results from physical, chemical, and mineralogical characterization of the sediment used in the batch microcosm and column experiments. The sediment was collected in Richland, WA, as described previously. For ease of reference, all of the tables and then all of the figures are presented at the end of this appendix.

Grain Size Analyses. Grain size analyses were performed at the New Mexico State University (NMSU) Soil Water and Air Testing (SWAT) Laboratory. Two samples were analyzed with sieve and hydrometer methods. Six additional samples were analyzed with the pipet method. The results are shown in Table A-1. The sediment was primarily sand (91-95%), with minor amounts of silt (1-3%) and clay (5-6%), and trace gravel. The sieve analysis revealed that the sand was primarily medium and coarse grained sand.

Chemical Analyses. Chemical analyses also were performed for sediment samples at the NMSU SWAT Laboratory. Samples were analyzed for cation exchange capacity and organic matter content; both were low for the sediment (Table A-2). Major ions and pH were determined for a saturated paste prepared from the two samples (Table A-2). The pH was slightly alkaline. NO_3^-, potassium, and electrical conductivity were determined from a 1:5 soil-water extract. Background NO_3^- in the sediment ranged from

1.1 to 1.4 μg g^{-1}, which is less than 1% of the concentration used in the column experiments. Phosphorus was extracted with a sodium bicarbonate solution.

Background levels of total Cr in unsieved and sieved sediment were determined with XRF spectroscopy performed at Pacific Northwest National Laboratory in Richland, WA. The sediment was dried and mixed, then 5-g samples were ground to a powder. These samples were quartered and further divided into three aliquots. The aliquots were ground to a fine powder and pressed into thin wafers for XRF analysis. Sixteen individual samples were analyzed and some were analyzed more than once, in which case the mean for that sample was used to determine the overall mean for the sediment. The dates listed in some of the sample ID's represents the date on which they were analyzed. Samples labeled with a number (e.g., 1-2, 3-3, 9-3) were samples from the batch microcosm experiment. The first number represents the treatment: samples labeled "1" received artificial pore water only, samples labeled "3" received high concentrations of molasses dissolved in artificial pore water, and samples labeled "9" received high levels of both nitrate and molasses dissolved in artificial pore water. The second number represents the replicate number, which can range from 1 to 3 because this experiment was run in triplicate. Background Cr in the sediment was quite variable, having a mean of 37 μg g^{-1} and standard deviation of 7 μg g^{-1} (Table A-3). Sieved fractions (mm diameter) and background total Cr concentrations (in parentheses; ug g^{-1}) were <0.125 (391), 0.125-0.25 (95), 0.25-0.5 (22), 0.5-1.0 (28), and >1.0 (35). Background Cr was highest in the finest grain fractions, probably due to a higher percentage of Cr-containing mafic minerals.

Background levels of Cr(VI) and Cr(III) were determined with XANES spectroscopy. The samples were analyzed at the Advanced Photon Source at Argonne National Laboratory. Scans were made from 20 eV below the Cr K-edge (5989 eV) to 100 eV above the edge at a resolution of 0.5 eV within 20 eV of the edge and at 1 eV from 20 to 100 eV above the edge. Fluorescence data were corrected for changes in the incident intensity during the scan. X-ray energy was selected using a Si (111) double-crystal flat-plate monochromator of the BESSRC type with 3 mm X 8 mm beam. Cr fluorescence was measured using a Canberra Ge detector. Samples were prepared by packing sediment into a slotted sample holder (5 mm X 5 mm X 22 mm) sealed with 25-μm thick Kapton film. A Cr standard was prepared with a physical mixture of Cr(III) and Cr(VI) diluted in quartz sand. The total Cr concentration of this standard was 30900 ug g^{-1}, of which 10% was Cr(VI). Results are shown in Figure A-1. The absence of a peak for the sediment at 5993 eV indicates that there was no measurable Cr(VI) (detection limit = 5 μg g^{-1}). Although there is some intensity in this energy region, there is no clearly identifiable peak. Presence of Cr(VI) would result in a peak at this energy, as illustrated by the 10% Cr(VI) standard.

Mineralogy. Mineralogy was determined by visual methods and with x-ray diffraction (XRD) analysis. The sediment was examined with reflected-light microscopy by Chris Young at the New Mexico Tech Department of Earth and Environmental Sciences. This analysis revealed that the sediment is composed primarily of quartz and feldspar. The dark grains are primarily volcanic glass with some biotite, magnetite, and possibly other mafic minerals. XRD analysis was performed at the New Mexico Bureau of Mines and Mineral Resources X-Ray Facility. Because the felsic grains are primarily quartz and feldspar and are easily identified, dark grains were selected for the sample analyzed with XRD. The results of this analysis were inconclusive. The XRD analysis indicated that quartz and plagioclase feldspar were present; however, no mafic minerals were identified.

Sorption of Cr(VI). Batch sorption experiments were performed to determine the sorption of Cr(VI) on the sediment. Solutions were prepared by spiking synthetic pore water with potassium chromate to produce Cr(VI) concentrations ranging from 0.1 mg L^{-1} to 36 mg L^{-1}. Sorption isotherms were prepared by placing 4 g of sediment and 4 ml of chromate solution in a 50-ml Oak Ridge centrifuge tube. Triplicate samples and blanks were prepared for each solution concentration. Samples were mechanically shaken for 24 hours at 25 C. Samples were centrifuged and supernatant was decanted for chemical analysis. Aqueous Cr(VI) concentrations were analyzed with HPLC using a method developed by Li and Bowman (*24*). Sorbed Cr(VI) concentrations were determined by the difference between initial concentrations of solutions added to the sediment and final aqueous Cr(VI) concentrations measured for the supernatant (Table A-4). In a few cases (samples 3A, 5A, and 6B), negative values were calculated for some of the sorbed Cr(VI) concentrations. This likely occurred because the amount of Cr(VI) sorbed was very small relative to the initial and final aqueous Cr(VI) concentrations. Thus relatively small errors in the aqueous Cr (VI) concentration measurements could lead to large errors in the sorbed Cr(VI) concentrations calculated.

The sorption isotherm for the 1:1 soil-water ratio is shown in Figure A-2. The sorption isotherm was well described by a Freundlich model of the form:

$$S = K_f C^N.$$

where: S = equilibrium sorbed concentration on soil (mmol kg^{-1});

K_f = 0.041 (log K_f is equal to intercept with the y-axis on the plot of log S versus log C)

C = equilibrium aqueous concentration (mmol L^{-1}); and

N = 0.78 (N is equal to the slope of the line on a plot of log S versus log C).

Although the data fit the Freundlich model, this does not necessarily imply that the assumptions of the Freundlich model were met. Some of the Cr(VI) that was lost from solution may have been reduced to Cr(III) and precipitated.

Soil Water Retention Curves. Soil water retention curves for wetting and drying conditions were prepared for the sediment. Soil water pressure and water content measurements were performed with a hanging column/porous plate apparatus and a repacked sediment sample. To generate the main wetting curve, the sediment was packed into a 5-cm diameter brass sleeve then dried in an oven prior to placement on the porous plate. The porous plate assembly created tension on the soil water within the sample. The sediment sample was weighed periodically (usually daily) to determine its gravimetric water content which was subsequently converted to a volumetric water content. Once the soil water content was stable (i.e., weight measurements were constant on two consecutive days), the tension was reduced by lowering the porous plate assembly and the process was repeated until the water content was once again stable at a lower soil water tension. Once the sample was saturated at atmospheric pressure, negative heads were applied to the sample to generate the main drying curve. The main wetting and drying curves (Figure A-3 and Table A-5) are different from one another, indicating hysteresis, which is typical for sand.

Table A-1. Grain size analyses of the sediment.

Pipet method	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	mean	std. deviation
sand	92.1	91.5	91.2	91.6	91.9	90.7	91.5	0.5
silt	2.5	2.3	3.0	2.8	2.1	2.8	2.6	0.3
clay	5.4	6.2	5.9	5.7	6.0	6.4	5.9	0.4

Sieve and hydrometer method	sample 7	sample 8	mean	std. deviation
sand	94.6	92.6	93.6	1.4
silt	0.8	2.8	1.8	1.4
clay	4.6	4.6	4.6	0
very fine sand (0.062-0.125 mm)	1.4	2.2	1.8	0.5
fine sand (0.125-0.25 mm)	9.4	14.8	12.1	3.8
medium sand (0.25-0.5 mm)	39.3	45.3	42.3	4.2
coarse sand (0.5-1.0 mm)	40.8	28.4	34.6	8.8
very coarse sand (1.0-2.0 mm)	3.7	1.9	2.8	1.2
sand total	94.6	92.6	93.6	1.4

Table A-2. Chemical analyses of the sediment.

Parameter	Detection Limit	Units	sample 1	sample 2	mean
pH			8.00	8.08	8.04
Electrical Conductivity	0.01	mmhos cm-1	0.21	0.20	0.21
Cation Exchange Capacity	0.01	meq 100 g-1	2.63	2.67	2.65
Organic Matter	0.01	percent	0.35	0.32	0.34
Magnesium	0.01	meq L-1	0.21	0.19	0.20
Calcium	0.01	meq L-1	1.49	1.40	1.45
Sodium	0.01	meq L-1	0.21	0.17	0.19
Nitrate as N	0.1	mg L-1	1.4	1.1	1.3
Phosphorus	0.1	mg L-1	2.4	2.0	2.2
Potassium	1	mg L-1	26	28	27
Carbonate	0.01	meq L-1	<0.01	<0.01	<0.01
Bicarbonate	0.01	meq L-1	1.69	1.80	1.75
Chloride	0.5	mg L-1	5.6	5.6	5.6
Sulfate	2	mg L-1	6.0	5.0	5.5

Table A-3. Results of XRF analyses for background Cr in sediment.

Sample ID	**run**	**total Cr (ug g^{-1})**	**Mean total Cr for sample (ug g^{-1})**	**standard deviation of measurements**
no treatment (8/4/2000)	1	30	30.0	2
no treatment (1/29/2000)	1	39		3
no treatment (1/29/2000)	2	40		3
no treatment (1/29/2000)	3	42	40.3	0
no treatment (7/26/2000)	1	21		2
no treatment (7/26/2000)	2	22	21.5	1
no treatment-1	1	38		0
no treatment-1	2	37	37.5	1
no treatment-2	1	34		2
no treatment-2	2	35	34.5	3
1-1 (3/16/2000)	1	32		0
1-1 (3/16/2000)	2	34	33.0	1
1-2 (3/16/2000)	1	49		2
1-2 (3/16/2000)	2	51	50.0	2
1-3 (3/16/2000)	1	32		2
1-3 (3/16/2000)	2	34	33.0	2
1-3 (1/29/2000)	1	45		2
1-3 (1/29/2000)	2	47	46.0	3
3-3 (1/29/2000)	1	41		1
3-3 (1/29/2000)	2	38		1
3-3 (1/29/2000)	3	40	39.7	3
9-1 (3/16/2000)	1	32		3
9-1 (3/16/2000)	2	33	32.5	1
9-2 (3/16/2000)	1	35		3
9-2 (3/16/2000)	2	36	35.5	4
9-3 (1/29/2000)	1	36		1
9-3 (1/29/2000)	2	38	37.0	1
9-3a (3/16/2000)	1	42		1
9-3a (3/16/2000)	2	47	44.5	4
9-3b (3/16/2000)	1	41		3
9-3b (3/16/2000)	2	43	42.0	4
9-3c (3/16/2000)	1	37		5
9-3c (3/16/2000)	2	41	39.0	0
mean Cr concentration (ug g^{-1})			37.3	
standard deviation (ug g^{-1})			6.8	

Table A-4. Batch sorption experiment data for Cr(VI) on the sediment for 1:1 solution to solids ratio.

Sample ID	Equilibrium Aqueous Concentration C (mmol L^{-1})	Sorbed Concentration S (mmol kg^{-1})	log C	log S
2A	2.14E-03	5.90E-05	-2.67	-4.23
2B	1.90E-03	2.95E-04	-2.72	-3.53
2C	1.91E-03	2.81E-04	-2.72	-3.55
3A	5.34E-03	-3.89E-04	-2.27	
3B	3.88E-03	1.07E-03	-2.41	-2.97
3C	4.31E-03	6.33E-04	-2.37	-3.20
4A	3.40E-02	2.44E-03	-1.47	-2.61
4B	3.34E-02	3.10E-03	-1.48	-2.51
4C	2.70E-02	9.48E-03	-1.57	-2.02
5A	8.32E-02	-1.62E-03	-1.08	
5B	7.03E-02	1.14E-02	-1.15	-1.94
5C	6.74E-02	1.42E-02	-1.17	-1.85
6A	2.43E-01	1.05E-02	-0.61	-1.98
6B	2.81E-01	-2.80E-02	-0.55	
6C	2.47E-01	5.85E-03	-0.61	-2.23
7A	4.58E-01	2.74E-02	-0.34	-1.56
7C	4.71E-01	1.40E-02	-0.33	-1.85
8A	6.92E-01	2.64E-02	-0.16	-1.58
8B	6.94E-01	2.42E-02	-0.16	-1.62
8C	6.91E-01	2.67E-02	-0.16	-1.57

Table A-5. Soil water retention curve data for the sediment.

Main Wetting Curve

Volumetric Water Content (%)	Tension (cm)
6.4	40
11.2	20
22.6	10
36.1	2
37.6	0.1

Main Drying Curve

Volumetric Water Content (%)	Tension (cm)
37.6	0.1
37.1	2
34.7	10
19	20
12.4	30
9.6	40
8.3	50
7.6	60
7.1	70
6.84	80
6.14	100
5.91	110
5.36	160
5.23	190

Figure A-1. Cr K-edge XANES for untreated sediment.

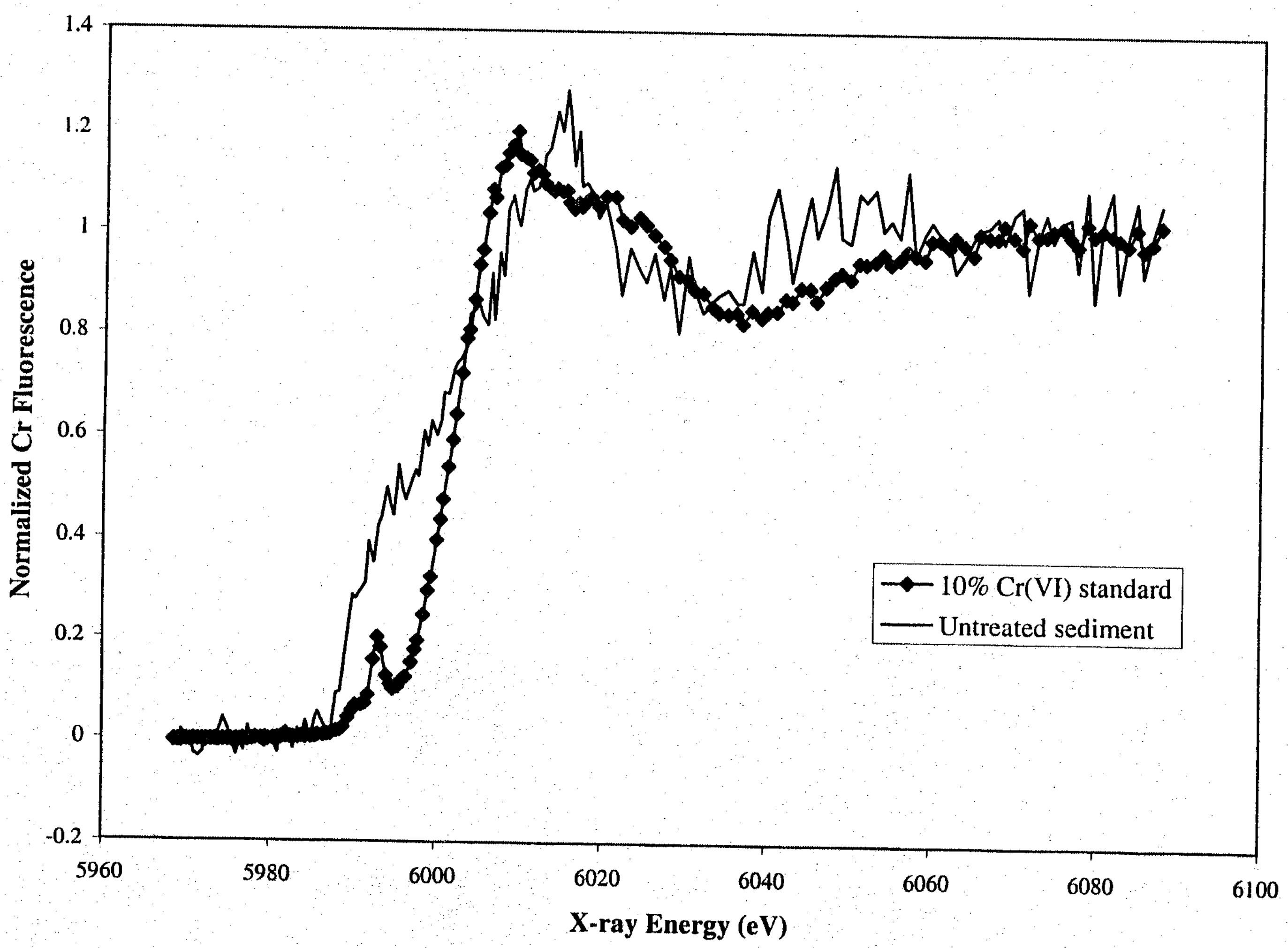


Figure A-2. Batch sorption isotherm for Cr(VI) on the sediment.

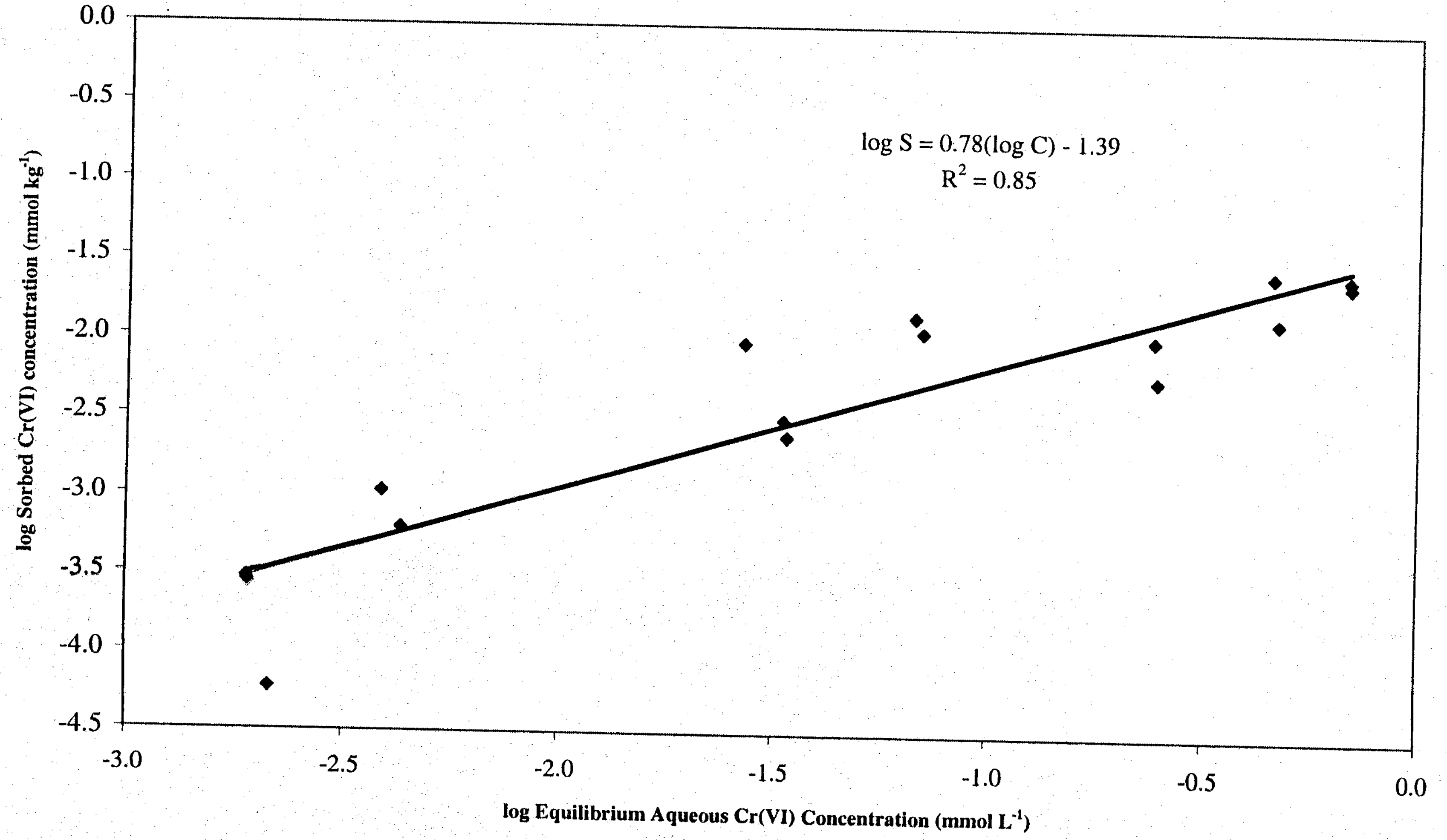
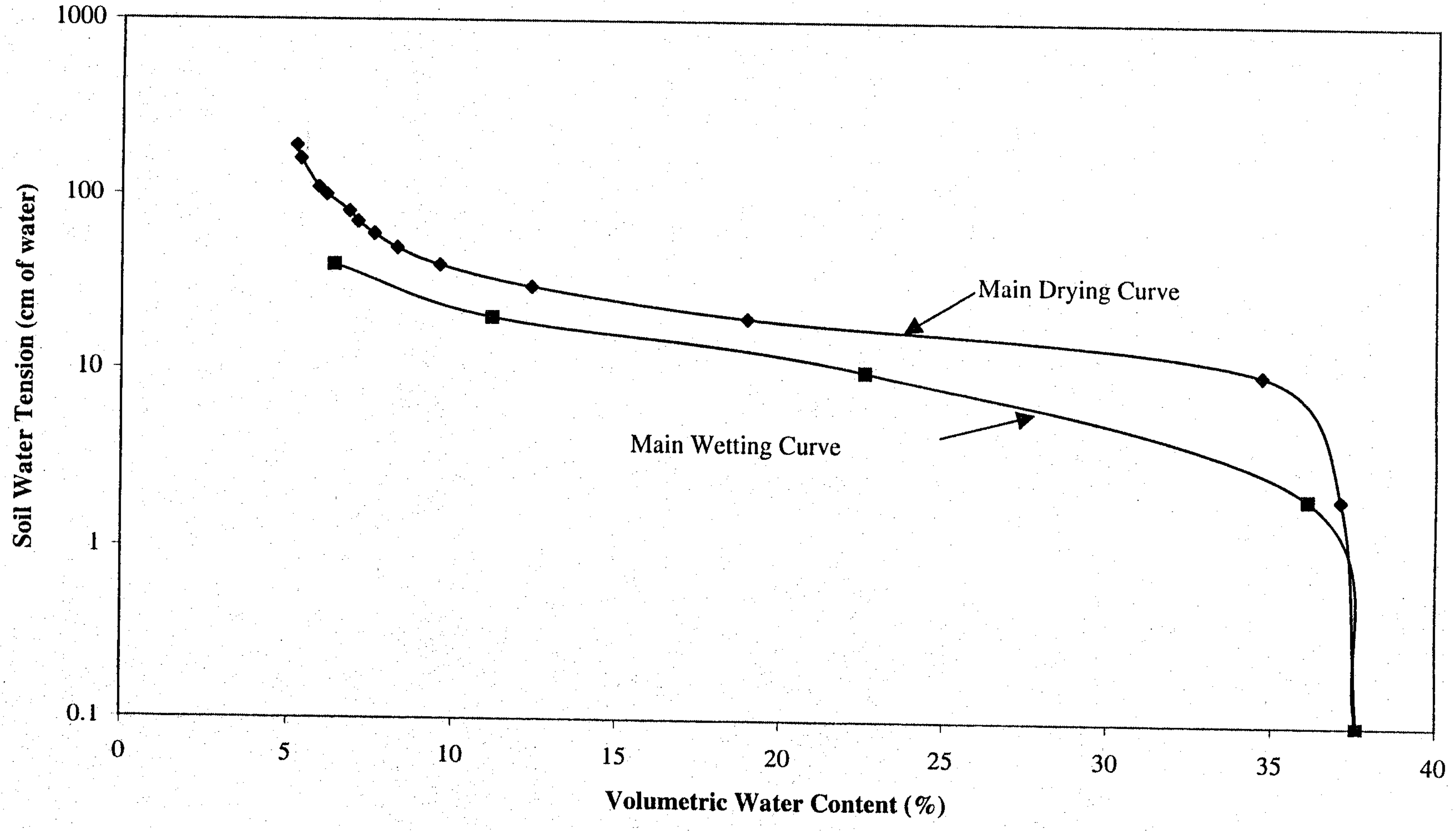


Figure A-3. Soil water retention curves for the sediment.



APPENDIX B

BATCH MICROCOSM EXPERIMENTS

This appendix provides the data and results from batch microcosm experiments performed at New Mexico Tech to assess the relative contributions of biological reduction and abiotic reduction of Cr(VI) in the sediment. The batch microcosm experiment included sediment containing its native microbial community and abiotic controls. Abiotic controls consisted of 1) an autoclaved set, autoclaved at 121 C for 20 minutes on three successive days and 2) a $HgCl_2$-poisoned set, poisoned with 200 mg Hg L^{-1}. Sterile synthetic pore water (2 mL containing 250 mg Cr(VI) L^{-1}) was added to sediment samples of 20.6 g (with initial gravimetric water content of 3%) in glass vials to achieve gravimetric water contents of 13%. A second set of samples was prepared in which 2000 mg L^{-1} molasses (Grandma's Molasses) was added to the Cr(VI) solution. Samples were prepared in duplicate. The samples were incubated statically at room temperature in the dark for 35 days followed by pore water extraction as described above.

This experiment originally included additions of NO_3^- alone and NO_3^- with molasses, however, the NO_3^- interfered with the analysis of Cr(VI) with the HPLC method used. Thus only the results of the molasses-only and control (no nutrient additives) treatments are provided (Table B-1). The initial Cr(VI) concentration in the experiment had to be corrected for dilution with pore water that was initially in the soil. As well, final Cr(VI) concentrations had to be corrected for final water contents as they changed due to evaporation.

Microbially mediated removal of Cr(VI) was greater than abiotic Cr(VI) loss from the aqueous phase in the batch microcosms for the range of Cr(VI) concentrations used in the experiments (Table B-1). Aqueous Cr(VI) loss was 9% for the live treatment receiving no amendments. This is in contrast to 0 - 2% loss for the two abiotic controls. Aqueous Cr loss was 21% for the live treatment receiving organic carbon additions. Abiotic controls treated with organic carbon had aqueous Cr(VI) loss of 4 - 8%. This indicates that microbial reduction of Cr(VI) is greater than abiotic reduction. The differences in Cr(VI) reduction between the two batch experiments (Tables 2 and 3) was likely due to increased microbial inhibition encountered at the higher initial Cr(VI) concentration. Cr loss for the live samples with no additives was only 9% for the batch microcosm experiment with initial Cr(VI) concentration of 250 mg L^{-1} compared to 26% in the other batch microcosm experiment that had an initial Cr(VI) concentration of 67 mg L^{-1}. Likewise, reduction in the live sample with organic carbon additives was only 21% for the batch microcosm experiment with initial Cr(VI) concentration of 250 mg L^{-1} compared to 69% in the other batch microcosm experiment. It is likely that the higher Cr(VI) concentration was inhibitory to microbial growth, which led to less Cr(VI) reduction.

Table B-1. Water content and aqueous Cr(VI) data from batch microcosm experiment.

Sample ID	sterilization	nutrient addition	gravimetric water cont.	final Cr (mM)	final Cr(mg L^{-1})	corrected initial Cr	% Cr reduced	% Cr reduced (mean)
LV-O-35a	live	none-control	0.121	3.418	178	191	6.8	
LV-O-35b	live	none-control	0.126	3.097	161	183	11.9	9.3
STA-O-35a	autoclaved	none-control	0.106	4.329	225	218	-3.4	
STA-O-35b	autoclaved	none-control	0.099	4.329	225	232	3.1	-0.1
STM-O-35a	Hg-poisoned	none-control	0.121	3.562	185	191	2.8	
STM-O-35b	Hg-poisoned	none-control	0.118	3.703	193	196	1.6	2.2
LV-C-35a	live	org. carbon	0.122	2.864	149	188	20.9	
LV-C-35b	live	org. carbon	0.116	2.992	156	198	21.3	21.1
STA-C-35a	autoclaved	org. carbon	0.115	3.748	195	200	2.7	
STA-C-35b	autoclaved	org. carbon	0.111	3.786	197	207	5.0	3.9
STM-C-35a	Hg-poisoned	org. carbon	0.127	3.173	165	181	8.7	
STM-C-35b	Hg-poisoned	org. carbon	0.126	3.269	170	183	7.2	7.9

APPENDIX C

COLUMN EXPERIMENTS

This appendix provides the data and results from Cr(VI) reduction column experiments performed at New Mexico Tech. Included are flow rate data, soil water tension data, soil water content data, chemical data (for influent, effluent, and the sediment), and tracer test data and results. The analytical data include influent and effluent concentrations for total Cr and NO_3^-, as well as pH. The approach used to correct effluent Cr and NO_3^- concentrations for evaporation is discussed. Column discharge data and the method used to correct these data for evaporation are presented. The evaporation data used for these corrections also are provided. Following the column experiment, the columns were sacrificed and the sediments were analyzed for total Cr with XRF. Further, the sediment from columns B2 and NC2 was analyzed for Cr(VI) and Cr(III) with XANES spectroscopy. For ease of reference, all of the tables and then all of the figures are presented at the end of the appendix.

Leaching of the columns with synthetic pore water began on April 15, 2000. After four days, soil water contents appeared to have stabilized, although not completely (see Figure 1). At this point, the first tracer test was begun. The effluent sample vial labeled "1" started filling at the beginning of this tracer test. The Cr(VI) reduction column experiment (influent containing Cr(VI) and nutrient additions) began on April 24, 2000. All times in the data tables are referenced with respect to the start of the Cr(VI) reduction column experiment, designated as $t = 0$. The other references in the data tables are the effluent sample vial numbers. Sample vial 32 began to fill at the beginning of the

Cr(VI) reduction column experiment. Sample vials for effluent collection were changed every 4 hours by the fraction collectors. The second tracer test began 38 days into the Cr(VI) reduction column experiment. Sample vial 268 was the first to fill during the second tracer test. Column leaching was ended on June 8, 2000 while filling sample vial 300, 45 days after beginning the Cr(VI) reduction column experiment.

Soil Water Pressures. Soil water tensions were measured approximately twice daily during the column experiment in the columns and vacuum chambers using a tensimeter (SMS, Tucson, AZ), a device that measures the vacuum in a tensiometer. Tensiometers with 1-cm diameter porous ceramic cups were installed through the column wall 4 cm from each end. Soil water tensions (reported as pressures in cm of water) are presented in Table C-1. Tensions of zero (atmospheric conditions) represented tensiometers that were cracked, broken, or were not in contact with the sediment. Examples of tensiometers that were not working included NC2 bottom and N2 bottom. The top tensiometer in column NC1 was broken, but was replaced prior to the start of the first tracer test. Positive values of soil water pressures represent hydrostatic pressures greater than atmospheric pressure, indicative of fully saturated conditions. The pressures measured in tensiometers for column C1 became greater than atmospheric after that column became saturated. Once fully saturated, the tension difference between the top and bottom tensiometers was approximately 7 cm, equal to the difference in elevation of the two tensiometers. A vacuum of approximately 200 mbar was maintained in the vacuum chambers for the duration of the test. This vacuum was broken briefly (typically for 15 minutes) approximately every 3 days to remove sample vials from the fraction collectors. The pressure in the columns was approximately –20 cm when the volumetric water contents were approximately 12%, at the beginning of the column experiment. This combination of pressure head and volumetric water content is in agreement with the soil water retention curves developed for the sediment (Figure A-3). The soil water pressure approached zero as the water contents increased in columns NC1, NC2, and C1. The soil water tensions measured in the tensiometers indicated that unit gradient conditions occurred at times in some of the unsaturated columns. Because tensiometers in columns NC2, N1, and N2 were broken, it was not possible to determine the hydraulic gradients in these columns.

Gravimetric Water Contents. The columns were weighed periodically (approximately daily) to determine soil water contents. The data are presented in Figure 1 and Table C-2. At the end of the Cr(VI) reduction column experiment, soil samples from the columns were weighed, dried, and reweighed to get a more direct measure of the water contents. Samples were collected from the top, middle, and bottom of each column for this analysis. The water contents that were measured directly very closely matched (less than 1% difference) those determined by weighing the columns on the last day of the experiment (immediately prior to sacrificing the columns).

Syringe Pump Discharge Rate. Direct flow rate data from the syringe pump were collected starting on day 21 of the Cr(VI) reduction column experiment. An extra syringe was added to the syringe pump so that flow rates could be measured directly. The syringe pumped water from a reservoir to another flask that was weighed periodically to determine the flow rate. The discharge flask was covered and weighed frequently (usually 4 times daily) to minimize the effects of evaporation. For the 22-day period that these data were collected, the syringe pump discharged 1129 mL. The flow volume measured through this method corresponded reasonably well with the volume of effluent measured for all columns for this period (within 8% after evaporation correction), except for columns C1 and C2, which discharged 944 mL and 824 mL, respectively. Storage of water in columns C1 and C2 (as their water contents increased) and leakage (once fully saturated) accounts for the difference between the syringe pump discharge (influent volume) and measured discharge from these columns.

Inlet Solution Schedule. Inlet solutions were prepared and changed periodically (every 2 to 8 days). Because the each inlet solution had a slightly different Cr(VI) concentration, effluent samples had to be normalized to the appropriate inlet solution. The inlet solution schedule for each batch is provided in Table C-4.

Effluent Vial Removal Schedule. In order to recover the effluent samples, the experiment had to be temporarily stopped so that the vacuum chambers could be opened to access the fraction collectors. To minimize system disruption this was done infrequently (typically every 2 to 3 days, but ranging from 1 to 5 days). The effluent vial removal schedule is given in Table C-5.

Evaporation Data. Part way through the experiment, it became evident that water evaporated from the effluent sample vials as they sat in the fraction collectors, thus decreasing the effluent discharge volume measured and increasing the aqueous Cr and NO_3^- concentrations measured. In order to correct the Cr and NO_3^- concentrations for evaporation, as well as the effluent discharge volumes, it was first necessary to quantify evaporation. This was accomplished by placing vials of water in the fraction collectors and periodically weighing these vials. The vials were weighed every time the vacuum chambers were opened to remove samples. The evaporation rate was assumed to be constant for the period between measurements. This assumption is reasonable given that the temperature of the room did not vary drastically during the experiment. The evaporation rate was different for each vacuum chamber due to differences in the seals; some chambers leaked more air than others and thus had higher evaporation rates. The evaporation data are provided in Table C-6. Evaporation data also were used to correct the column discharge volumes used to calculate the pore volumes for the tracer tests.

Column Discharge Data. Column discharge data were measured by weighing effluent sample vials (Table C-7). Column discharge rates were not always equal to the measured pump flow rate for a number of reasons, including malfunctions with individual syringes (e.g., gasket failure), changes in water contents in the columns (changes in column storage), evaporation from the sample vials, and leakage from the columns (only for column C1 after it became fully saturated). Discharge volumes were corrected for evaporation with the evaporation data provided in Table C-6.

Analytical Results for Influent and Effluent Solutions. Influent and effluent Cr concentrations are provided in Table C-8. Early in the experiment, it became apparent that evaporation from the sample vials was significant. Evaporation increased the Cr concentrations such that the measured effluent concentrations were greater than influent concentrations. Two actions were undertaken to reduce the problems associated with evaporation. First, samples sent to the lab for analysis were limited to samples that were recently collected, that is, samples that had undergone minimal evaporation. Second, Cr concentrations were corrected for evaporation with a simple mass balance approach using the total sample volume, the measured Cr concentration, the evaporation rate, and the amount of time that the sample sat in the fraction collector prior to removal. Additional evaporation occurred in the vials once they were capped (foil lined caps). However, Cr concentrations were easily corrected for this effect because the empty vials were weighed prior to use and the vials with effluent samples were weighed when removed from the fraction collector. Any subsequent evaporation could be determined by reweighing the sample immediately prior to analysis. To determine the corrected effluent Cr concentration the following equation was used:

$$C_f = (V_{meas} * C_{meas}) / (V_{meas} + [E * t])$$

where C_f is the corrected effluent concentration

V_{meas} is the measured sample volume

C_{meas} is the measured effluent concentration

E is the evaporation rate in the vacuum chamber

t is the time the sample remained in the vacuum chamber.

The numerator represents the total mass of Cr in the sample. The denominator represents the total sample volume corrected for evaporation. For samples that were analyzed long after they were collected, an additional correction was performed to correct for evaporation that occurred in the capped sample vials. This was accomplished by multiplying the corrected Cr concentration by the sample volume as measured immediately prior to analysis and dividing by the original sample volume as measured when the sample was removed from the fraction collector. Finally, the corrected effluent concentrations were normalized by the influent sample concentrations.

Effluent samples from the columns were analyzed for NO_3^- and corrected for evaporation by the same approach described to correct Cr concentrations (Table C-9). The NO_3^- data were rather inconclusive. The concentrations used in the experiment were much greater than the amount that may have been converted to nitrite (NO_2^-), thus the amount of nitrate used (the difference between influent and effluent concentrations) may have been smaller than the analytical variability in the measurements. Also, given the duration between sample collection and sample analysis, the NO_2^- could have reverted back to NO_3^-.

The pH of the influent and effluent from each column was measured periodically (Table C-10). Although the sample vials were preserved with sulfuric acid to keep the Cr in solution, every fifth sample vial was left unpreserved for pH measurements. The pH of the solutions were generally between 7.5 and 8.5 but varied between approximately 6.5 and 9.3. The influent solutions containing molasses had slightly lower pH than the others. However, the effluent pHs for all columns were similar. For the columns receiving molasses, the pH of the effluent was slightly greater than the influent. For columns receiving no molasses, influent and effluent pH values were similar.

Tracer Tests. Tritium data from the two tracer tests are provided in Tables C-11 (first tracer test) and C-12 (second tracer test). Because the dimensionless times (pore volumes) are measured by weighing the effluent sample vials, these were affected by evaporation as previously discussed. The net effect of the evaporation is an apparent acceleration of the tracer (i.e., retardation factor of less than 1). To eliminate this problem, column discharge data were corrected for evaporation prior to parameter estimation with CXTFIT2. Breakthrough curves for the two tracer tests are shown for each column except columns C2 and B1, which were dropped from the test due to problems discussed as previously described (Figures C-1 through C-10). Figures for each breakthrough curve were prepared individually because the slug widths were different for each column and each test. A breakthrough curve for column N2 for the first tracer test is not shown because the water content of the column was far from equilibrium during this test. A breakthrough curve for column C1 for the second tracer test is not shown because the column was fully saturated and leaked significant quantities of water during this test. A constant tracer application time (slug volume) was used for the tracer tests. This resulted in different slug widths for the two tests and for each column because the slug width is a function of the column's water content. The breakthrough curves were fit with CXTFIT2; results are shown in Table 4.

Analyses of Sediment. XRF analysis was performed on sediment from all of the columns. Samples were analyzed for the top, middle, and bottom of each column to determine the spatial distribution of Cr reduction. Results from these analyses are presented in Table C-13. Total Cr measured with XRF for the sediments after completion of the column experiment corroborates the values calculated for Cr immobilized (shown in Figure 4). The calculated values included background Cr in the sediment (37 $\mu g\ g^{-1}$), Cr remaining in the pore water at the end of the experiment (5-24 $\mu g\ g^{-1}$, depending on the water content), sorbed Cr (approximately 2 $\mu g\ g^{-1}$), and the calculated amount of Cr immobilized in the sediments (27 $\mu g\ g^{-1}$ for column NC1, 37 $\mu g\ g^{-1}$ for column NC2, and 0 for all other columns). For columns NC1 and NC2, total Cr measured with XRF was 93 $\mu g\ g^{-1}$ and 96 $\mu g\ g^{-1}$, respectively. For all other columns, total Cr measured with XRF was between 35 and 44 $\mu g\ g^{-1}$, except for column C1 which had 70 $\mu g\ g^{-1}$. A mass balance was calculated for the sediment in each column by subtracting the calculated Cr concentration from the measured Cr concentration (measured with XRF) and then dividing by the measured Cr concentration (measured with XRF). The data used in these calculations and mass balance results are presented in Table C-14. Mass balance errors were minor ($\leq$ 22%) considering the spatial variability of background Cr levels in replicate untreated subsamples by XRF (standard deviation of 7 $\mu g\ g^{-1}$, see Table A-3).

Sieved fractions of sediment from columns NC2 and B2 were analyzed for total Cr using XRF spectroscopy (Table C-15). Sieved fractions (mm diameter) were <0.125, 0.125-0.25, 0.25-0.5, 0.5-1.0, and >1.0. Background Cr was highest in the finest grain fractions, probably due to a higher percentage of Cr-containing mafic minerals. Cr immobilization was highest on finer fractions as well, probably as a result of abiotic reduction of Cr(VI) by iron-containing mafic minerals which are more prevalent in the finer fractions.

To determine the speciation of Cr in the sediment, XANES spectroscopy was performed. XANES analyses were performed on samples from columns NC2 and B2. The results of these analyses are shown in Figures C-11 through C-17. No clear peaks were observed at 5993 eV, indicating that most if not all of the Cr is present as Cr(III). Cr(VI) was below the detection limit of 5 $\mu g\ g^{-1}$, except for the 0.15-0.42 mm grain fraction from the bottom of column NC2 (Figure C-13) which has a peak at 5993 eV, indicating some Cr(VI) may be present.

Table C-1. Soil water pressures (cm) measured during the column experiments.

		Tensiometer							
date and time	Time since addition of Cr(VI) and nutrients (d)	NC1 top	NC1 bottom	NC2 top	NC2 bottom	C1 top	C1 bottom	C2 top	C2 bottom
4/19/00 10:54	-5.22	0	-13	-14	-14	-19	-20	-54	-53
4/20/00 9:15	-4.28	-18	-17	-17	-16	-21	-21	-55	-54
4/20/00 18:00	-3.92	-11	-17	-16	-18	-21	-21	-53	-54
4/21/00 10:40	-3.23	-23	-26	-24	-24	-30	-29	-69	-62
4/24/00 21:45	0.24	-13	-16	20	0	-15	-15	-32	-51
4/25/00 10:30	0.77	-11	-13	-6	0	-14	-14	-45	-51
4/25/00 21:45	1.24	-12	-15	-12	0	-13	-16	-12	-42
4/26/00 8:40	1.69	-27	-15	-16	0	-18	-17	-55	-52
4/26/00 21:45	2.24	-12	-12	-12	0	-18	-15	-34	-34
4/27/00 9:30	2.73	-27	-13	-15	0	-19	-18	-54	-49
4/27/00 13:35	2.90	-18	-11	-14	0	-18	-15	-49	-44
4/28/00 10:15	3.76	-24	-12	-13	0	-17	-16	-35	-31
4/28/00 15:50	3.99	-14	-8	-11	0	-15	-11	-35	-29
4/28/00 22:30	4.27	-15	-12	-12	0	-15	-15	-41	-41
4/29/00 9:55	4.74	-30	-4	-9	0	-15	-10	-32	-31
4/29/00 20:35	5.19	-17	-1	-7	0	-12	-8	-39	-34
4/30/00 9:40	5.73	-28	-4	-11	0	-17	-13	-18	-18
4/30/00 20:40	6.19	-22	-3	-9	0	-13	-8	-18	-17
5/1/00 9:40	6.73	-33	-8	-11	0	-16	-11	-28	-31
5/1/00 21:40	7.23	-21	-3	-8	0	-13	-10	-26	-24
5/2/00 9:45	7.74	-27	-3	-10	0	-11	-6	-73	-71
5/2/00 21:05	8.21	-10	-1	-9	0	-9	-4	-69	-62
5/3/00 10:25	8.76	-23	-2	-8	0	-13	-7	-27	-28
5/4/00 10:00	9.75	-20	-2	-8	0	-13	-8	-25	-28
5/4/00 21:00	10.21	-6	-2	-6	0	-14	-11	-25	-20
5/5/00 7:45	10.65	-22	-10	-18	0	-23	-16	-15	-31
5/5/00 19:50	11.16	-6	-1	-5	0	-8	-4	6	-26
5/6/00 9:00	11.71	-25	-10	-13	0	-25	-19	-13	-38
5/6/00 20:00	12.16	-18	-2	-4	0	-9	-8	-1	-30
5/7/00 8:00	12.66	-38	-9	-8	0	-23	-19	-17	-32
5/7/00 20:00	13.16	-34	-7	-8	0	-9	-9	-3	-20
5/8/00 8:00	13.66	-53	-5	-2	0	-16	-10	-15	-28
5/8/00 20:12	14.17	-41	-3	-7	0	-9	-9	-3	-16
5/9/00 10:30	14.77	-65	-12	-15	0	-25	-24	-20	-25
5/9/00 14:20	14.93	-57	-7	-3	0	-16	-16	-11	-14
5/9/00 21:00	15.21	-52	-2	-2	0	-10	-12	-9	-21
5/10/00 8:25	15.68	-70	-7	-6	0	-19	-12	-17	-26

Table C-1. Continued.

5/10/00 20:00	16.16	-54	-6	-3	0	-6	-6	-2	-44
5/11/00 5:55	16.58	-69	-10	-7	0	-19	-15	-17	-39
5/11/00 12:00	16.83	-61	-3	-3	0	-11	-7	-11	-30
5/11/00 22:55	17.28	-59	-4	-2	0	-10	-10	-10	-26
5/12/00 9:00	17.71	-80	-4	-3	0	-27	-19	-5	-38
5/12/00 20:55	18.20	-80	-4	-29	0	-19	-11	-6	-31
5/13/00 10:10	18.75	-5	-9	-3	0	-30	-20	-2	-38
5/13/00 21:25	19.22	-2	-5	8	0	-8	-5	18	-16
5/14/00 10:20	19.76	-9	-13	-8	0	-15	-9	6	-19
5/14/00 19:00	20.12	-5	-6	4	0	-3	-4	25	-6
5/15/00 9:15	20.72	-7	-12	-6	0	-19	-17	3	-19
5/15/00 21:10	21.21	-3	-8	-4	0	-5	-5	25	-7
5/16/00 9:00	21.71	-2	-6	-6	0	-13	-10	15	-12
5/16/00 21:10	22.21	-6	-12	-6	0	-6	-7	22	-12
5/17/00 9:30	22.73	-2	-7	-6	0	-19	-16	7	-19
5/17/00 21:40	23.23	-1	-7	-7	0	-16	-6	9	-16
5/18/00 10:00	23.75	-1	-6	-5	0	-27	-16	-15	-23
5/18/00 22:55	24.28	-7	-15	-5	0	-19	-11	-14	-16
5/19/00 10:10	24.75	-2	-6	-2	0	-24	-10	-12	-14
5/19/00 22:35	25.27	0	-3	-1	0	-14	-4	-10	-9
5/20/00 10:35	25.77	-1	-5	-1	0	-20	-4	-10	-10
5/20/00 22:40	26.27	-1	-5	-2	0	-9	-3	-10	-7
5/21/00 8:40	26.69	0	-4	-1	0	-17	-6	-12	-12
5/21/00 22:25	27.26	0	-10	0	0	-6	-6	-9	-7
5/22/00 9:00	27.71	0	-10	0	0	-16	-3	-17	-13
5/22/00 22:30	28.27	-2	-8	-1	0	-7	-8	-10	-7
5/23/00 8:45	28.69	-1	-5	-1	0	-18	-8	-17	-11
5/23/00 22:40	29.27	0	-12	-1	0	-6	-5	-10	-5
5/24/00 9:10	29.71	0	-3	0	0	-11	-2	-15	-11
5/24/00 22:30	30.27	0	-7	0	0	-7	0	-13	-10
5/25/00 9:05	30.71	-1	-7	0	0	-15	-1	-20	-12
5/25/00 21:40	31.23	0	-9	0	0	-11	-4	-18	-13
5/26/00 8:35	31.69	0	-3	0	0	-20	-3	-28	-18
5/26/00 21:10	32.21	-1	-9	-1	0	-10	-3	-18	-13
5/27/00 9:07	32.71	0	-1	-2	0	-21	0	-28	-17
5/27/00 20:45	33.19	-1	-4	-3	0	-12	0	-17	-7
5/28/00 8:57	33.70	-10	-15	-1	0	-23	-1	-29	-15
5/28/00 20:55	34.20	-8	-14	-12	0	-6	0	-13	-6
5/29/00 9:35	34.73	-10	-18	-13	0	-14	-12	-21	-16
5/29/00 21:20	35.22	-8	-19	-11	0	-4	-2	-11	-5

Table C-1. Continued.

5/30/00 9:45	35.74	-3	-7	0	0	-13	0	-20	-17
5/30/00 20:30	36.18	0	-2	0	0	-3	0	-10	-9
5/31/00 9:15	36.72	-1	-4	0	0	-12	4	-24	-23
5/31/00 22:42	37.28	-5	-12	0	0	-1	9	-22	-17
6/1/00 8:55	37.70	0	-5	-2	0	-7	0	-48	-40
6/1/00 22:42	38.28	-7	-15	-1	0	0	7	-53	-35
6/2/00 9:15	38.72	0	-2	-2	0	5	11	-63	-31
6/2/00 23:45	39.32	0	-2	0	0	-13	-4	-60	-25
6/3/00 7:35	39.65	-1	-8	0	0	5	11	-16	-22
6/3/00 14:30	39.93	0	0	0	0	7	13	-12	-12
6/3/00 22:35	40.27	0	-7	0	0	8	14	-14	-14
6/4/00 10:15	40.76	0	-4	1	0	10	18	-20	-13
6/4/00 22:10	41.25	-2	-9	-2	0	7	13	-13	-6
6/5/00 8:50	41.70	0	-7	2	0	11	17	-19	3
6/5/00 22:32	42.27	4	-6	0	0	11	18	-12	-9
6/6/00 10:43	42.78	1	-3	-1	0	13	19	-16	-1
6/6/00 22:35	43.27	0	-5	0	0	14	22	-11	-10
6/7/00 8:55	43.70	0	-4	2	0	14	21	-17	-10
6/7/00 22:40	44.27	-2	-4	2	0	13	20	-10	-12
6/8/00 10:30	44.77	0	-4	1	0	15	23	-18	-9

Table C-1. Continued.

		Tensiometer							
date and time	Time since addition of Cr(VI) and nutrients (d)	N1 top	N1 bottom	N2 top	N2 bottom	B1 top	B1 bottom	B2 top	B2 bottom
4/19/00 10:54	-5.22	-115	-124	-9	-7	-70	-70	-11	-12
4/20/00 9:15	-4.28	-71	-131	-17	-11	-87	-87	-21	-21
4/20/00 18:00	-3.92	-22	-131	-17	0	-90	-91	-18	-20
4/21/00 10:40	-3.23	-27	-138	-25	0	-93	-93	-28	-28
4/24/00 21:45	0.24	-14	-3	-18	0	-83	45	-14	-14
4/25/00 10:30	0.77	-29	-111	-19	0	-95	25	-16	-16
4/25/00 21:45	1.24	-12	-128	-16	0	-77	-147	-16	-21
4/26/00 8:40	1.69	-34	-89	-19	0	-94	-136	-19	-21
4/26/00 21:45	2.24	-13	-71	-19	0	-67	-149	-19	-21
4/27/00 9:30	2.73	-32	-129	-19	0	-95	-146	-21	-22
4/27/00 13:35	2.90	-21	-127	-18	0	-84	-150	-20	-21
4/28/00 10:15	3.76	-27	-87	-16	0	-44	-153	-15	-18
4/28/00 15:50	3.99	-11	-80	-17	0	-30	-156	-18	-21
4/28/00 22:30	4.27	-17	-102	-17	0	-66	-165	-20	-23
4/29/00 9:55	4.74	-33	-100	-15	0	-78	-148	-15	-18
4/29/00 20:35	5.19	-20	-100	-15	2	-65	-155	-10	-12
4/30/00 9:40	5.73	-37	-43	-16	0	-21	-21	-18	-21
4/30/00 20:40	6.19	-36	-46	-18	0	-22	-22	-18	-20
5/1/00 9:40	6.73	-48	-52	-16	0	-24	-24	-22	-24
5/1/00 21:40	7.23	-36	-52	-15	0	-23	-23	-21	-23
5/2/00 9:45	7.74	-44	-50	-17	0	-20	-20	-24	-26
5/2/00 21:05	8.21	-21	-47	-17	0	-20	-20	-6	-9
5/3/00 10:25	8.76	-37	-50	-15	0	-28	-28	-18	-21
5/4/00 10:00	9.75	-32	-48	-15	0	-30	-30	-10	-11
5/4/00 21:00	10.21	-15	-35	-16	0	-18	-14	3	1
5/5/00 7:45	10.65	-34	-46	-26	0	-23	-20	-22	-25
5/5/00 19:50	11.16	-10	-18	-14	0	-24	-23	-18	-20
5/6/00 9:00	11.71	-29	-13	-23	0	-28	-29	0	-13
5/6/00 20:00	12.16	-15	-34	-15	0	-26	-28	-13	-15
5/7/00 8:00	12.66	-34	-35	-22	0	-27	-29	0	-9
5/7/00 20:00	13.16	-14	-21	-16	0	-23	-26	5	-2
5/8/00 8:00	13.66	-29	-37	-13	0	-23	-25	9	0
5/8/00 20:12	14.17	-13	-34	-17	0	-24	-24	-21	-20
5/9/00 10:30	14.77	-33	-17	-24	0	-86	-85	-10	-15
5/9/00 14:20	14.93	-23	-24	-13	0	-94	-94	-8	-9
5/9/00 21:00	15.21	-17	-30	-15	0	-75	-75	-14	-20
5/10/00 8:25	15.68	-34	-51	-17	0	-75	-75	-28	-31

Table C-1. Continued.

5/10/00 20:00	16.16	-7	-62	-18	0	-75	-75	0	-4
5/11/00 5:55	16.58	-27	-50	-17	0	-24	-24	-14	-17
5/11/00 12:00	16.83	-19	-44	-15	0	-20	-22	-14	-14
5/11/00 22:55	17.28	-16	-43	-16	0	-25	-25	-15	-17
5/12/00 9:00	17.71	-40	-48	-17	0	-31	-31	-18	-19
5/12/00 20:55	18.20	-22	-50	-16	0	-19	-15	-16	-18
5/13/00 10:10	18.75	-39	-49	-16	0	-21	-17	-15	-19
5/13/00 21:25	19.22	19	-56	-18	0	-24	-23	-17	-21
5/14/00 10:20	19.76	-28	-57	-17	0	-25	-24	-23	-25
5/14/00 19:00	20.12	-9	-57	-14	0	-20	-20	-21	-23
5/15/00 9:15	20.72	-31	-55	-14	0	-22	-20	-24	-26
5/15/00 21:10	21.21	-6	-67	-15	0	-23	-22	-15	-16
5/16/00 9:00	21.71	-13	0	-18	0	-26	-26	-16	-20
5/16/00 21:10	22.21	-2	0	-25	0	-21	-23	-21	-24
5/17/00 9:30	22.73	-14	0	-24	0	-10	-10	-14	-15
5/17/00 21:40	23.23	-15	0	-22	0	-15	-11	-15	-19
5/18/00 10:00	23.75	-14	-14	-27	0	-17	-17	-16	-18
5/18/00 22:55	24.28	-12	0	-28	0	-22	-22	-22	-25
5/19/00 10:10	24.75	-11	0	-10	0	-17	-16	-21	-21
5/19/00 22:35	25.27	-10	0	-12	0	-18	-16	-20	-20
5/20/00 10:35	25.77	-11	0	-10	0	-19	-17	-21	-21
5/20/00 22:40	26.27	-10	0	-11	0	-20	-21	-20	-22
5/21/00 8:40	26.69	-12	0	-12	0	-12	-11	-15	-15
5/21/00 22:25	27.26	-16	0	-12	0	-12	-17	-13	-18
5/22/00 9:00	27.71	-10	0	-11	0	-10	-13	-25	-29
5/22/00 22:30	28.27	-12	0	-14	0	-13	-17	-22	-22
5/23/00 8:45	28.69	-12	0	-14	0	-13	-15	-26	-31
5/23/00 22:40	29.27	-11	0	-14	0	-12	-20	-10	-18
5/24/00 9:10	29.71	-10	0	-12	0	-11	-12	-13	-15
5/24/00 22:30	30.27	-68	-61	-13	0	-12	-16	-14	-19
5/25/00 9:05	30.71	-70	-63	-13	0	-12	-14	-14	-19
5/25/00 21:40	31.23	-16	-5	-14	0	-12	-17	-14	-19
5/26/00 8:35	31.69	-17	-7	-12	0	-12	-14	-15	-19
5/26/00 21:10	32.21	-26	-15	-14	0	-13	-17	-14	-19
5/27/00 9:07	32.71	-29	-19	-14	0	-14	-16	-15	-20
5/27/00 20:45	33.19	-29	-17	-13	0	-12	-15	-15	-19
5/28/00 8:57	33.70	-21	-10	-13	0	-14	-15	-16	-22
5/28/00 20:55	34.20	-25	-6	-13	0	-12	-14	-20	-23
5/29/00 9:35	34.73	-36	-13	-25	0	-23	-25	-25	-27
5/29/00 21:20	35.22	-41	-19	-22	0	-21	-20	-24	-24

Table C-1. Continued.

5/30/00 9:45	35.74	-31	-18	-20	0	-9	-11	-20	-21
5/30/00 20:30	36.18	-29	-21	-12	0	-9	-10	-14	-14
5/31/00 9:15	36.72	-30	-23	-12	0	-12	-17	-18	-21
5/31/00 22:42	37.28	-25	-16	-11	0	-11	-15	-20	-22
6/1/00 8:55	37.70	-29	-20	-13	0	-12	-14	-14	-15
6/1/00 22:42	38.28	-32	-22	-13	0	-13	-20	-13	-20
6/2/00 9:15	38.72	-30	-20	-12	0	-12	-13	-12	-17
6/2/00 23:45	39.32	-29	-19	-14	0	-20	-21	-15	-19
6/3/00 7:35	39.65	-34	-25	-12	0	-12	-12	-14	-19
6/3/00 14:30	39.93	-50	-43	-12	0	-21	-19	-14	-18
6/3/00 22:35	40.27	-11	-1	-12	0	-24	-26	-13	-19
6/4/00 10:15	40.76	-13	-2	-12	0	-10	-12	-13	-19
6/4/00 22:10	41.25	-13	0	-14	0	-14	-20	-15	-20
6/5/00 8:50	41.70	-9	0	-10	0	-10	-14	-12	-16
6/5/00 22:32	42.27	-11	0	-13	0	-11	-19	-13	-18
6/6/00 10:43	42.78	-10	0	-12	0	-12	-14	-13	-18
6/6/00 22:35	43.27	-8	0	-11	0	-11	-18	-13	-19
6/7/00 8:55	43.70	-10	0	-11	0	-11	-14	-12	-18
6/7/00 22:40	44.27	-12	0	-14	0	-14	-21	-15	-21
6/8/00 10:30	44.77	-32	-24	-12	0	-10	-11	-21	-24

Table C-2. Gravimetric water content data (g g^{-1}).

date and time	Time since addition of Cr(VI) and nutrients (d)	Column							
		NC1	NC2	C1	C2	N1	N2	B1	B2
4/14/00 23:45	-9.67	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
4/16/00 20:30	-7.80	0.11	0.11	0.08	0.11	0.11	0.13	0.11	0.11
4/17/00 9:20	-7.27	0.09	0.09		0.08	0.09	0.10	0.08	0.08
4/18/00 9:30	-6.26	0.08	0.09	0.08	0.08	0.09	0.11	0.08	0.08
4/19/00 10:54	-5.20	0.09	0.08	0.08	0.08	0.09	0.14	0.09	0.09
4/20/00 9:15	-4.27	0.08	0.08	0.08	0.07	0.09	0.12	0.08	0.08
4/25/00 10:30	0.78	0.08	0.08	0.08	0.06	0.09	0.07	0.08	0.08
4/26/00 21:45	2.25	0.09	0.10	0.09	0.06	0.08	0.07	0.07	0.08
4/27/00 13:35	2.91	0.10	0.11	0.09	0.08	0.07	0.07	0.07	0.08
4/28/00 15:50	4.01	0.10	0.12	0.09	0.08	0.08	0.07	0.07	0.08
4/29/00 20:35	5.20	0.12	0.14	0.12	0.10	0.07	0.07	0.07	0.08
4/30/00 20:40	6.21	0.15	0.15	0.12	0.11	0.07	0.07	0.08	0.08
5/1/00 21:40	7.25	0.14	0.14	0.12	0.12	0.08	0.08	0.07	0.07
5/2/00 21:05	8.23	0.15	0.14	0.14	0.12	0.08	0.07	0.07	0.08
5/4/00 10:00	9.76	0.15	0.15	0.13	0.13	0.08	0.07	0.05	0.09
5/5/00 7:45	10.67	0.13	0.12	0.10	0.11	0.06	0.06	0.07	0.07
5/8/00 21:40	14.25	0.16	0.15	0.12	0.13	0.09	0.08	0.07	0.09
5/9/00 14:20	14.94	0.14	0.12	0.10	0.12	0.08	0.07	0.07	0.08
5/10/00 8:25	15.70	0.15	0.14	0.13	0.13	0.08	0.07	0.07	0.08
5/11/00 12:00	16.85	0.16	0.13	0.13	0.12	0.08	0.08	0.07	0.09
5/12/00 9:00	17.72	0.16	0.14	0.14	0.12	0.08	0.08	0.06	0.08
5/13/00 10:10	18.77	0.16	0.14	0.13	0.13	0.07	0.08	0.07	0.08
5/14/00 19:00	20.14	0.16	0.14	0.13	0.13	0.08	0.09	0.07	0.07
5/15/00 21:10	21.23	0.17	0.14	0.14	0.14	0.07	0.08	0.06	0.08
5/16/00 9:00	21.72	0.17	0.14	0.14	0.12	0.08	0.06	0.06	0.08
5/18/00 10:00	23.76	0.17	0.15	0.14	0.14	0.08	0.05	0.09	0.09
5/19/00 10:10	24.77	0.16	0.14	0.15	0.14	0.08	0.08	0.08	0.07
5/20/00 10:35	25.79	0.17	0.15	0.15	0.15	0.08	0.08	0.08	0.07
5/21/00 8:40	26.71	0.17	0.15	0.15	0.15	0.08	0.08	0.10	0.09
5/22/00 9:00	27.72	0.17	0.16	0.12	0.14	0.08	0.08	0.09	0.08
5/23/00 8:45	28.71	0.17	0.15	0.16	0.15	0.08	0.08	0.09	0.08
5/24/00 9:10	29.73	0.17	0.16	0.17	0.14	0.08	0.08	0.09	0.09
5/25/00 9:05	30.73	0.17	0.16	0.17	0.15	0.08	0.08	0.09	0.09
5/26/00 8:35	31.70	0.18	0.16	0.17	0.12	0.09	0.08	0.09	0.09
5/30/00 22:10	36.27	0.17	0.16	0.20	0.14	0.09	0.09	0.11	0.09
5/31/00 9:15	36.73	0.17	0.16	0.23	0.12	0.09	0.08	0.09	0.08
6/1/00 8:55	37.72	0.17	0.16	0.25	0.10	0.08	0.08	0.10	0.09
6/2/00 9:15	38.73	0.17	0.16	0.26	0.14	0.08	0.08	0.10	0.09
6/3/00 14:30	39.95	0.18	0.16	0.25	0.15	0.09	0.08	0.08	0.09
6/4/00 10:15	40.77	0.18	0.16	0.26	0.16	0.08	0.08	0.10	0.09
6/5/00 8:50	41.72	0.17	0.17	0.26	0.19	0.09	0.08	0.10	0.09
6/6/00 10:43	42.79	0.18	0.16	0.27	0.16	0.08	0.08	0.09	0.09
6/7/00 8:55	43.72	0.18	0.17	0.27	0.16	0.09	0.08	0.10	0.09
6/8/00 10:30	44.78	0.18	0.16	0.27	0.16	0.09	0.08	0.10	0.07

Table C-2. Continued.

final measured gravimetric water content (6/8/00)	0.18	0.16	0.26	0.16	0.09	0.09	0.10	0.07
first tracer test average (4/19-4/20)	0.09	0.08	0.08	0.08	0.09	0.13	0.08	0.08
second tracer test average (6/2-6/8)	0.18	0.16	0.26	0.16	0.09	0.08	0.10	0.09
bulk density	1.38	1.40	1.46	1.52	1.51	1.52	1.52	1.51
porosity	0.48	0.47	0.45	0.43	0.43	0.43	0.43	0.43

Table C-3. Pumping rate and cumulative discharge for syringe pump.

start date and time	stop date and time	start vial	stop vial	flow rate (ml/d)	discharge for interval (ml)	cumulative discharge (ml)
5/16/00 12:30	5/16/00 21:15	162	165	60.48	22.05	22.05
5/16/00 21:15	5/17/00 9:30	165	168	60.85	31.06	53.11
5/17/00 9:30	5/17/00 21:50	168	171	65.17	33.49	86.60
5/17/00 21:50	5/18/00 10:05	171	174	56.42	28.80	115.40
5/18/00 10:05	5/18/00 14:42	174	175	65.14	12.53	127.93
5/18/00 14:42	5/18/00 23:10	175	178	51.19	18.06	145.99
5/18/00 23:10	5/19/00 10:40	178	180	52.01	24.92	170.91
5/19/00 10:40	5/19/00 22:42	180	183	59.16	29.66	200.57
5/19/00 22:42	5/20/00 10:42	183	186	52.24	26.12	226.69
5/20/00 10:42	5/20/00 22:42	186	189	47.80	23.90	250.59
5/20/00 22:42	5/21/00 8:42	189	192	50.86	21.19	271.78
5/21/00 8:42	5/21/00 22:42	192	195	50.07	29.21	300.99
5/21/00 22:42	5/22/00 10:42	195	198	53.82	26.91	327.90
5/22/00 10:42	5/22/00 14:42	198	199	11.16	1.86	329.76
5/22/00 14:42	5/22/00 22:42	199	201	55.92	18.64	348.40
5/22/00 22:42	5/23/00 8:45	201	204	52.35	21.92	370.32
5/23/00 8:45	5/23/00 21:45	204	207	51.27	27.77	398.09
5/24/00 0:10	5/24/00 22:43	207	213	54.61	51.31	449.40
5/24/00 22:43	5/25/00 9:10	213	216	53.37	23.24	472.64
5/25/00 9:10	5/25/00 11:09	216	217	31.95	2.64	475.28
5/25/00 11:09	5/25/00 21:45	217	219	42.59	18.81	494.09
5/25/00 21:45	5/26/00 8:42	219	222	53.90	24.59	518.68
5/26/00 8:42	5/26/00 21:16	222	225	51.51	26.97	545.65
5/26/00 21:16	5/27/00 9:15	225	228	33.03	16.49	562.14
5/27/00 9:15	5/27/00 20:45	228	231	27.55	13.20	575.34
5/27/00 20:45	5/28/00 8:58	231	234	25.87	13.17	588.51
5/28/00 8:58	5/28/00 20:58	234	237	28.26	14.13	602.64
5/28/00 20:58	5/29/00 9:35	237	240	22.54	11.85	614.49
5/29/00 9:35	5/29/00 21:20	240	243	31.95	15.64	630.13
5/29/00 21:20	5/30/00 9:45	243	246	53.29	27.57	657.70
5/30/00 9:45	5/30/00 20:30	246	249	38.56	17.27	674.97
5/30/00 20:30	5/31/00 9:22	249	252	54.99	29.48	704.45
5/31/00 9:22	5/31/00 11:00	252	253	22.63	1.54	705.99
5/31/00 11:00	5/31/00 14:42	253	253	59.42	9.16	715.15
5/31/00 14:42	5/31/00 22:42	253	255	50.88	16.96	732.11
5/31/00 22:42	6/1/00 10:42	255	258	53.44	26.72	758.83
6/1/00 10:42	6/1/00 22:42	258	261	50.98	25.49	784.32
6/1/00 22:42	6/2/00 9:22	261	264	51.05	22.69	807.01
6/2/00 9:22	6/2/00 22:42	264	267	54.54	30.30	837.31
6/2/00 22:42	6/3/00 7:42	267	270	58.59	21.97	859.28
6/3/00 7:42	6/3/00 14:42	270	271	65.21	19.02	878.30
6/3/00 14:42	6/3/00 22:42	271	273	58.05	19.35	897.65
6/3/00 22:42	6/4/00 10:42	273	276	51.52	25.76	923.41
6/4/00 10:42	6/4/00 22:10	276	279	53.98	25.79	949.20
6/4/00 22:10	6/5/00 10:42	279	282	50.21	26.22	975.42
6/5/00 10:42	6/5/00 22:42	282	285	52.42	26.21	1001.63
6/5/00 22:42	6/6/00 10:42	285	288	50.38	25.19	1026.82

Table C-3. Continued.

6/6/00 10:42	6/6/00 22:42	288	291	50.00	25.00	1051.82
6/6/00 22:42	6/7/00 9:00	291	294	54.06	23.20	1075.02
6/7/00 9:00	6/7/00 10:52	294	295	38.83	3.02	1078.04
6/7/00 10:52	6/7/00 22:42	295	297	54.92	27.08	1105.12
6/7/00 22:42	6/8/00 10:42	297	300	48.62	24.31	1129.43

Table C-4. Inlet solution schedule.

date and time at start	date and time at stop	elapsed time (d)	effluent vial ID at start	effluent vial ID at stop	influent Cr concentrations (mg L^{-1})			
					NC1&NC2	C1&C2	N1&N2	B1&B2
4/24/00 16:10	4/27/00 13:40	2.90	32	49	66	61	63	61
4/28/00 2:35	5/4/00 1:20	5.95	52	88	67	70	63	56
5/4/00 2:40	5/11/00 12:20	7.40	88	133	65	65	65	64
5/11/00 13:00	5/17/00 21:45	6.36	133	171	64	61	64	61
5/17/00 23:00	5/23/00 22:45	5.99	172	208	63	59	64	64
5/24/00 0:10	5/26/00 8:45	2.36	208	222	63	61	63	61
5/26/00 9:50	6/3/00 22:43	8.54	222	273	64	62	64	60
6/3/00 23:15	6/8/00 10:45	4.48	274	301	63	61	64	60

Table C-5. Effluent sample vial removal schedule.

date and time at start	date and time at stop	elapsed time (d)	effluent vial ID at start	effluent vial ID at stop
4/24/00 16:10	4/27/00 13:40	2.90	32	49
4/28/00 2:35	4/30/00 20:50	2.76	52	69
4/30/00 22:40	5/3/00 16:00	2.72	70	85
5/3/00 16:00	5/4/00 13:00	0.88	86	90
5/4/00 13:00	5/9/00 14:30	5.06	91	121
5/9/00 16:20	5/12/00 9:10	2.70	122	137
5/12/00 10:45	5/16/00 9:20	3.94	138	161
5/16/00 10:30	5/18/00 14:30	2.17	162	174
5/18/00 15:00	5/22/00 11:00	3.83	175	198
5/22/00 11:00	5/25/00 9:10	2.92	199	215
5/25/00 9:50	5/26/00 9:45	1.00	216	221
5/26/00 9:45	5/31/00 9:40	5.00	222	251
5/31/00 9:40	6/2/00 9:45	2.00	252	263
6/2/00 10:15	6/5/00 9:10	2.95	264	281
6/5/00 9:40	6/7/00 9:15	1.98	282	293
6/7/00 9:50	6/8/00 10:45	1.04	294	300

Table C-6. Evaporation rates (mL d^{-1}) for water in vials in fraction collectors.

Begin date and time	**End date and time**	**Column**							
		NC1	**NC2**	**C1**	**C2**	**N1**	**N2**	**B1**	**B2**
5/12/00 9:10	5/16/00 9:20	0.27	0.35	0.27	0.36	0.19	0.25	0.34	0.39
5/16/00 9:20	5/18/00 14:30	0.23	0.36	0.30	0.35	0.14	0.29	0.33	0.45
5/18/00 14:30	5/22/00 11:00	0.16	0.29	0.25	0.33	0.13	0.25	0.25	0.38
5/22/00 11:00	5/25/00 9:10	0.29	0.36	0.29	0.41	0.16	0.29	0.30	0.41
5/25/00 9:10	5/26/00 9:45	0.26	0.30	0.24	0.37	0.12	0.25	0.24	0.34
5/26/00 9:45	5/31/00 9:40	0.27	0.29	0.23	0.35	0.16	0.23	0.24	0.36
5/31/00 9:40	6/2/00 9:45	0.25	0.28	0.24	0.35	0.17	0.25	0.23	0.37
6/2/00 9:45	6/5/00 9:10	0.22	0.25	0.22	0.24	0.15	0.18	0.19	0.27
6/5/00 9:10	6/7/00 9:15	0.22	0.22	0.21	0.23	0.17	0.19	0.22	0.29
6/7/00 9:15	6/8/00 10:45	0.24	0.24	0.25	0.28	0.09	0.22	0.21	0.27
average evaporation rate		0.24	0.30	0.25	0.33	0.15	0.24	0.26	0.36

Table C-7. Column effluent discharge (measured and corrected for evaporation). Average evaporation rates (Table C-6) used in calculations.

Effluent Vial ID	Time (evap. corrections) (d)	NC1 measured (ml)	NC1 corrected (ml)	NC1 cumulative (ml)	NC2 measured (ml)	NC2 corrected (ml)	NC2 cumulative (ml)
1	1.88	4.26	4.71	4.71	4.71	5.27	5.27
2	1.81	3.15	3.59	8.30	4.01	4.55	9.83
3	1.75	2.94	3.36	11.66	3.11	3.64	13.46
4	1.69	2.68	3.09	14.74	3.08	3.59	17.05
5	1.63	2.69	3.08	17.82	2.60	3.09	20.14
6	1.56	2.54	2.92	20.74	2.71	3.18	23.31
7	1.50	2.81	3.17	23.91	2.31	2.76	26.07
8	1.44	3.20	3.55	27.45	2.70	3.13	29.21
9	1.38	3.07	3.40	30.85	2.74	3.15	32.36
10	1.31	3.12	3.44	34.29	2.60	2.99	35.35
11	1.25	3.03	3.33	37.62	2.82	3.20	38.55
12	1.19	3.07	3.36	40.97	2.59	2.95	41.49
13	1.13	3.04	3.31	44.28	2.70	3.04	44.53
14	1.06	2.47	2.73	47.01	2.34	2.66	47.19
15	1.00	5.54	5.78	52.79	4.98	5.28	52.47
16	0.94	2.99	3.22	56.00	3.87	4.15	56.62
17	0.88	3.06	3.27	59.27	3.44	3.70	60.32
18	0.81	2.65	2.85	62.12	3.13	3.37	63.70
19	0.75	2.52	2.70	64.82	3.32	3.55	67.24
20	0.69	2.34	2.51	67.32	2.90	3.11	70.35
21	0.63	2.81	2.96	70.28	3.20	3.39	73.74
22	0.56	2.42	2.56	72.84	2.59	2.76	76.49
23	0.50	2.65	2.77	75.61	2.98	3.13	79.62
24	0.44	2.75	2.86	78.46	2.79	2.92	82.55
25	0.38	2.46	2.55	81.01	2.49	2.60	85.15
26	0.31	2.46	2.54	83.55	2.86	2.95	88.10
27	0.25	2.37	2.43	85.98	2.41	2.49	90.59
28	0.19	1.91	1.96	87.93	1.88	1.94	92.52
29	0.13	1.24	1.27	89.20	0.80	0.84	93.36
30	0.06	0.75	0.77	89.97	0.38	0.40	93.76
31	0.00	0.37	0.37	90.34	0.37	0.37	94.13
32	2.83	1.29	1.97	92.31	0.37	1.22	95.35
33	2.67	6.69	7.33	99.64	6.77	7.57	102.92
34	2.50	9.24	9.84	109.48	8.74	9.49	112.41
35	2.33	9.28	9.84	119.32	8.44	9.14	121.55
36	2.17	12.10	12.62	131.94	11.65	12.30	133.85
37	2.00	10.42	10.90	142.84	10.19	10.79	144.64
38	1.83	8.57	9.01	151.85	7.09	7.64	152.28
39	1.67	18.96	19.36	171.21	13.25	13.75	166.03
40	1.50	9.99	10.35	181.56	9.49	9.94	175.97
41	1.33	7.47	7.79	189.35	7.13	7.53	183.50
42	1.17	10.12	10.40	199.75	9.30	9.65	193.15
43	1.00	8.64	8.88	208.63	7.66	7.96	201.11
44	0.83	8.19	8.39	217.02	6.84	7.09	208.20
45	0.67	13.08	13.24	230.26	13.07	13.27	221.47

Table C-7. Continued.

46	0.50	7.72	7.84	238.10	7.31	7.46	228.93
47	0.33	6.28	6.36	244.46	5.13	5.23	234.16
48	0.17	6.83	6.87	251.33	5.04	5.09	239.25
49	0.00	2.95	2.95	254.28	2.70	2.70	241.95
52	2.83	9.59	10.27	264.55	9.54	10.39	252.34
53	2.67	5.65	6.29	270.84	5.60	6.40	258.74
54	2.50	6.88	7.48	278.32	5.15	5.90	264.64
55	2.33	6.55	7.11	285.43	6.45	7.15	271.79
56	2.17	12.85	13.37	298.80	13.87	14.52	286.31
57	2.00	6.26	6.74	305.54	6.06	6.66	292.97
58	1.83	6.34	6.78	312.32	7.28	7.83	300.80
59	1.67	6.18	6.58	318.90	7.28	7.78	308.58
60	1.50	7.29	7.65	326.55	8.14	8.59	317.17
61	1.33	7.12	7.44	333.99	7.58	7.98	325.15
62	1.17	7.00	7.28	341.27	7.88	8.23	333.38
63	1.00	11.75	11.99	353.26	18.28	18.58	351.96
64	0.83	5.76	5.96	359.22	9.05	9.30	361.26
65	0.67	6.38	6.54	365.76	6.44	6.64	367.90
66	0.50	10.00	10.12	375.88	9.02	9.17	377.07
67	0.33	8.39	8.47	384.35	10.29	10.39	387.46
68	0.17	7.71	7.75	392.10	9.22	9.27	396.73
69	0.00	1.66	1.66	393.76	2.17	2.17	398.90
70	2.50	19.93	20.53	414.29	17.07	17.82	416.72
71	2.33	3.94	4.50	418.79	8.91	9.61	426.33
72	2.17	5.77	6.29	425.08	7.21	7.86	434.19
73	2.00	6.17	6.65	431.73	7.85	8.45	442.64
74	1.83	6.68	7.12	438.85	8.81	9.36	452.00
75	1.67	9.67	10.07	448.92	11.47	11.97	463.97
76	1.50	7.83	8.19	457.11	10.78	11.23	475.20
77	1.33	6.31	6.63	463.74	8.03	8.43	483.63
78	1.17	7.12	7.40	471.14	8.01	8.36	491.99
79	1.00	8.18	8.42	479.56	9.65	9.95	501.94
80	0.83	8.03	8.23	487.79	8.82	9.07	511.01
81	0.67	11.27	11.43	499.22	10.11	10.31	521.32
82	0.50	8.59	8.71	507.93	9.84	9.99	531.31
83	0.33	8.26	8.34	516.27	8.91	9.01	540.32
84	0.17	8.28	8.32	524.59	8.71	8.76	549.08
85	0.00	9.67	9.67	534.26	10.41	10.41	559.49
86	0.67	10.57	10.73	544.99	10.43	10.63	570.12
87	0.50	8.18	8.30	553.29	9.28	9.43	579.55
88	0.33	6.76	6.84	560.13	6.08	6.18	585.73
89	0.17	7.09	7.13	567.26	7.47	7.52	593.25
90	0.00	7.26	7.26	574.52	8.38	8.38	601.63
91	5.00	8.39	9.59	584.11	9.30	10.80	612.43
92	4.83	6.63	7.79	591.90	8.04	9.49	621.92
93	4.67	10.12	11.24	603.14	15.00	16.40	638.32
94	4.50	7.80	8.88	612.02	9.23	10.58	648.90
95	4.33	3.01	4.05	616.07	5.17	6.47	655.37
96	4.17	1.96	2.96	619.03	0.00	1.25	656.62
97	4.00	6.33	7.29	626.32	5.78	6.98	663.60

Table C-7. Continued.

98	3.83	9.24	10.16	636.48	10.08	11.23	674.83
99	3.67	7.95	8.83	645.31	10.06	11.16	685.99
100	3.50	7.19	8.03	653.34	8.99	10.04	696.03
101	3.33	3.75	4.55	657.89	4.20	5.20	701.23
102	3.17	2.09	2.85	660.74	3.00	3.95	705.18
103	3.00	4.65	5.37	666.11	4.55	5.45	710.63
104	2.83	8.08	8.76	674.87	7.64	8.49	719.12
105	2.67	8.38	9.02	683.89	9.24	10.04	729.16
106	2.50	6.92	7.52	691.41	8.66	9.41	738.57
107	2.33	3.70	4.26	695.67	4.65	5.35	743.92
108	2.17	2.54	3.06	698.73	3.24	3.89	747.81
109	2.00	6.77	7.25	705.98	5.47	6.07	753.88
110	1.83	6.76	7.20	713.18	7.21	7.76	761.64
111	1.67	4.44	4.84	718.02	5.31	5.81	767.45
112	1.50	8.46	8.82	726.84	7.62	8.07	775.52
113	1.33	7.47	7.79	734.63	7.75	8.15	783.67
114	1.17	5.05	5.33	739.96	6.25	6.60	790.27
115	1.00	8.76	9.00	748.96	8.74	9.04	799.31
116	0.83	7.98	8.18	757.14	9.34	9.59	808.90
117	0.67	10.78	10.94	768.08	12.62	12.82	821.72
118	0.50	5.86	5.98	774.06	7.44	7.59	829.31
119	0.33	3.31	3.39	777.45	4.74	4.84	834.15
120	0.17	2.36	2.40	779.85	3.86	3.91	838.06
121	0.00	2.62	2.62	782.47	3.10	3.10	841.16
122	2.50	2.87	3.47	785.94	3.33	4.08	845.24
123	2.33	9.39	9.95	795.89	6.98	7.68	852.92
124	2.17	10.38	10.90	806.79	9.24	9.89	862.81
125	2.00	9.15	9.63	816.42	8.35	8.95	871.76
126	1.83	8.27	8.71	825.13	8.09	8.64	880.40
127	1.67	7.28	7.68	832.81	9.03	9.53	889.93
128	1.50	8.03	8.39	841.20	8.74	9.19	899.12
129	1.33	12.32	12.64	853.84	15.18	15.58	914.70
130	1.17	10.53	10.81	864.65	11.59	11.94	926.64
131	1.00	7.88	8.12	872.77	8.91	9.21	935.85
132	0.83	7.15	7.35	880.12	7.82	8.07	943.92
133	0.67	8.25	8.41	888.53	9.24	9.44	953.36
134	0.50	7.56	7.68	896.21	8.99	9.14	962.50
135	0.33	7.69	7.77	903.98	8.49	8.59	971.09
136	0.17	8.36	8.40	912.38	8.37	8.42	979.51
137	0.00	8.58	8.58	920.96	8.38	8.38	987.89
138	3.83	3.89	4.81	925.77	3.73	4.88	992.77
139	3.67	8.51	9.39	935.16	9.14	10.24	1003.01
140	3.50	5.99	6.83	941.99	7.44	8.49	1011.50
141	3.33	10.42	11.22	953.21	8.10	9.10	1020.60
142	3.17	9.31	10.07	963.28	8.81	9.76	1030.36
143	3.00	8.33	9.05	972.33	8.43	9.33	1039.69
144	2.83	6.81	7.49	979.82	7.12	7.97	1047.66
145	2.67	6.19	6.83	986.65	7.58	8.38	1056.04
146	2.50	7.51	8.11	994.76	8.18	8.93	1064.97
147	2.33	8.84	9.40	1004.16	8.63	9.33	1074.30

Table C-7. Continued.

148	2.17	9.58	10.10	1014.26	9.87	10.52	1084.82
149	2.00	7.39	7.87	1022.13	8.60	9.20	1094.02
150	1.83	4.84	5.28	1027.41	6.00	6.55	1100.57
151	1.67	6.46	6.86	1034.27	6.94	7.44	1108.01
152	1.50	9.14	9.50	1043.77	8.43	8.88	1116.89
153	1.33	11.67	11.99	1055.76	14.90	15.30	1132.19
154	1.17	10.09	10.37	1066.13	10.83	11.18	1143.37
155	1.00	8.50	8.74	1074.87	8.77	9.07	1152.44
156	0.83	6.92	7.12	1081.99	8.55	8.80	1161.24
157	0.67	10.75	10.91	1092.90	9.89	10.09	1171.33
158	0.50	9.74	9.86	1102.76	9.79	9.94	1181.27
159	0.33	11.24	11.32	1114.08	9.70	9.80	1191.07
160	0.17	9.15	9.19	1123.27	10.30	10.35	1201.42
161	0.00	8.74	8.74	1132.01	9.44	9.44	1210.86
162	2.00	5.23	5.71	1137.72	5.21	5.81	1216.67
163	1.83	9.36	9.80	1147.52	11.42	11.97	1228.64
164	1.67	6.45	6.85	1154.37	9.64	10.14	1238.78
165	1.50	5.59	5.95	1160.32	8.09	8.54	1247.32
166	1.33	6.28	6.60	1166.92	8.98	9.38	1256.70
167	1.17	8.02	8.30	1175.22	8.72	9.07	1265.77
168	1.00	8.28	8.52	1183.74	7.76	8.06	1273.83
169	0.83	11.41	11.61	1195.35	9.74	9.99	1283.82
170	0.67	9.30	9.46	1204.81	9.59	9.79	1293.61
171	0.50	6.56	6.68	1211.49	7.28	7.43	1301.04
172	0.33	4.56	4.64	1216.13	12.71	12.81	1313.85
173	0.17	7.30	7.34	1223.47	10.72	10.77	1324.62
174	0.00	7.34	7.34	1230.81	9.78	9.78	1334.40
175	3.83	5.81	6.73	1237.54	8.30	9.45	1343.85
176	3.67	5.59	6.47	1244.01	10.50	11.60	1355.45
177	3.50	3.80	4.64	1248.65	8.98	10.03	1365.48
178	3.33	3.46	4.26	1252.91	7.88	8.88	1374.36
179	3.17	6.21	6.97	1259.88	8.33	9.28	1383.64
180	3.00	5.08	5.80	1265.68	7.48	8.38	1392.02
181	2.83	5.07	5.75	1271.43	7.88	8.73	1400.75
182	2.67	6.29	6.93	1278.36	7.43	8.23	1408.98
183	2.50	8.32	8.92	1287.28	7.88	8.63	1417.61
184	2.33	7.93	8.49	1295.77	8.43	9.13	1426.74
185	2.17	9.65	10.17	1305.94	9.45	10.10	1436.84
186	2.00	7.49	7.97	1313.91	8.51	9.11	1445.95
187	1.83	6.46	6.90	1320.81	8.16	8.71	1454.66
188	1.67	7.11	7.51	1328.32	8.88	9.38	1464.04
189	1.50	5.87	6.23	1334.55	8.25	8.70	1472.74
190	1.33	5.93	6.25	1340.80	7.90	8.30	1481.04
191	1.17	7.34	7.62	1348.42	7.85	8.20	1489.24
192	1.00	8.80	9.04	1357.46	6.99	7.29	1496.53
193	0.83	10.37	10.57	1368.03	8.70	8.95	1505.48
194	0.67	10.66	10.82	1378.85	8.58	8.78	1514.26
195	0.50	7.96	8.08	1386.93	8.51	8.66	1522.92
196	0.33	7.38	7.46	1394.39	7.89	7.99	1530.91
197	0.17	9.78	9.82	1404.21	8.85	8.90	1539.81

Table C-7. Continued.

198	0.00	7.99	7.99	1412.20	7.64	7.64	1547.45
199	2.67	7.96	8.60	1420.80	11.17	11.97	1559.42
200	2.50	8.33	8.93	1429.73	8.40	9.15	1568.57
201	2.33	9.49	10.05	1439.78	8.40	9.10	1577.67
202	2.17	9.60	10.12	1449.90	8.28	8.93	1586.60
203	2.00	7.15	7.63	1457.53	8.74	9.34	1595.94
204	1.83	6.79	7.23	1464.76	6.79	7.34	1603.28
205	1.67	8.55	8.95	1473.71	6.59	7.09	1610.37
206	1.50	10.01	10.37	1484.08	7.97	8.42	1618.79
207	1.33	7.37	7.69	1491.77	7.34	7.74	1626.53
208	1.17	5.88	6.16	1497.93	5.09	5.44	1631.97
209	1.00	6.46	6.70	1504.63	7.00	7.30	1639.27
210	0.83	7.27	7.47	1512.10	9.11	9.36	1648.63
211	0.67	10.05	10.21	1522.31	9.48	9.68	1658.31
212	0.50	8.82	8.94	1531.25	9.05	9.20	1667.51
213	0.33	7.07	7.15	1538.40	8.51	8.61	1676.12
214	0.17	7.22	7.26	1545.66	8.76	8.81	1684.93
215	0.00	9.63	9.63	1555.29	8.55	8.55	1693.48
216	0.83	6.11	6.31	1561.60	7.21	7.46	1700.94
217	0.67	6.93	7.09	1568.69	8.08	8.28	1709.22
218	0.50	7.93	8.05	1576.74	8.48	8.63	1717.85
219	0.33	9.26	9.34	1586.08	8.83	8.93	1726.78
220	0.17	8.59	8.63	1594.71	9.58	9.63	1736.41
221	0.00	8.87	8.87	1603.58	8.95	8.95	1745.36
222	4.83	4.72	5.88	1609.46	6.62	8.07	1753.43
223	4.67	7.78	8.90	1618.36	9.07	10.47	1763.90
224	4.50	7.56	8.64	1627.00	8.25	9.60	1773.50
225	4.33	8.17	9.21	1636.21	7.59	8.89	1782.39
226	4.17	7.04	8.04	1644.25	7.68	8.93	1791.32
227	4.00	10.37	11.33	1655.58	8.34	9.54	1800.86
228	3.83	7.68	8.60	1664.18	9.46	10.61	1811.47
229	3.67	10.56	11.44	1675.62	9.51	10.61	1822.08
230	3.50	7.14	7.98	1683.60	9.43	10.48	1832.56
231	3.33	10.91	11.71	1695.31	8.99	9.99	1842.55
232	3.17	7.68	8.44	1703.75	9.25	10.20	1852.75
233	3.00	5.98	6.70	1710.45	8.98	9.88	1862.63
234	2.83	4.06	4.74	1715.19	9.88	10.73	1873.36
235	2.67	4.08	4.72	1719.91	9.53	10.33	1883.69
236	2.50	4.60	5.20	1725.11	7.42	8.17	1891.86
237	2.33	4.23	4.79	1729.90	3.95	4.65	1896.51
238	2.17	4.14	4.66	1734.56	3.62	4.27	1900.78
239	2.00	3.86	4.34	1738.90	3.73	4.33	1905.11
240	1.83	3.45	3.89	1742.79	2.99	3.54	1908.65
241	1.67	3.29	3.69	1746.48	2.83	3.33	1911.98
242	1.50	3.26	3.62	1750.10	2.97	3.42	1915.40
243	1.33	2.84	3.16	1753.26	2.86	3.26	1918.66
244	1.17	2.97	3.25	1756.51	2.93	3.28	1921.94
245	1.00	3.49	3.73	1760.24	6.55	6.85	1928.79
246	0.83	4.36	4.56	1764.80	8.04	8.29	1937.08
247	0.67	5.09	5.25	1770.05	10.66	10.86	1947.94

Table C-7. Continued.

248	0.50	5.35	5.47	1775.52	5.47	5.62	1953.56
249	0.33	6.30	6.38	1781.90	6.56	6.66	1960.22
250	0.17	10.32	10.36	1792.26	11.44	11.49	1971.71
251	0.00	9.09	9.09	1801.35	10.04	10.04	1981.75
252	1.83	5.01	5.45	1806.80	6.44	6.99	1988.74
253	1.67	6.01	6.41	1813.21	9.81	10.31	1999.05
254	1.50	8.74	9.10	1822.31	9.16	9.61	2008.66
255	1.33	5.76	6.08	1828.39	9.14	9.54	2018.20
256	1.17	5.11	5.39	1833.78	8.30	8.65	2026.85
257	1.00	6.71	6.95	1840.73	8.76	9.06	2035.91
258	0.83	9.15	9.35	1850.08	8.41	8.66	2044.57
259	0.67	6.83	6.99	1857.07	8.35	8.55	2053.12
260	0.50	7.82	7.94	1865.01	8.27	8.42	2061.54
261	0.33	5.28	5.36	1870.37	8.46	8.56	2070.10
262	0.17	4.68	4.72	1875.09	9.68	9.73	2079.83
263	0.00	5.12	5.12	1880.21	9.63	9.63	2089.46
264	2.83	5.97	6.65	1886.86	7.05	7.90	2097.36
265	2.67	9.34	9.98	1896.84	9.03	9.83	2107.19
266	2.50	7.96	8.56	1905.40	9.17	9.92	2117.11
267	2.33	5.25	5.81	1911.21	9.26	9.96	2127.07
268	2.17	7.32	7.84	1919.05	8.52	9.17	2136.24
269	2.00	10.85	11.33	1930.38	9.55	10.15	2146.39
270	1.83	9.20	9.64	1940.02	9.79	10.34	2156.73
271	1.67	8.50	8.90	1948.92	10.13	10.63	2167.36
272	1.50	9.82	10.18	1959.10	10.00	10.45	2177.81
273	1.33	10.32	10.64	1969.74	9.64	10.04	2187.85
274	1.17	7.61	7.89	1977.63	8.92	9.27	2197.12
275	1.00	10.70	10.94	1988.57	9.07	9.37	2206.49
276	0.83	7.89	8.09	1996.66	8.72	8.97	2215.46
277	0.67	7.74	7.90	2004.56	11.08	11.28	2226.74
278	0.50	9.98	10.10	2014.66	10.07	10.22	2236.96
279	0.33	10.56	10.64	2025.30	8.94	9.04	2246.00
280	0.17	6.32	6.36	2031.66	8.16	8.21	2254.21
281	0.00	9.38	9.38	2041.04	9.21	9.21	2263.42
282	1.83	9.24	9.68	2050.72	7.86	8.41	2271.83
283	1.67	6.05	6.45	2057.17	10.24	10.74	2282.57
284	1.50	7.86	8.22	2065.39	9.28	9.73	2292.30
285	1.33	10.94	11.26	2076.65	8.50	8.90	2301.20
286	1.17	6.42	6.70	2083.35	8.66	9.01	2310.21
287	1.00	8.82	9.06	2092.41	8.63	8.93	2319.14
288	0.83	8.89	9.09	2101.50	8.43	8.68	2327.82
289	0.67	5.68	5.84	2107.34	7.42	7.62	2335.44
290	0.50	7.69	7.81	2115.15	7.92	8.07	2343.51
291	0.33	11.55	11.63	2126.78	8.12	8.22	2351.73
292	0.17	7.93	7.97	2134.75	9.35	9.40	2361.13
293	0.00	8.11	8.11	2142.86	9.68	9.68	2370.81
294	1.00	9.96	10.20	2153.06	7.78	8.08	2378.89
295	0.83	7.08	7.28	2160.34	10.24	10.49	2389.38
296	0.67	6.27	6.43	2166.77	9.80	10.00	2399.38
297	0.50	8.32	8.44	2175.21	8.97	9.12	2408.50

Table C-7. Continued.

298	0.33	10.57	10.65	2185.86	9.21	9.31	2417.81
299	0.17	5.38	5.42	2191.28	9.36	9.41	2427.22
300	0.00	7.93	7.93	2199.21	7.81	7.81	2435.03
Mean flow rate (ml/d)			48			53	
Total discharge for Cr(VI) and nutrient additions vials 32 through 300 (ml)			2109			2341	

Table C-7. Continued.

Effluent Vial ID	Time (evap. corrections) (d)	C1 measured (ml)	C1 corrected (ml)	C1 cumulative (ml)	C2 measured (ml)	C2 corrected (ml)	C2 cumulative (ml)
1	1.88	3.13	3.60	3.60	1.47	2.09	2.09
2	1.81	2.54	2.99	6.59	0.93	1.53	3.62
3	1.75	2.65	3.09	9.68	0.40	0.98	4.59
4	1.69	2.45	2.87	12.55	0.12	0.68	5.27
5	1.63	2.25	2.66	15.21	0.02	0.56	5.83
6	1.56	2.39	2.78	17.99	0.01	0.53	6.35
7	1.50	2.19	2.57	20.55	0.01	0.51	6.86
8	1.44	2.30	2.66	23.21	0.00	0.00	6.86
9	1.38	2.32	2.66	25.88	0.00	0.00	6.86
10	1.31	2.35	2.68	28.55	0.00	0.00	6.86
11	1.25	2.12	2.43	30.99	0.00	0.00	6.86
12	1.19	2.10	2.40	33.38	0.00	0.00	6.86
13	1.13	2.16	2.44	35.83	0.03	0.00	6.86
14	1.06	1.85	2.12	37.94	0.00	0.00	6.86
15	1.00	2.53	2.78	40.72	0.48	0.81	7.67
16	0.94	3.01	3.24	43.97	0.61	0.92	8.59
17	0.88	2.61	2.83	46.79	0.35	0.64	9.23
18	0.81	2.66	2.86	49.66	0.36	0.63	9.85
19	0.75	2.41	2.60	52.25	0.41	0.66	10.51
20	0.69	2.09	2.26	54.52	0.19	0.42	10.93
21	0.63	2.56	2.72	57.23	0.08	0.29	11.22
22	0.56	2.15	2.29	59.52	0.01	0.20	11.41
23	0.50	2.28	2.41	61.93	0.00	0.00	11.41
24	0.44	2.15	2.26	64.19	0.04	0.18	11.60
25	0.38	2.22	2.31	66.50	0.00	0.00	11.60
26	0.31	1.97	2.05	68.55	0.00	0.00	11.60
27	0.25	1.70	1.76	70.31	0.00	0.00	11.60
28	0.19	0.47	0.52	70.83	0.00	0.00	11.60
29	0.13	0.08	0.11	70.94	0.00	0.00	11.60
30	0.06	0.03	0.05	70.99	0.00	0.00	11.60
31	0.00	0.06	0.06	71.05	0.00	0.00	11.60
32	2.83	0.25	0.96	72.01	0.00	0.94	12.53
33	2.67	6.19	6.86	78.87	0.00	0.88	13.41
34	2.50	8.19	8.82	87.68	0.00	0.83	14.24
35	2.33	7.62	8.20	95.89	0.00	0.77	15.01
36	2.17	9.54	10.08	105.97	0.00	0.72	15.72
37	2.00	10.76	11.26	117.23	0.00	0.66	16.38
38	1.83	8.84	9.30	126.53	0.00	0.61	16.99
39	1.67	17.02	17.44	143.96	0.38	0.93	17.92
40	1.50	11.13	11.51	155.47	3.21	3.71	21.62
41	1.33	7.44	7.77	163.24	2.28	2.72	24.34
42	1.17	8.37	8.66	171.90	8.31	8.70	33.04
43	1.00	8.19	8.44	180.34	5.26	5.59	38.63
44	0.83	7.82	8.03	188.37	2.65	2.93	41.55
45	0.67	9.96	10.13	198.50	1.87	2.09	43.64

Table C-7. Continued.

46	0.50	8.81	8.94	207.43	2.73	2.90	46.54
47	0.33	7.44	7.52	214.96	2.48	2.59	49.13
48	0.17	7.65	7.69	222.65	3.07	3.13	52.25
49	0.00	3.60	3.60	226.25	1.49	1.49	53.74
52	2.83	4.15	4.86	231.11	2.34	3.28	57.02
53	2.67	10.02	10.69	241.79	3.38	4.26	61.28
54	2.50	7.80	8.43	250.22	3.77	4.60	65.87
55	2.33	7.68	8.26	258.48	4.15	4.92	70.79
56	2.17	10.07	10.61	269.09	6.54	7.26	78.05
57	2.00	7.67	8.17	277.26	2.75	3.41	81.46
58	1.83	7.09	7.55	284.81	2.38	2.99	84.44
59	1.67	6.80	7.22	292.03	3.09	3.64	88.08
60	1.50	6.53	6.91	298.93	3.96	4.46	92.54
61	1.33	6.79	7.12	306.06	3.92	4.36	96.90
62	1.17	6.96	7.25	313.31	3.39	3.78	100.67
63	1.00	13.89	14.14	327.45	7.11	7.44	108.11
64	0.83	9.03	9.24	336.69	3.62	3.90	112.01
65	0.67	7.74	7.91	344.59	2.89	3.11	115.12
66	0.50	7.53	7.66	352.25	6.79	6.96	122.07
67	0.33	7.96	8.04	360.29	10.92	11.03	133.10
68	0.17	7.67	7.71	368.00	0.00	0.06	133.16
69	0.00	1.46	1.46	369.46	0.00	0.00	133.16
70	2.50	13.33	13.96	383.42	9.09	9.92	143.07
71	2.33	8.77	9.35	392.77	4.35	5.12	148.19
72	2.17	7.19	7.73	400.50	3.35	4.07	152.26
73	2.00	7.45	7.95	408.45	3.01	3.67	155.93
74	1.83	6.82	7.28	415.73	3.28	3.89	159.81
75	1.67	6.79	7.21	422.94	4.22	4.77	164.58
76	1.50	9.25	9.63	432.56	5.06	5.56	170.14
77	1.33	8.00	8.33	440.90	5.35	5.79	175.93
78	1.17	7.38	7.67	448.57	4.18	4.57	180.49
79	1.00	7.59	7.84	456.41	6.40	6.73	187.22
80	0.83	7.95	8.16	464.57	5.90	6.18	193.40
81	0.67	10.31	10.48	475.04	5.16	5.38	198.78
82	0.50	11.36	11.49	486.53	6.05	6.22	204.99
83	0.33	9.70	9.78	496.31	5.87	5.98	210.97
84	0.17	9.04	9.08	505.39	5.36	5.42	216.39
85	0.00	14.53	14.53	519.92	7.41	7.41	223.80
86	0.67	7.20	7.37	527.29	8.21	8.43	232.23
87	0.50	8.38	8.51	535.79	8.38	8.55	240.77
88	0.33	6.69	6.77	542.57	4.54	4.65	245.42
89	0.17	7.94	7.98	550.55	4.90	4.96	250.38
90	0.00	7.14	7.14	557.69	5.89	5.89	256.27
91	5.00	15.42	16.67	574.36	6.70	8.35	264.62
92	4.83	7.62	8.83	583.19	7.16	8.76	273.37
93	4.67	9.47	10.64	593.82	7.54	9.08	282.45
94	4.50	6.34	7.47	601.29	7.52	9.01	291.46
95	4.33	4.99	6.07	607.36	4.58	6.01	297.47
96	4.17	2.58	3.62	610.98	0.46	1.84	299.30
97	4.00	3.80	4.80	615.78	1.63	2.95	302.25

Table C-7. Continued.

98	3.83	6.06	7.02	622.80	6.80	8.07	310.32
99	3.67	17.43	18.35	641.15	7.14	8.35	318.67
100	3.50	5.12	6.00	647.14	5.29	6.45	325.11
101	3.33	5.18	6.01	653.16	3.83	4.93	330.04
102	3.17	2.56	3.35	656.51	1.63	2.68	332.72
103	3.00	1.95	2.70	659.21	1.48	2.47	335.19
104	2.83	3.06	3.77	662.98	4.17	5.11	340.29
105	2.67	9.64	10.31	673.28	6.14	7.02	347.31
106	2.50	5.90	6.53	679.81	6.18	7.01	354.32
107	2.33	5.56	6.14	685.95	3.89	4.66	358.98
108	2.17	4.64	5.18	691.13	2.06	2.78	361.75
109	2.00	4.88	5.38	696.51	10.23	10.89	372.64
110	1.83	5.54	6.00	702.51	0.00	0.61	373.25
111	1.67	5.56	5.98	708.49	5.87	6.42	379.67
112	1.50	5.50	5.88	714.36	6.68	7.18	386.84
113	1.33	5.83	6.16	720.53	4.98	5.42	392.26
114	1.17	5.51	5.80	726.33	6.47	6.86	399.12
115	1.00	6.61	6.86	733.19	8.57	8.90	408.02
116	0.83	9.07	9.28	742.47	9.75	10.03	418.04
117	0.67	20.10	20.27	762.73	0.00	0.22	418.26
118	0.50	8.14	8.27	771.00	6.20	6.37	424.63
119	0.33	1.98	2.06	773.06	4.96	5.07	429.70
120	0.17	1.09	1.13	774.19	1.97	2.03	431.72
121	0.00	0.81	0.81	775.00	1.68	1.68	433.40
122	2.50	1.69	2.32	777.32	0.06	0.89	434.29
123	2.33	5.61	6.19	783.51	1.88	2.65	436.94
124	2.17	8.56	9.10	792.61	12.02	12.74	449.67
125	2.00	6.45	6.95	799.56	7.48	8.14	457.81
126	1.83	5.61	6.07	805.63	6.09	6.70	464.51
127	1.67	9.11	9.53	815.16	6.00	6.55	471.06
128	1.50	8.34	8.72	823.87	16.70	17.20	488.25
129	1.33	15.30	15.63	839.51	4.74	5.18	493.43
130	1.17	9.58	9.87	849.38	10.13	10.52	503.95
131	1.00	7.95	8.20	857.58	5.96	6.29	510.24
132	0.83	7.18	7.39	864.97	5.04	5.32	515.55
133	0.67	8.95	9.12	874.08	5.72	5.94	521.49
134	0.50	8.69	8.82	882.90	5.67	5.84	527.33
135	0.33	8.41	8.49	891.39	5.02	5.13	532.46
136	0.17	7.90	7.94	899.33	6.50	6.56	539.01
137	0.00	7.51	7.51	906.84	9.70	9.70	548.71
138	3.83	3.29	4.25	911.09	6.20	7.47	556.18
139	3.67	12.04	12.96	924.05	6.60	7.81	563.99
140	3.50	9.31	10.19	934.23	6.20	7.36	571.34
141	3.33	8.62	9.45	943.69	9.40	10.50	581.84
142	3.17	8.22	9.01	952.70	7.16	8.21	590.05
143	3.00	7.46	8.21	960.91	2.79	3.78	593.83
144	2.83	7.05	7.76	968.67	3.92	4.86	598.68
145	2.67	7.74	8.41	977.07	5.99	6.87	605.55
146	2.50	7.31	7.94	985.01	6.45	7.28	612.83
147	2.33	7.33	7.91	992.92	8.38	9.15	621.98

Table C-7. Continued.

148	2.17	9.03	9.57	1002.49	8.56	9.28	631.25
149	2.00	7.78	8.28	1010.77	6.88	7.54	638.79
150	1.83	8.13	8.59	1019.36	7.21	7.82	646.61
151	1.67	16.42	16.84	1036.20	11.35	11.90	658.51
152	1.50	13.12	13.50	1049.69	10.77	11.27	669.77
153	1.33	15.19	15.52	1065.22	8.75	9.19	678.96
154	1.17	10.54	10.83	1076.05	11.42	11.81	690.77
155	1.00	9.21	9.46	1085.51	15.15	15.48	706.25
156	0.83	7.82	8.03	1093.54	5.18	5.46	711.70
157	0.67	9.37	9.54	1103.07	4.86	5.08	716.78
158	0.50	8.18	8.31	1111.38	6.35	6.52	723.30
159	0.33	8.56	8.64	1120.02	7.12	7.23	730.53
160	0.17	8.91	8.95	1128.97	8.38	8.44	738.96
161	0.00	9.08	9.08	1138.05	9.89	9.89	748.85
162	2.00	4.78	5.28	1143.33	13.27	13.93	762.78
163	1.83	13.87	14.33	1157.66	6.12	6.73	769.51
164	1.67	10.91	11.33	1168.99	5.13	5.68	775.19
165	1.50	8.99	9.37	1178.35	4.13	4.63	779.81
166	1.33	8.47	8.80	1187.16	10.58	11.02	790.83
167	1.17	7.85	8.14	1195.30	1.84	2.23	793.06
168	1.00	7.02	7.27	1202.57	8.74	9.07	802.13
169	0.83	8.00	8.21	1210.78	11.07	11.35	813.47
170	0.67	8.40	8.57	1219.34	7.95	8.17	821.64
171	0.50	6.58	6.71	1226.05	3.10	3.27	824.91
172	0.33	20.70	20.78	1246.83	11.05	11.16	836.07
173	0.17	10.15	10.19	1257.02	6.93	6.99	843.05
174	0.00	9.00	9.00	1266.02	8.65	8.65	851.70
175	3.83	7.27	8.23	1274.25	4.73	6.00	857.70
176	3.67	8.43	9.35	1283.60	6.88	8.09	865.79
177	3.50	7.74	8.62	1292.21	6.38	7.54	873.32
178	3.33	7.31	8.14	1300.36	6.82	7.92	881.24
179	3.17	6.48	7.27	1307.63	6.54	7.59	888.83
180	3.00	6.43	7.18	1314.81	10.64	11.63	900.46
181	2.83	7.02	7.73	1322.54	5.87	6.81	907.26
182	2.67	9.85	10.52	1333.05	5.02	5.90	913.16
183	2.50	8.54	9.17	1342.22	6.16	6.99	920.15
184	2.33	8.44	9.02	1351.24	7.55	8.32	928.47
185	2.17	7.92	8.46	1359.70	8.60	9.32	937.78
186	2.00	7.91	8.41	1368.11	7.53	8.19	945.97
187	1.83	8.44	8.90	1377.01	9.50	10.11	956.08
188	1.67	9.42	9.84	1386.85	10.18	10.73	966.81
189	1.50	8.08	8.46	1395.30	8.05	8.55	975.35
190	1.33	7.09	7.42	1402.73	4.17	4.61	979.96
191	1.17	10.49	10.78	1413.51	6.52	6.91	986.87
192	1.00	10.01	10.26	1423.77	10.31	10.64	997.51
193	0.83	11.91	12.12	1435.89	7.13	7.41	1004.91
194	0.67	7.30	7.47	1443.35	8.34	8.56	1013.47
195	0.50	7.28	7.41	1450.76	6.19	6.36	1019.83
196	0.33	6.05	6.13	1456.89	8.13	8.24	1028.07
197	0.17	5.80	5.84	1462.73	9.39	9.45	1037.51

Table C-7. Continued.

198	0.00	6.68	6.68	1469.41	8.50	8.50	1046.01
199	2.67	8.21	8.88	1478.29	6.44	7.32	1053.33
200	2.50	13.38	14.01	1492.30	4.51	5.34	1058.67
201	2.33	8.93	9.51	1501.81	6.93	7.70	1066.37
202	2.17	10.47	11.01	1512.82	7.34	8.06	1074.42
203	2.00	6.00	6.50	1519.32	7.82	8.48	1082.90
204	1.83	5.36	5.82	1525.14	8.92	9.53	1092.43
205	1.67	5.37	5.79	1530.93	7.94	8.49	1100.92
206	1.50	9.32	9.70	1540.62	6.43	6.93	1107.84
207	1.33	7.53	7.86	1548.48	4.67	5.11	1112.95
208	1.17	9.22	9.51	1558.00	3.84	4.23	1117.18
209	1.00	10.18	10.43	1568.43	4.02	4.35	1121.53
210	0.83	8.68	8.89	1577.31	5.27	5.55	1127.07
211	0.67	7.58	7.75	1585.06	1.92	2.14	1129.21
212	0.50	8.11	8.24	1593.30	3.03	3.20	1132.41
213	0.33	8.34	8.42	1601.72	2.69	2.80	1135.21
214	0.17	8.87	8.91	1610.63	2.86	2.92	1138.12
215	0.00	8.83	8.83	1619.46	3.52	3.52	1141.64
216	0.83	7.15	7.36	1626.82	2.40	2.68	1144.32
217	0.67	11.23	11.40	1638.22	3.65	3.87	1148.19
218	0.50	7.57	7.70	1645.91	3.25	3.42	1151.60
219	0.33	8.42	8.50	1654.41	5.90	6.01	1157.61
220	0.17	8.43	8.47	1662.89	3.59	3.65	1161.26
221	0.00	8.83	8.83	1671.72	0.85	0.85	1162.11
222	4.83	6.26	7.47	1679.18	0.00	1.60	1163.70
223	4.67	11.12	12.29	1691.47	0.04	1.58	1165.28
224	4.50	6.40	7.53	1699.00	1.14	2.63	1167.91
225	4.33	6.27	7.35	1706.35	-0.01	1.42	1169.33
226	4.17	6.45	7.49	1713.84	1.44	2.82	1172.14
227	4.00	7.29	8.29	1722.13	1.34	2.66	1174.80
228	3.83	8.40	9.36	1731.49	1.47	2.74	1177.54
229	3.67	9.70	10.62	1742.11	1.42	2.63	1180.17
230	3.50	8.27	9.15	1751.25	3.06	4.22	1184.38
231	3.33	7.35	8.18	1759.43	6.44	7.54	1191.92
232	3.17	7.50	8.29	1767.73	3.38	4.43	1196.35
233	3.00	7.79	8.54	1776.27	2.96	3.95	1200.30
234	2.83	10.62	11.33	1787.59	3.44	4.38	1204.67
235	2.67	8.80	9.47	1797.06	3.60	4.48	1209.15
236	2.50	7.64	8.27	1805.33	2.24	3.07	1212.22
237	2.33	8.16	8.74	1814.07	1.77	2.54	1214.76
238	2.17	9.16	9.70	1823.77	1.10	1.82	1216.57
239	2.00	9.04	9.54	1833.31	-0.01	0.65	1217.22
240	1.83	3.76	4.22	1837.53	0.13	0.74	1217.96
241	1.67	2.18	2.60	1840.13	0.00	0.55	1218.51
242	1.50	2.83	3.21	1843.33	0.17	0.67	1219.17
243	1.33	3.14	3.47	1846.80	0.06	0.50	1219.67
244	1.17	3.97	4.26	1851.07	0.39	0.77	1220.45
245	1.00	5.31	5.56	1856.63	0.35	0.68	1221.13
246	0.83	6.08	6.29	1862.91	0.18	0.46	1221.58
247	0.67	8.61	8.78	1871.69	0.18	0.40	1221.98

Table C-7. Continued.

248	0.50	10.76	10.89	1882.58	0.80	0.97	1222.95
249	0.33	9.44	9.52	1892.10	2.02	2.13	1225.08
250	0.17	6.29	6.33	1898.43	5.61	5.67	1230.74
251	0.00	5.58	5.58	1904.01	0.79	0.79	1231.53
252	1.83	3.54	4.00	1908.01	0.00	0.61	1232.14
253	1.67	4.17	4.59	1912.60	0.00	0.55	1232.69
254	1.50	3.31	3.69	1916.28	0.00	0.50	1233.18
255	1.33	5.23	5.56	1921.84	0.00	0.44	1233.62
256	1.17	7.71	8.00	1929.85	0.00	0.39	1234.01
257	1.00	8.40	8.65	1938.50	0.00	0.33	1234.34
258	0.83	8.54	8.75	1947.24	0.05	0.32	1234.66
259	0.67	6.92	7.09	1954.33	0.00	0.22	1234.88
260	0.50	6.20	6.33	1960.66	0.70	0.86	1235.75
261	0.33	5.87	5.95	1966.61	14.35	14.46	1250.21
262	0.17	5.47	5.51	1972.12	10.02	10.08	1260.28
263	0.00	5.15	5.15	1977.27	5.03	5.03	1265.31
264	2.83	3.50	4.21	1981.48	13.08	14.02	1279.33
265	2.67	3.90	4.57	1986.05	4.84	5.72	1285.05
266	2.50	3.58	4.21	1990.25	9.28	10.11	1295.15
267	2.33	3.30	3.88	1994.13	8.19	8.96	1304.11
268	2.17	2.81	3.35	1997.49	8.07	8.79	1312.90
269	2.00	3.54	4.04	2001.53	8.29	8.95	1321.85
270	1.83	3.30	3.76	2005.28	8.94	9.55	1331.39
271	1.67	3.26	3.68	2008.96	9.22	9.77	1341.16
272	1.50	3.13	3.51	2012.47	9.08	9.58	1350.74
273	1.33	2.95	3.28	2015.75	8.44	8.88	1359.62
274	1.17	2.61	2.90	2018.65	8.97	9.36	1368.97
275	1.00	2.98	3.23	2021.88	9.48	9.81	1378.78
276	0.83	2.84	3.05	2024.93	3.58	3.86	1382.64
277	0.67	2.86	3.03	2027.96	9.10	9.32	1391.96
278	0.50	2.77	2.90	2030.85	6.39	6.56	1398.51
279	0.33	2.76	2.84	2033.69	6.13	6.24	1404.75
280	0.17	2.77	2.81	2036.51	6.13	6.19	1410.94
281	0.00	2.75	2.75	2039.26	6.36	6.36	1417.30
282	1.83	2.20	2.66	2041.91	7.37	7.98	1425.27
283	1.67	2.31	2.73	2044.64	19.16	19.71	1444.98
284	1.50	2.51	2.89	2047.53	15.86	16.36	1461.34
285	1.33	2.59	2.92	2050.45	3.30	3.74	1465.08
286	1.17	2.42	2.71	2053.16	5.15	5.54	1470.61
287	1.00	2.55	2.80	2055.96	9.57	9.90	1480.51
288	0.83	2.58	2.79	2058.75	12.56	12.84	1493.35
289	0.67	2.16	2.33	2061.08	15.21	15.43	1508.78
290	0.50	2.34	2.47	2063.54	9.62	9.79	1518.56
291	0.33	2.47	2.55	2066.09	6.07	6.18	1524.74
292	0.17	2.56	2.60	2068.70	9.18	9.24	1533.98
293	0.00	2.56	2.56	2071.26	8.33	8.33	1542.31
294	1.00	2.24	2.49	2073.75	5.29	5.62	1547.93
295	0.83	2.06	2.27	2076.01	8.35	8.63	1556.55
296	0.67	1.93	2.10	2078.11	5.16	5.38	1561.93
297	0.50	2.24	2.37	2080.48	1.53	1.70	1563.63

Table C-7. Continued.

298	0.33	2.21	2.29	2082.77	4.36	4.47	1568.10
299	0.17	2.36	2.40	2085.17	9.03	9.09	1577.18
300	0.00	2.14	2.14	2087.31	8.90	8.90	1586.08
Mean flow rate (ml/d)			45			36	
Total discharge for Cr(VI) and nutrient additions vials 32 through 300 (ml)			2016			1574	

Table C-7. Continued.

Effluent Vial ID	Time (evap. corrections) (d)	N1 measured (ml)	N1 corrected (ml)	N1 cumulative (ml)	N2 measured (ml)	N2 corrected (ml)	N2 cumulative (ml)
1	1.88	4.52	4.80	4.80	3.89	4.34	4.34
2	1.81	4.12	4.39	9.19	3.85	4.29	8.63
3	1.75	3.65	3.91	13.11	3.75	4.17	12.80
4	1.69	3.30	3.55	16.66	3.75	4.16	16.95
5	1.63	2.99	3.23	19.89	3.72	4.11	21.06
6	1.56	2.79	3.02	22.92	3.61	3.99	25.05
7	1.50	2.71	2.94	25.85	3.38	3.74	28.79
8	1.44	2.74	2.96	28.81	3.42	3.77	32.55
9	1.38	2.68	2.89	31.69	3.55	3.88	36.43
10	1.31	2.70	2.90	34.59	3.18	3.50	39.93
11	1.25	2.66	2.85	37.44	3.20	3.50	43.43
12	1.19	2.50	2.68	40.12	3.07	3.36	46.78
13	1.13	2.48	2.65	42.77	3.11	3.38	50.16
14	1.06	2.32	2.48	45.24	3.57	3.83	53.99
15	1.00	4.35	4.50	49.74	1.99	2.23	56.22
16	0.94	3.53	3.67	53.42	3.32	3.55	59.76
17	0.88	3.32	3.45	56.87	3.35	3.56	63.32
18	0.81	3.32	3.44	60.31	3.48	3.68	67.00
19	0.75	3.24	3.35	63.66	3.51	3.69	70.69
20	0.69	3.09	3.19	66.85	3.67	3.84	74.52
21	0.63	3.08	3.17	70.03	3.43	3.58	78.10
22	0.56	3.10	3.18	73.21	3.46	3.60	81.70
23	0.50	2.91	2.99	76.20	3.40	3.52	85.22
24	0.44	2.80	2.87	79.06	3.33	3.44	88.65
25	0.38	2.71	2.77	81.83	3.22	3.31	91.96
26	0.31	2.65	2.70	84.53	3.17	3.25	95.21
27	0.25	2.60	2.64	87.16	2.90	2.96	98.17
28	0.19	2.42	2.45	89.61	2.98	3.03	101.19
29	0.13	1.52	1.54	91.15	2.93	2.96	104.15
30	0.06	0.92	0.93	92.08	2.87	2.89	107.04
31	0.00	0.63	0.63	92.71	3.19	3.19	110.23
32	2.83	0.49	0.92	93.62	8.81	9.49	119.72
33	2.67	6.37	6.77	100.39	8.73	9.37	129.09
34	2.50	8.47	8.85	109.24	8.03	8.63	137.72
35	2.33	7.91	8.26	117.50	7.80	8.36	146.08
36	2.17	10.13	10.46	127.95	7.69	8.21	154.29
37	2.00	11.80	12.10	140.05	9.12	9.60	163.89
38	1.83	8.48	8.76	148.81	9.49	9.93	173.82
39	1.67	17.52	17.77	166.58	10.75	11.15	184.97
40	1.50	12.16	12.39	178.96	11.43	11.79	196.76
41	1.33	8.60	8.80	187.76	9.93	10.25	207.01
42	1.17	9.34	9.52	197.28	9.65	9.93	216.94
43	1.00	9.57	9.72	207.00	10.34	10.58	227.52
44	0.83	8.57	8.70	215.69	9.32	9.52	237.04
45	0.67	8.68	8.78	224.47	7.47	7.63	244.67

Table C-7. Continued.

46	0.50	9.48	9.56	234.03	7.68	7.80	252.47
47	0.33	8.03	8.08	242.11	7.18	7.26	259.73
48	0.17	8.06	8.09	250.19	7.28	7.32	267.05
49	0.00	3.55	3.55	253.74	2.36	2.36	269.41
52	2.83	3.88	4.31	258.05	3.45	4.13	273.54
53	2.67	8.48	8.88	266.93	8.76	9.40	282.94
54	2.50	8.69	9.07	275.99	8.76	9.36	292.30
55	2.33	9.71	10.06	286.05	9.08	9.64	301.94
56	2.17	10.28	10.61	296.66	7.48	8.00	309.94
57	2.00	7.81	8.11	304.77	6.92	7.40	317.34
58	1.83	9.45	9.73	314.49	8.10	8.54	325.88
59	1.67	8.01	8.26	322.75	8.10	8.50	334.38
60	1.50	8.51	8.74	331.49	8.49	8.85	343.23
61	1.33	9.51	9.71	341.20	9.26	9.58	352.81
62	1.17	8.32	8.50	349.69	7.87	8.15	360.96
63	1.00	7.44	7.59	357.28	6.14	6.38	367.34
64	0.83	7.78	7.91	365.19	7.58	7.78	375.12
65	0.67	7.34	7.44	372.63	7.28	7.44	382.56
66	0.50	9.19	9.27	381.89	11.83	11.95	394.51
67	0.33	10.24	10.29	392.18	10.40	10.48	404.99
68	0.17	8.21	8.24	400.42	8.20	8.24	413.23
69	0.00	1.65	1.65	402.07	1.10	1.10	414.33
70	2.50	7.40	7.78	409.84	5.79	6.39	420.72
71	2.33	6.76	7.11	416.95	6.16	6.72	427.44
72	2.17	6.80	7.13	424.08	6.23	6.75	434.19
73	2.00	7.52	7.82	431.90	7.04	7.52	441.71
74	1.83	7.43	7.71	439.60	7.42	7.86	449.57
75	1.67	6.94	7.19	446.79	10.45	10.85	460.42
76	1.50	7.93	8.16	454.95	9.18	9.54	469.96
77	1.33	7.83	8.03	462.98	7.92	8.24	478.20
78	1.17	7.52	7.70	470.67	7.45	7.73	485.93
79	1.00	9.39	9.54	480.21	9.95	10.19	496.12
80	0.83	8.73	8.86	489.07	8.73	8.93	505.05
81	0.67	7.69	7.79	496.86	7.41	7.57	512.62
82	0.50	8.78	8.86	505.71	8.52	8.64	521.26
83	0.33	8.26	8.31	514.02	8.21	8.29	529.55
84	0.17	7.68	7.71	521.73	7.73	7.77	537.32
85	0.00	9.74	9.74	531.47	10.81	10.81	548.13
86	0.67	8.17	8.27	539.74	8.69	8.85	556.98
87	0.50	8.48	8.56	548.29	8.71	8.83	565.81
88	0.33	6.26	6.31	554.60	5.96	6.04	571.85
89	0.17	6.93	6.96	561.56	8.20	8.24	580.09
90	0.00	7.92	7.92	569.48	8.60	8.60	588.69
91	5.00	9.18	9.93	579.41	7.92	9.12	597.81
92	4.83	7.88	8.61	588.01	7.58	8.74	606.55
93	4.67	10.15	10.85	598.86	10.25	11.37	617.92
94	4.50	8.84	9.52	608.38	8.61	9.69	627.61
95	4.33	5.10	5.75	614.13	4.71	5.75	633.36
96	4.17	1.29	1.92	616.04	1.08	2.08	635.44
97	4.00	4.48	5.08	621.12	3.54	4.50	639.94

Table C-7. Continued.

98	3.83	9.77	10.35	631.47	11.11	12.03	651.97
99	3.67	9.16	9.71	641.18	9.01	9.89	661.86
100	3.50	8.05	8.58	649.75	8.17	9.01	670.87
101	3.33	4.27	4.77	654.52	3.94	4.74	675.61
102	3.17	1.79	2.27	656.79	1.54	2.30	677.91
103	3.00	3.27	3.72	660.51	3.07	3.79	681.70
104	2.83	7.30	7.73	668.23	7.52	8.20	689.90
105	2.67	9.01	9.41	677.64	8.94	9.58	699.48
106	2.50	8.39	8.77	686.41	8.53	9.13	708.61
107	2.33	4.07	4.42	690.83	4.03	4.59	713.20
108	2.17	2.02	2.35	693.17	1.83	2.35	715.55
109	2.00	5.62	5.92	699.09	5.34	5.82	721.37
110	1.83	6.99	7.27	706.36	7.26	7.70	729.07
111	1.67	4.68	4.93	711.29	4.47	4.87	733.94
112	1.50	8.36	8.59	719.87	7.40	7.76	741.70
113	1.33	7.60	7.80	727.67	7.35	7.67	749.37
114	1.17	5.37	5.55	733.22	5.69	5.97	755.34
115	1.00	8.09	8.24	741.46	8.63	8.87	764.21
116	0.83	8.13	8.26	749.71	8.13	8.33	772.54
117	0.67	10.93	11.03	760.74	7.92	8.08	780.62
118	0.50	5.78	5.86	766.60	7.68	7.80	788.42
119	0.33	1.96	2.01	768.61	2.46	2.54	790.96
120	0.17	1.09	1.12	769.72	1.48	1.52	792.48
121	0.00	0.76	0.76	770.48	1.04	1.04	793.52
122	2.50	5.25	5.63	776.11	4.49	5.09	798.61
123	2.33	8.43	8.78	784.89	7.06	7.62	806.23
124	2.17	11.19	11.52	796.40	10.93	11.45	817.68
125	2.00	7.45	7.75	804.15	8.56	9.04	826.72
126	1.83	7.83	8.11	812.26	7.84	8.28	835.00
127	1.67	8.60	8.85	821.11	8.29	8.69	843.69
128	1.50	7.59	7.82	828.92	7.61	7.97	851.66
129	1.33	9.98	10.18	839.10	6.85	7.17	858.83
130	1.17	9.23	9.41	848.51	7.59	7.87	866.70
131	1.00	7.18	7.33	855.84	7.07	7.31	874.01
132	0.83	6.96	7.09	862.92	6.95	7.15	881.16
133	0.67	11.05	11.15	874.07	8.65	8.81	889.97
134	0.50	11.58	11.66	885.73	9.04	9.16	899.13
135	0.33	9.30	9.35	895.08	8.58	8.66	907.79
136	0.17	8.08	8.11	903.18	7.59	7.63	915.42
137	0.00	8.69	8.69	911.87	7.22	7.22	922.64
138	3.83	4.43	5.01	916.88	3.39	4.31	926.95
139	3.67	7.38	7.93	924.81	6.65	7.53	934.48
140	3.50	7.24	7.77	932.57	6.59	7.43	941.91
141	3.33	10.31	10.81	943.38	7.02	7.82	949.73
142	3.17	10.40	10.88	954.26	6.84	7.60	957.33
143	3.00	7.23	7.68	961.94	6.38	7.10	964.43
144	2.83	6.42	6.85	968.78	0.55	1.23	965.66
145	2.67	6.75	7.15	975.93	7.31	7.95	973.61
146	2.50	7.57	7.95	983.88	8.01	8.61	982.22
147	2.33	7.80	8.15	992.03	7.40	7.96	990.18

Table C-7. Continued.

148	2.17	10.13	10.46	1002.48	7.39	7.91	998.09
149	2.00	7.77	8.07	1010.55	6.93	7.41	1005.50
150	1.83	6.91	7.19	1017.74	6.58	7.02	1012.52
151	1.67	16.07	16.32	1034.06	8.00	8.40	1020.92
152	1.50	9.39	9.62	1043.67	8.47	8.83	1029.75
153	1.33	13.22	13.42	1057.09	9.23	9.55	1039.30
154	1.17	9.44	9.62	1066.71	8.73	9.01	1048.31
155	1.00	7.72	7.87	1074.58	7.99	8.23	1056.54
156	0.83	7.86	7.99	1082.56	7.58	7.78	1064.32
157	0.67	10.34	10.44	1093.00	8.42	8.58	1072.90
158	0.50	8.72	8.80	1101.80	8.84	8.96	1081.86
159	0.33	7.24	7.29	1109.09	8.84	8.92	1090.78
160	0.17	8.02	8.05	1117.13	8.47	8.51	1099.29
161	0.00	7.51	7.51	1124.64	7.29	7.29	1106.58
162	2.00	4.34	4.64	1129.28	3.03	3.51	1110.09
163	1.83	8.58	8.86	1138.14	4.83	5.27	1115.36
164	1.67	7.63	7.88	1146.02	1.79	2.19	1117.55
165	1.50	7.00	7.23	1153.24	0.89	1.25	1118.80
166	1.33	8.93	9.13	1162.37	0.41	0.73	1119.53
167	1.17	7.46	7.64	1170.01	1.32	1.60	1121.13
168	1.00	7.04	7.19	1177.20	0.71	0.95	1122.08
169	0.83	10.78	10.91	1188.10	0.55	0.75	1122.83
170	0.67	7.55	7.65	1195.75	0.77	0.93	1123.76
171	0.50	4.69	4.77	1200.52	0.54	0.66	1124.42
172	0.33	6.70	6.75	1207.27	1.18	1.26	1125.68
173	0.17	8.86	8.89	1216.15	1.12	1.16	1126.84
174	0.00	8.98	8.98	1225.13	0.84	0.84	1127.68
175	3.83	9.83	10.41	1235.54	0.00	0.92	1128.60
176	3.67	9.02	9.57	1245.11	0.00	0.88	1129.48
177	3.50	8.68	9.21	1254.31	0.00	0.84	1130.32
178	3.33	8.72	9.22	1263.53	0.00	0.80	1131.12
179	3.17	8.56	9.04	1272.57	0.47	1.23	1132.35
180	3.00	9.05	9.50	1282.07	9.47	10.19	1142.54
181	2.83	8.23	8.66	1290.72	9.41	10.09	1152.63
182	2.67	5.88	6.28	1297.00	7.19	7.83	1160.46
183	2.50	6.88	7.26	1304.26	9.57	10.17	1170.63
184	2.33	8.77	9.12	1313.38	9.92	10.48	1181.11
185	2.17	9.24	9.57	1322.94	10.17	10.69	1191.80
186	2.00	8.86	9.16	1332.10	10.59	11.07	1202.87
187	1.83	11.18	11.46	1343.56	10.58	11.02	1213.89
188	1.67	9.71	9.96	1353.52	9.91	10.31	1224.20
189	1.50	8.90	9.13	1362.64	9.85	10.21	1234.41
190	1.33	8.96	9.16	1371.80	10.05	10.37	1244.78
191	1.17	8.79	8.97	1380.77	9.15	9.43	1254.21
192	1.00	8.58	8.73	1389.50	8.92	9.16	1263.37
193	0.83	8.94	9.07	1398.56	9.74	9.94	1273.31
194	0.67	8.39	8.49	1407.05	9.41	9.57	1282.88
195	0.50	7.22	7.30	1414.35	8.80	8.92	1291.80
196	0.33	3.72	3.77	1418.12	9.43	9.51	1301.31
197	0.17	7.17	7.20	1425.31	9.58	9.62	1310.93

Table C-7. Continued.

198	0.00	7.20	7.20	1432.51	8.35	8.35	1319.28
199	2.67	9.96	10.36	1442.87	10.76	11.40	1330.68
200	2.50	8.45	8.83	1451.70	9.26	9.86	1340.54
201	2.33	8.99	9.34	1461.04	9.67	10.23	1350.77
202	2.17	8.31	8.64	1469.67	9.06	9.58	1360.35
203	2.00	8.07	8.37	1478.04	8.63	9.11	1369.46
204	1.83	7.77	8.05	1486.09	8.44	8.88	1378.34
205	1.67	8.35	8.60	1494.69	9.70	10.10	1388.44
206	1.50	8.62	8.85	1503.53	9.42	9.78	1398.22
207	1.33	6.73	6.93	1510.46	7.19	7.51	1405.73
208	1.17	3.94	4.12	1514.58	4.81	5.09	1410.82
209	1.00	8.36	8.51	1523.09	9.15	9.39	1420.21
210	0.83	10.81	10.94	1534.02	9.75	9.95	1430.16
211	0.67	10.30	10.40	1544.42	10.37	10.53	1440.69
212	0.50	9.44	9.52	1553.94	9.84	9.96	1450.65
213	0.33	8.60	8.65	1562.59	9.34	9.42	1460.07
214	0.17	8.43	8.46	1571.04	9.79	9.83	1469.90
215	0.00	8.91	8.91	1579.95	9.70	9.70	1479.60
216	0.83	7.46	7.59	1587.54	8.75	8.95	1488.55
217	0.67	6.94	7.04	1594.58	7.92	8.08	1496.63
218	0.50	8.35	8.43	1603.00	9.61	9.73	1506.36
219	0.33	8.75	8.80	1611.80	9.35	9.43	1515.79
220	0.17	9.49	9.52	1621.32	10.02	10.06	1525.85
221	0.00	9.25	9.25	1630.57	9.51	9.51	1535.36
222	4.83	7.42	8.15	1638.71	7.85	9.01	1544.37
223	4.67	8.38	9.08	1647.79	7.87	8.99	1553.36
224	4.50	8.51	9.19	1656.98	8.96	10.04	1563.40
225	4.33	8.26	8.91	1665.89	8.38	9.42	1572.82
226	4.17	8.19	8.82	1674.70	8.83	9.83	1582.65
227	4.00	8.59	9.19	1683.89	8.59	9.55	1592.20
228	3.83	8.28	8.86	1692.75	7.91	8.83	1601.03
229	3.67	8.87	9.42	1702.17	9.05	9.93	1610.96
230	3.50	8.74	9.27	1711.43	9.01	9.85	1620.81
231	3.33	8.57	9.07	1720.50	8.37	9.17	1629.98
232	3.17	8.51	8.99	1729.49	8.51	9.27	1639.25
233	3.00	8.34	8.79	1738.28	7.91	8.63	1647.88
234	2.83	7.92	8.35	1746.62	7.42	8.10	1655.98
235	2.67	8.95	9.35	1755.97	9.01	9.65	1665.63
236	2.50	8.92	9.30	1765.27	8.80	9.40	1675.03
237	2.33	8.24	8.59	1773.86	7.88	8.44	1683.47
238	2.17	8.45	8.78	1782.63	8.30	8.82	1692.29
239	2.00	3.38	3.68	1786.31	3.62	4.10	1696.39
240	1.83	1.56	1.84	1788.15	1.96	2.40	1698.79
241	1.67	0.85	1.10	1789.25	1.78	2.18	1700.97
242	1.50	1.32	1.55	1790.79	1.80	2.16	1703.13
243	1.33	1.24	1.44	1792.23	1.53	1.85	1704.98
244	1.17	2.17	2.35	1794.58	1.71	1.99	1706.97
245	1.00	8.54	8.69	1803.27	7.97	8.21	1715.18
246	0.83	5.32	5.45	1808.71	4.28	4.48	1719.66
247	0.67	4.15	4.25	1812.96	3.98	4.14	1723.80

Table C-7. Continued.

248	0.50	10.36	10.44	1823.40	11.02	11.14	1734.94
249	0.33	10.87	10.92	1834.32	10.63	10.71	1745.65
250	0.17	11.71	11.74	1846.05	12.04	12.08	1757.73
251	0.00	9.94	9.94	1855.99	10.23	10.23	1767.96
252	1.83	7.84	8.12	1864.11	8.52	8.96	1776.92
253	1.67	9.91	10.16	1874.27	10.81	11.21	1788.13
254	1.50	9.66	9.89	1884.15	9.59	9.95	1798.08
255	1.33	9.80	10.00	1894.15	9.85	10.17	1808.25
256	1.17	10.82	11.00	1905.15	10.74	11.02	1819.27
257	1.00	10.19	10.34	1915.49	10.32	10.56	1829.83
258	0.83	10.30	10.43	1925.91	10.78	10.98	1840.81
259	0.67	9.72	9.82	1935.73	9.78	9.94	1850.75
260	0.50	9.66	9.74	1945.47	9.40	9.52	1860.27
261	0.33	9.35	9.40	1954.87	9.48	9.56	1869.83
262	0.17	9.91	9.94	1964.80	9.93	9.97	1879.80
263	0.00	10.29	10.29	1975.09	10.57	10.57	1890.37
264	2.83	8.52	8.95	1984.04	9.37	10.05	1900.42
265	2.67	9.85	10.25	1994.29	9.85	10.49	1910.91
266	2.50	9.89	10.27	2004.55	9.83	10.43	1921.34
267	2.33	9.59	9.94	2014.49	9.72	10.28	1931.62
268	2.17	8.70	9.03	2023.52	9.65	10.17	1941.79
269	2.00	9.78	10.08	2033.60	10.32	10.80	1952.59
270	1.83	9.74	10.02	2043.61	10.28	10.72	1963.31
271	1.67	10.89	11.14	2054.75	10.52	10.92	1974.23
272	1.50	10.68	10.91	2065.66	10.32	10.68	1984.91
273	1.33	9.82	10.02	2075.68	10.31	10.63	1995.54
274	1.17	9.11	9.29	2084.96	9.86	10.14	2005.68
275	1.00	9.96	10.11	2095.07	9.79	10.03	2015.71
276	0.83	9.75	9.88	2104.95	9.55	9.75	2025.46
277	0.67	10.37	10.47	2115.42	10.56	10.72	2036.18
278	0.50	10.03	10.11	2125.52	9.81	9.93	2046.11
279	0.33	9.09	9.14	2134.66	9.23	9.31	2055.42
280	0.17	7.99	8.02	2142.68	8.39	8.43	2063.85
281	0.00	9.30	9.30	2151.98	9.51	9.51	2073.36
282	1.83	8.94	9.22	2161.19	8.59	9.03	2082.39
283	1.67	10.21	10.46	2171.65	9.69	10.09	2092.48
284	1.50	9.68	9.91	2181.56	9.11	9.47	2101.95
285	1.33	8.97	9.17	2190.73	8.78	9.10	2111.05
286	1.17	9.76	9.94	2200.66	9.39	9.67	2120.72
287	1.00	9.62	9.77	2210.43	9.20	9.44	2130.16
288	0.83	9.05	9.18	2219.61	8.82	9.02	2139.18
289	0.67	7.19	7.29	2226.90	10.29	10.45	2149.63
290	0.50	3.23	3.31	2230.20	9.66	9.78	2159.41
291	0.33	8.12	8.17	2238.37	9.26	9.34	2168.75
292	0.17	9.94	9.97	2248.34	9.58	9.62	2178.37
293	0.00	10.52	10.52	2258.86	10.69	10.69	2189.06
294	1.00	10.57	10.72	2269.58	8.91	9.15	2198.21
295	0.83	9.65	9.78	2279.35	9.94	10.14	2208.35
296	0.67	9.85	9.95	2289.30	10.30	10.46	2218.81
297	0.50	9.20	9.28	2298.58	9.54	9.66	2228.47

Table C-7. Continued.

298	0.33	9.59	9.64	2308.22	10.38	10.46	2238.93
299	0.17	9.59	9.62	2317.83	10.59	10.63	2249.56
300	0.00	9.45	9.45	2327.28	9.45	9.45	2259.01
Mean flow rate (ml/d)			50			48	
Total discharge for Cr(VI) and nutrient additions vials 32 through 300 (ml)			2235			2149	

Table C-7. Continued.

Effluent Vial ID	Time (evap. corrections) (d)	B1 measured (ml)	B1 corrected (ml)	B1 cumulative (ml)	B2 measured (ml)	B2 corrected (ml)	B2 cumulative (ml)
1	1.88	6.19	6.68	6.68	5.46	6.14	6.14
2	1.81	3.56	4.03	10.71	3.35	4.00	10.14
3	1.75	2.74	3.20	13.90	2.93	3.56	13.70
4	1.69	2.33	2.77	16.67	2.58	3.19	16.89
5	1.63	2.13	2.55	19.23	2.33	2.92	19.80
6	1.56	2.03	2.44	21.66	2.16	2.72	22.52
7	1.50	1.88	2.27	23.93	2.11	2.65	25.17
8	1.44	2.07	2.44	26.38	2.35	2.87	28.04
9	1.38	2.03	2.39	28.76	2.51	3.01	31.05
10	1.31	2.11	2.45	31.21	2.45	2.92	33.97
11	1.25	2.01	2.34	33.55	2.28	2.73	36.70
12	1.19	2.02	2.33	35.88	2.12	2.55	39.25
13	1.13	1.90	2.19	38.07	2.09	2.50	41.74
14	1.06	1.73	2.01	40.08	1.99	2.37	44.11
15	1.00	3.31	3.57	43.65	3.28	3.64	47.75
16	0.94	2.73	2.97	46.62	2.83	3.17	50.92
17	0.88	2.51	2.74	49.36	2.78	3.10	54.02
18	0.81	2.38	2.59	51.95	2.69	2.98	57.00
19	0.75	2.31	2.51	54.45	2.69	2.96	59.96
20	0.69	2.21	2.39	56.84	2.55	2.80	62.76
21	0.63	2.22	2.38	59.23	2.49	2.72	65.47
22	0.56	2.29	2.44	61.66	2.60	2.80	68.27
23	0.50	2.15	2.28	63.94	2.76	2.94	71.21
24	0.44	2.08	2.19	66.14	2.78	2.94	74.15
25	0.38	2.07	2.17	68.30	2.79	2.93	77.08
26	0.31	2.02	2.10	70.40	2.77	2.88	79.96
27	0.25	2.00	2.07	72.47	2.66	2.75	82.71
28	0.19	1.56	1.61	74.08	2.33	2.40	85.11
29	0.13	0.96	0.99	75.07	1.39	1.44	86.54
30	0.06	0.78	0.80	75.87	0.81	0.83	87.37
31	0.00	0.46	0.46	76.33	0.52	0.83	88.20
32	2.83	0.54	1.28	77.61	0.00	1.02	89.22
33	2.67	3.96	4.65	82.26	6.61	7.57	96.79
34	2.50	5.79	6.44	88.70	6.50	7.40	104.19
35	2.33	4.94	5.55	94.25	5.46	6.30	110.49
36	2.17	5.73	6.29	100.54	6.87	7.65	118.14
37	2.00	7.45	7.97	108.51	7.10	7.82	125.96
38	1.83	5.81	6.29	114.80	6.53	7.19	133.15
39	1.67	10.74	11.17	125.97	11.90	12.50	145.65
40	1.50	10.86	11.25	137.22	13.06	13.60	159.25
41	1.33	7.17	7.52	144.74	8.47	8.95	168.20
42	1.17	7.56	7.86	152.60	7.25	7.67	175.87
43	1.00	6.93	7.19	159.79	7.28	7.64	183.51
44	0.83	5.74	5.96	165.75	6.71	7.01	190.52
45	0.67	5.37	5.54	171.29	6.35	6.59	197.11

Table C-7. Continued.

46	0.50	6.84	6.97	178.26	7.24	7.42	204.53
47	0.33	6.12	6.21	184.47	6.30	6.42	210.95
48	0.17	5.94	5.98	190.45	5.77	5.83	216.78
49	0.00	2.62	2.62	193.07	2.63	2.63	219.41
52	2.83	2.26	3.00	196.07	2.83	3.85	223.26
53	2.67	5.67	6.36	202.43	7.52	8.48	231.74
54	2.50	6.35	7.00	209.43	8.22	9.12	240.86
55	2.33	7.25	7.86	217.29	8.63	9.47	250.33
56	2.17	7.83	8.39	225.68	7.42	8.20	258.53
57	2.00	5.69	6.21	231.89	6.10	6.82	265.35
58	1.83	7.46	7.94	239.83	7.10	7.76	273.11
59	1.67	5.81	6.24	246.07	6.79	7.39	280.50
60	1.50	5.66	6.05	252.12	6.40	6.94	287.44
61	1.33	6.58	6.93	259.05	8.09	8.57	296.01
62	1.17	5.93	6.23	265.28	6.52	6.94	302.95
63	1.00	5.19	5.45	270.73	6.64	7.00	309.95
64	0.83	5.78	6.00	276.73	6.95	7.25	317.20
65	0.67	5.48	5.65	282.38	6.28	6.52	323.72
66	0.50	7.61	7.74	290.12	7.21	7.39	331.11
67	0.33	9.06	9.15	299.27	9.01	9.13	340.24
68	0.17	7.00	7.04	306.31	7.20	7.26	347.50
69	0.00	1.33	1.33	307.64	1.37	1.37	348.87
70	2.50	6.59	7.24	314.88	6.65	7.55	356.42
71	2.33	6.08	6.69	321.57	6.44	7.28	363.70
72	2.17	5.45	6.01	327.58	5.43	6.21	369.91
73	2.00	5.84	6.36	333.94	5.74	6.46	376.37
74	1.83	6.09	6.57	340.51	5.89	6.55	382.92
75	1.67	5.67	6.10	346.61	5.72	6.32	389.24
76	1.50	6.11	6.50	353.11	5.94	6.48	395.72
77	1.33	6.24	6.59	359.70	6.20	6.68	402.40
78	1.17	5.76	6.06	365.76	5.61	6.03	408.43
79	1.00	7.78	8.04	373.80	7.59	7.95	416.38
80	0.83	7.50	7.72	381.52	7.21	7.51	423.89
81	0.67	6.76	6.93	388.45	6.52	6.76	430.65
82	0.50	3.70	3.83	392.28	7.23	7.41	438.06
83	0.33	1.48	1.57	393.85	6.82	6.94	445.00
84	0.17	0.97	1.01	394.86	6.36	6.42	451.42
85	0.00	0.77	0.77	395.63	7.87	7.87	459.29
86	0.67	0.32	0.49	396.12	7.68	7.92	467.21
87	0.50	0.37	0.50	396.62	3.81	3.99	471.20
88	0.33	0.00	0.09	396.71	1.39	1.51	472.71
89	0.17	0.03	0.07	396.78	1.59	1.65	474.36
90	0.00	0.59	0.59	397.37	9.77	9.77	484.13
91	5.00	0.02	1.32	398.69	9.41	11.21	495.34
92	4.83	0.45	1.71	400.40	8.58	10.32	505.66
93	4.67	1.81	3.02	403.42	11.48	13.16	518.82
94	4.50	1.81	2.98	406.40	9.85	11.47	530.29
95	4.33	0.99	2.12	408.52	4.87	6.43	536.72
96	4.17	0.78	1.86	410.38	1.05	2.55	539.27
97	4.00	0.96	2.00	412.38	5.39	6.83	546.10

Table C-7. Continued.

98	3.83	0.32	1.32	413.70	13.34	14.72	560.82
99	3.67	0.41	1.36	415.06	11.36	12.68	573.50
100	3.50	0.11	1.02	416.08	9.09	10.35	583.85
101	3.33	0.11	0.98	417.06	4.21	5.41	589.26
102	3.17	0.02	0.84	417.90	1.07	2.21	591.47
103	3.00	0.00	0.78	418.68	3.66	4.74	596.21
104	2.83	0.23	0.97	419.65	8.62	9.64	605.85
105	2.67	0.09	0.78	420.43	10.59	11.55	617.40
106	2.50	0.10	0.75	421.18	9.09	9.99	627.39
107	2.33	0.08	0.69	421.87	4.14	4.98	632.37
108	2.17	0.06	0.62	422.49	1.55	2.33	634.70
109	2.00	0.07	0.59	423.08	6.93	7.65	642.35
110	1.83	0.04	0.52	423.60	8.02	8.68	651.03
111	1.67	0.12	0.55	424.15	4.70	5.30	656.33
112	1.50	0.18	0.57	424.72	9.45	9.99	666.32
113	1.33	0.01	0.36	425.08	8.37	8.85	675.17
114	1.17	0.39	0.69	425.77	5.55	5.97	681.14
115	1.00	0.28	0.54	426.31	10.44	10.80	691.94
116	0.83	0.36	0.58	426.89	9.61	9.91	701.85
117	0.67	0.26	0.43	427.32	13.36	13.60	715.45
118	0.50	7.60	7.73	435.05	6.45	6.63	722.08
119	0.33	4.38	4.47	439.52	2.10	2.22	724.30
120	0.17	2.11	2.15	441.67	1.23	1.29	725.59
121	0.00	1.36	1.36	443.03	0.89	0.89	726.48
122	2.50	0.01	0.66	443.69	7.68	8.58	735.06
123	2.33	1.04	1.65	445.34	9.91	10.75	745.81
124	2.17	0.83	1.39	446.73	11.96	12.74	758.55
125	2.00	0.73	1.25	447.98	8.48	9.20	767.75
126	1.83	0.63	1.11	449.09	9.27	9.93	777.68
127	1.67	0.55	0.98	450.07	9.28	9.88	787.56
128	1.50	0.55	0.94	451.01	8.92	9.46	797.02
129	1.33	0.71	1.06	452.07	11.37	11.85	808.87
130	1.17	0.30	0.60	452.67	10.40	10.82	819.69
131	1.00	0.19	0.45	453.12	8.42	8.78	828.47
132	0.83	0.20	0.42	453.54	8.43	8.73	837.20
133	0.67	0.24	0.41	453.95	10.95	11.19	848.39
134	0.50	0.40	0.53	454.48	7.82	8.00	856.39
135	0.33	0.46	0.55	455.03	8.31	8.43	864.82
136	0.17	0.40	0.44	455.47	8.27	8.33	873.15
137	0.00	0.40	0.40	455.87	8.65	8.65	881.80
138	3.83	0.00	1.00	456.87	3.54	4.92	886.72
139	3.67	0.00	0.95	457.82	7.12	8.44	895.16
140	3.50	0.00	0.91	458.73	9.13	10.39	905.55
141	3.33	0.98	1.85	460.58	11.94	13.14	918.69
142	3.17	1.36	2.18	462.76	10.32	11.46	930.15
143	3.00	1.07	1.85	464.61	7.20	8.28	938.43
144	2.83	0.83	1.57	466.18	6.06	7.08	945.51
145	2.67	0.77	1.46	467.64	9.29	10.25	955.76
146	2.50	0.66	1.31	468.95	9.15	10.05	965.81
147	2.33	0.39	1.00	469.95	8.29	9.13	974.94

Table C-7. Continued.

148	2.17	0.62	1.18	471.13	11.12	11.90	986.84
149	2.00	0.36	0.88	472.01	8.09	8.81	995.65
150	1.83	0.25	0.73	472.74	3.86	4.52	1000.17
151	1.67	0.36	0.79	473.53	6.82	7.42	1007.59
152	1.50	0.49	0.88	474.41	8.01	8.55	1016.14
153	1.33	1.04	1.39	475.80	7.71	8.19	1024.33
154	1.17	1.79	2.09	477.89	8.66	9.08	1033.41
155	1.00	1.38	1.64	479.53	5.80	6.16	1039.57
156	0.83	1.19	1.41	480.94	2.24	2.54	1042.11
157	0.67	1.07	1.24	482.18	11.19	11.43	1053.54
158	0.50	1.23	1.36	483.54	9.89	10.07	1063.61
159	0.33	0.81	0.90	484.44	10.02	10.14	1073.75
160	0.17	0.46	0.50	484.94	8.57	8.63	1082.38
161	0.00	0.87	0.87	485.81	7.11	7.11	1089.49
162	2.00	0.01	0.53	486.34	3.89	4.61	1094.10
163	1.83	0.00	0.48	486.82	11.24	11.90	1106.00
164	1.67	0.00	0.43	487.25	6.83	7.43	1113.43
165	1.50	0.34	0.73	487.98	2.42	2.96	1116.39
166	1.33	1.75	2.10	490.08	3.53	4.01	1120.40
167	1.17	6.86	7.16	497.24	5.43	5.85	1126.25
168	1.00	9.30	9.56	506.80	7.75	8.11	1134.36
169	0.83	11.68	11.90	518.70	11.62	11.92	1146.28
170	0.67	7.27	7.44	526.14	6.80	7.04	1153.32
171	0.50	4.39	4.52	530.66	3.88	4.06	1157.38
172	0.33	12.15	12.24	542.90	6.58	6.70	1164.08
173	0.17	9.29	9.33	552.23	8.71	8.77	1172.85
174	0.00	9.16	9.16	561.39	9.26	9.26	1182.11
175	3.83	9.05	10.05	571.44	8.86	10.24	1192.35
176	3.67	8.65	9.60	581.04	7.99	9.31	1201.66
177	3.50	4.16	5.07	586.11	3.43	4.69	1206.35
178	3.33	1.48	2.35	588.46	1.99	3.19	1209.54
179	3.17	4.63	5.45	593.91	6.56	7.70	1217.24
180	3.00	4.51	5.29	599.20	3.85	4.93	1222.17
181	2.83	4.07	4.81	604.01	2.69	3.71	1225.88
182	2.67	4.89	5.58	609.59	5.23	6.19	1232.07
183	2.50	6.16	6.81	616.40	6.80	7.70	1239.77
184	2.33	4.60	5.21	621.61	3.78	4.62	1244.39
185	2.17	7.99	8.55	630.16	7.44	8.22	1252.61
186	2.00	6.50	7.02	637.18	5.76	6.48	1259.09
187	1.83	5.31	5.79	642.97	3.37	4.03	1263.12
188	1.67	7.25	7.68	650.65	7.73	8.33	1271.45
189	1.50	4.91	5.30	655.95	8.68	9.22	1280.67
190	1.33	2.80	3.15	659.10	4.55	5.03	1285.70
191	1.17	7.53	7.83	666.93	6.97	7.39	1293.09
192	1.00	13.20	13.46	680.39	10.68	11.04	1304.13
193	0.83	10.67	10.89	691.28	9.33	9.63	1313.76
194	0.67	9.83	10.00	701.28	8.60	8.84	1322.60
195	0.50	9.10	9.23	710.51	8.15	8.33	1330.93
196	0.33	8.97	9.06	719.57	8.67	8.79	1339.72
197	0.17	9.20	9.24	728.81	8.78	8.84	1348.56

Table C-7. Continued.

198	0.00	8.18	8.18	736.99	7.69	7.69	1356.25
199	2.67	12.43	13.12	750.12	9.00	9.96	1366.21
200	2.50	9.60	10.25	760.37	8.66	9.56	1375.77
201	2.33	9.31	9.92	770.28	9.00	9.84	1385.61
202	2.17	8.80	9.36	779.65	8.42	9.20	1394.81
203	2.00	8.46	8.98	788.63	8.13	8.85	1403.66
204	1.83	10.24	10.72	799.34	8.30	8.96	1412.62
205	1.67	10.24	10.67	810.02	8.76	9.36	1421.98
206	1.50	9.55	9.94	819.96	9.09	9.63	1431.61
207	1.33	7.52	7.87	827.82	7.16	7.64	1439.25
208	1.17	4.99	5.29	833.12	4.95	5.37	1444.62
209	1.00	8.39	8.65	841.77	10.10	10.46	1455.08
210	0.83	12.13	12.35	854.11	11.73	12.03	1467.11
211	0.67	10.93	11.10	865.22	10.99	11.23	1478.34
212	0.50	9.62	9.75	874.97	9.91	10.09	1488.43
213	0.33	9.07	9.16	884.12	9.48	9.60	1498.03
214	0.17	9.05	9.09	893.22	9.30	9.36	1507.39
215	0.00	9.28	9.28	902.50	9.75	9.75	1517.14
216	0.83	9.23	9.45	911.94	8.76	9.06	1526.20
217	0.67	10.11	10.28	922.23	8.66	8.90	1535.10
218	0.50	8.50	8.63	930.86	9.36	9.54	1544.64
219	0.33	8.73	8.82	939.67	9.27	9.39	1554.03
220	0.17	9.23	9.27	948.95	9.95	10.01	1564.04
221	0.00	9.42	9.42	958.37	9.57	9.57	1573.61
222	4.83	7.43	8.69	967.05	7.12	8.86	1582.47
223	4.67	9.90	11.11	978.17	8.01	9.69	1592.16
224	4.50	9.10	10.27	988.44	8.74	10.36	1602.52
225	4.33	8.50	9.63	998.06	8.17	9.73	1612.25
226	4.17	8.61	9.69	1007.76	7.98	9.48	1621.73
227	4.00	8.53	9.57	1017.33	8.36	9.80	1631.53
228	3.83	7.65	8.65	1025.97	7.37	8.75	1640.28
229	3.67	8.78	9.73	1035.71	8.48	9.80	1650.08
230	3.50	8.59	9.50	1045.21	8.49	9.75	1659.83
231	3.33	8.05	8.92	1054.12	7.74	8.94	1668.77
232	3.17	8.41	9.23	1063.36	8.06	9.20	1677.97
233	3.00	7.85	8.63	1071.99	7.66	8.74	1686.71
234	2.83	6.88	7.62	1079.60	6.41	7.43	1694.14
235	2.67	8.42	9.11	1088.72	7.77	8.73	1702.87
236	2.50	8.31	8.96	1097.68	8.24	9.14	1712.01
237	2.33	7.30	7.91	1105.58	5.02	5.86	1717.87
238	2.17	7.60	8.16	1113.75	4.05	4.83	1722.70
239	2.00	5.05	5.57	1119.32	2.89	3.61	1726.31
240	1.83	1.61	2.09	1121.40	0.88	1.54	1727.85
241	1.67	0.90	1.33	1122.74	0.75	1.35	1729.20
242	1.50	1.08	1.47	1124.21	0.81	1.35	1730.55
243	1.33	1.17	1.52	1125.72	0.74	1.22	1731.77
244	1.17	1.80	2.10	1127.83	1.89	2.31	1734.08
245	1.00	7.82	8.08	1135.91	9.71	10.07	1744.15
246	0.83	11.34	11.56	1147.46	5.32	5.62	1749.77
247	0.67	9.90	10.07	1157.54	4.07	4.31	1754.08

Table C-7. Continued.

248	0.50	6.64	6.77	1164.31	4.76	4.94	1759.02
249	0.33	9.84	9.93	1174.23	8.86	8.98	1768.00
250	0.17	15.07	15.11	1189.35	11.03	11.09	1779.09
251	0.00	10.28	10.28	1199.63	10.53	10.53	1789.62
252	1.83	7.07	7.55	1207.17	5.92	6.58	1796.20
253	1.67	11.76	12.19	1219.37	6.93	7.53	1803.73
254	1.50	9.56	9.95	1229.32	9.90	10.44	1814.17
255	1.33	9.53	9.88	1239.19	6.85	7.33	1821.50
256	1.17	9.96	10.26	1249.46	3.01	3.43	1824.93
257	1.00	10.48	10.74	1260.20	9.51	9.87	1834.80
258	0.83	12.80	13.02	1273.21	12.47	12.77	1847.57
259	0.67	10.71	10.88	1284.10	10.66	10.90	1858.47
260	0.50	9.77	9.90	1294.00	10.29	10.47	1868.94
261	0.33	9.26	9.35	1303.34	9.71	9.83	1878.77
262	0.17	9.65	9.69	1313.04	10.32	10.38	1889.15
263	0.00	10.27	10.27	1323.31	10.92	10.92	1900.07
264	2.83	10.16	10.90	1334.20	10.14	11.16	1911.23
265	2.67	12.12	12.81	1347.02	9.68	10.64	1921.87
266	2.50	9.89	10.54	1357.56	9.88	10.78	1932.65
267	2.33	4.06	4.67	1362.22	9.76	10.60	1943.25
268	2.17	1.29	1.85	1364.08	9.53	10.31	1953.56
269	2.00	3.78	4.30	1368.38	10.08	10.80	1964.36
270	1.83	7.17	7.65	1376.02	9.95	10.61	1974.97
271	1.67	5.11	5.54	1381.57	10.99	11.59	1986.56
272	1.50	3.17	3.56	1385.13	10.80	11.34	1997.90
273	1.33	1.16	1.51	1386.63	10.22	10.70	2008.60
274	1.17	0.31	0.61	1387.25	9.71	10.13	2018.73
275	1.00	3.29	3.55	1390.80	10.51	10.87	2029.60
276	0.83	10.13	10.35	1401.14	10.40	10.70	2040.30
277	0.67	14.01	14.18	1415.33	11.16	11.40	2051.70
278	0.50	9.68	9.81	1425.14	10.22	10.40	2062.10
279	0.33	8.81	8.90	1434.03	9.33	9.45	2071.55
280	0.17	7.64	7.68	1441.72	8.16	8.22	2079.77
281	0.00	8.40	8.40	1450.12	9.43	9.43	2089.20
282	1.83	9.96	10.44	1460.55	9.39	10.05	2099.25
283	1.67	11.03	11.46	1472.02	8.83	9.43	2108.68
284	1.50	9.31	9.70	1481.72	9.40	9.94	2118.62
285	1.33	8.43	8.78	1490.49	8.71	9.19	2127.81
286	1.17	8.70	9.00	1499.50	10.11	10.53	2138.34
287	1.00	9.01	9.27	1508.77	9.89	10.25	2148.59
288	0.83	8.62	8.84	1517.60	9.41	9.71	2158.30
289	0.67	11.08	11.25	1528.86	11.15	11.39	2169.69
290	0.50	9.84	9.97	1538.83	10.50	10.68	2180.37
291	0.33	9.73	9.82	1548.64	9.73	9.85	2190.22
292	0.17	9.53	9.57	1558.22	11.19	11.25	2201.47
293	0.00	10.25	10.25	1568.47	11.53	11.53	2213.00
294	1.00	11.17	11.43	1579.90	10.16	10.52	2223.52
295	0.83	12.46	12.68	1592.57	10.89	11.19	2234.71
296	0.67	11.36	11.53	1604.11	11.06	11.30	2246.01
297	0.50	10.48	10.61	1614.72	10.31	10.49	2256.50

Table C-7. Continued.

298	0.33	9.86	9.95	1624.66	10.29	10.41	2266.91
299	0.17	10.06	10.10	1634.77	9.64	9.70	2276.61
300	0.00	10.81	10.81	1645.58	3.63	3.63	2280.24
Mean flow rate (ml/d)			35			49	
Total discharge for Cr(VI) and nutrient additions vials 32 through 300 (ml)			1569			2192	

Table C-8. Effluent Cr concentration and corrections.

Effluent Vial ID	sample collection date and time	Time since addition of Cr(VI) and nutrients (d)	Measured sample volume (ml) NC1	NC2	C1	C2	N1	N2	B1	B2
35	4/25/00 6:42	0.61	9.28	8.44	7.62	0.00	7.91	7.80	4.94	5.46
45	4/26/00 22:42	2.28	13.08	13.07	9.96	1.87	8.68	7.47	5.37	6.35
60	4/29/00 10:42	4.78	7.29	8.14	6.53	3.96	8.51	8.49	5.66	6.40
80	5/2/00 18:42	8.11	8.03	8.82	7.95	5.90	8.73	8.73	7.50	7.21
109	5/7/00 14:42	12.94	6.77	5.47	4.88	10.23	5.62	5.34	0.07	6.93
118	5/9/00 2:42	14.44	5.86	7.44	8.14	6.20	5.78	7.68	7.60	6.45
132	5/11/00 10:42	16.78	7.15	7.82	7.18	5.04	6.96	6.95	0.20	8.43
137	5/12/00 6:42	17.61	8.58	8.38	7.51	9.70	8.69	7.22	0.40	8.65
158	5/15/00 18:42	21.11	9.74	9.79	8.18	6.35	8.72	8.84	1.23	9.89
160	5/16/00 2:42	21.44	9.15	10.30	8.91	8.38	8.02	8.47	0.46	8.57
170	5/17/00 18:42	23.11	9.30	9.59	8.40	7.95	7.55	0.77	7.27	6.80
186	5/20/00 10:42	25.78	7.49	8.51	7.91	7.53	8.86	10.59	6.50	5.76
196	5/22/00 2:42	27.44	7.38	7.89	6.05	8.13	3.72	9.43	8.97	8.67
197	5/22/00 6:42	27.61	9.78	8.85	5.80	9.39	7.17	9.58	9.20	8.78
215	5/25/00 6:42	30.61	9.63	8.55	8.83	3.52	8.91	9.70	9.28	9.75
221	5/26/00 6:42	31.61	8.87	8.95	8.83	0.85	9.25	9.51	9.42	9.57
251	5/31/00 6:42	36.61	9.09	10.04	5.58	0.79	9.94	10.23	10.28	10.53
281	6/5/00 6:42	41.61	9.38	9.21	2.75	6.36	9.30	9.51	8.40	9.43
293	6/7/00 6:42	43.61	8.11	9.68	2.56	8.33	10.52	10.69	10.25	11.53
299	6/8/00 6:42	44.61	5.38	9.36	2.36	9.03	9.59	10.59	10.06	9.64
300	6/8/00 10:42	44.78	7.93	7.81	2.14	8.90	9.45	9.45	10.81	3.63

Table C-8. Continued

Evaporation rate (ml d^{-1})								Time for evap. correction (d)
NC1	NC2	C1	C2	N1	N2	B1	B2	
0.24	0.30	0.25	0.33	0.15	0.24	0.26	0.36	2.29
0.24	0.30	0.25	0.33	0.15	0.24	0.26	0.36	0.63
0.24	0.30	0.25	0.33	0.15	0.24	0.26	0.36	1.42
0.24	0.30	0.25	0.33	0.15	0.24	0.26	0.36	0.88
0.24	0.30	0.25	0.33	0.15	0.24	0.26	0.36	2.00
0.24	0.30	0.25	0.33	0.15	0.24	0.26	0.36	0.50
0.24	0.30	0.25	0.33	0.15	0.24	0.26	0.36	0.96
0.24	0.30	0.25	0.33	0.15	0.24	0.26	0.36	0.08
0.27	0.35	0.27	0.36	0.19	0.25	0.34	0.39	0.63
0.27	0.35	0.27	0.36	0.19	0.25	0.34	0.39	0.29
0.23	0.36	0.30	0.35	0.14	0.29	0.33	0.45	0.83
0.16	0.29	0.25	0.33	0.13	0.25	0.25	0.38	2.00
0.16	0.29	0.25	0.33	0.13	0.25	0.25	0.38	0.33
0.16	0.29	0.25	0.33	0.13	0.25	0.25	0.38	0.17
0.29	0.36	0.29	0.41	0.16	0.29	0.30	0.41	0.13
0.26	0.30	0.24	0.37	0.12	0.25	0.24	0.34	0.08
0.27	0.29	0.23	0.35	0.16	0.23	0.24	0.36	0.13
0.22	0.25	0.22	0.24	0.15	0.18	0.19	0.27	0.13
0.22	0.22	0.21	0.23	0.17	0.19	0.22	0.29	0.13
0.24	0.24	0.25	0.28	0.09	0.22	0.21	0.27	0.17
0.24	0.24	0.25	0.28	0.09	0.22	0.21	0.27	0.00

Table C-8. Continued

Measured effluent Cr concentration (mg L^{-1})								Influent Cr concentration (mg L^{-1})							
NC1	NC2	C1	C2	N1	N2	B1	B2	NC1	NC2	C1	C2	N1	N2	B1	B2
43	40	42	n.a.	14	24	11	21	66	66	61	61	63	63	61	61
62	60	64	186	56	58	60	61	66	66	61	61	63	63	61	61
74	66	71	118	65	69	59	61	67	67	70	70	63	63	56	56
67	65	74	97	70	71	63	60	67	67	70	70	63	63	56	56
64	63	68	88	68	70	n.a.	71	65	65	65	65	65	65	64	64
60	58	65	78	67	66	60	64	65	65	65	65	65	65	64	64
66	70	74	93	72	77	n.a.	72	65	65	65	65	65	65	64	64
58	56	63	72	64	65	77	63	65	65	65	65	65	65	62	62
58	59	64	73	66	65	75	64	64	64	61	61	64	64	61	61
67	63	64	68	70	66	n.a.	62	64	64	61	61	64	64	61	61
60	60	65	70	67	84	62	67	64	64	61	61	64	64	61	61
62	61	63	71	67	69	69	75	63	63	59	59	64	64	64	64
60	58	65	64	67	65	61	67	63	63	59	59	64	64	64	64
59	56	62	66	65	66	63	67	63	63	59	59	64	64	64	64
57	53	62	73	66	65	61	61	63	63	59	59	63	63	61	61
58	55	62	79	64	64	60	61	63	63	61	61	63	63	61	61
56	55	63	107	64	62	61	61	64	64	62	62	64	64	60	60
58	58	59	67	64	64	62	62	63	63	61	61	64	64	60	60
58	58	55	65	65	65	60	62	63	63	61	61	64	64	60	60
56	56	53	64	62	62	61	62	63	63	61	61	64	64	60	60
57	57	55	63	65	66	60	64	63	63	61	61	64	64	60	60

Table C-8. Continued

Final sample volume/initial sample volume for additional evaporation correction								Effluent Cr concentration (corrected for evaporation and normalized to influent Cr concentration)							
NC1	**NC2**	**C1**	**C2**	**N1**	**N2**	**B1**	**B2**	**NC1**	**NC2**	**C1**	**C2**	**N1**	**N2**	**B1**	**B2**
0.94	0.95	0.97	n.a.	0.98	0.94	n.a.	0.95	0.58	0.53	0.62	n.a.	0.21	0.33	0.16	0.29
0.97	0.98	0.98	n.a.	1.00	0.95	n.a.	0.97	0.91	0.88	1.02	2.76	0.88	0.85	0.96	0.95
0.85	0.95	0.98	n.a.	0.97	0.89	n.a.	0.93	0.91	0.90	0.95	1.52	0.97	0.94	0.99	0.93
0.92	0.98	0.92	n.a.	0.91	0.90	n.a.	0.96	0.90	0.92	0.94	1.33	1.00	0.99	1.09	0.98
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.92	0.87	0.95	1.27	1.00	0.99	n.a.	1.01
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.90	0.87	0.98	1.17	1.02	1.00	0.92	0.98
0.90	0.82	0.88	n.a.	0.91	0.87	n.a.	0.92	0.89	0.86	0.96	1.35	0.99	0.99	n.a.	0.99
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.89	0.86	0.97	1.10	0.99	1.00	1.19	1.02
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.89	0.90	1.03	1.16	1.01	0.99	1.04	1.02
0.87	0.92	0.98	n.a.	0.92	0.99	n.a.	0.98	0.90	0.90	1.01	1.10	0.99	1.01	n.a.	0.98
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.91	0.90	1.03	1.11	1.03	0.99	0.97	1.04
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.94	0.91	1.00	1.10	1.01	1.02	1.01	1.04
0.97	0.98	0.97	n.a.	0.95	0.99	n.a.	0.94	0.92	0.88	1.04	1.06	0.97	0.98	0.95	0.98
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.93	0.88	1.04	1.11	1.01	1.02	0.98	1.04
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.90	0.84	1.04	1.21	1.05	1.03	1.00	1.00
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.92	0.87	1.02	1.26	1.01	1.01	0.98	1.00
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.87	0.86	1.01	1.63	1.01	0.97	1.01	1.01
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.91	0.91	0.96	1.09	1.01	1.01	1.03	1.03
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.91	0.91	0.89	1.06	1.02	1.02	1.00	1.03
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.88	0.88	0.85	1.04	0.97	0.97	1.01	1.03
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.90	0.90	0.90	1.03	1.02	1.04	1.00	1.07

Table C-9. Effluent NO_3^- concentration and corrections.

Effluent Vial ID	sample collection date and time	Time since addition of Cr(VI) and nutrients (d)	Measured sample volume (ml)				Evaporation rate (ml d^{-1})			
			NC1	NC2	N1	N2	NC1	NC2	N1	N2
137	5/12/00 6:42	17.61	8.58	8.38	8.69	7.22	0.24	0.30	0.15	0.24
158	5/15/00 18:42	21.11	9.74	9.79	8.72	8.84	0.27	0.35	0.19	0.25
186	5/20/00 10:42	25.78	7.49	8.51	8.86	10.59	0.16	0.29	0.13	0.25
197	5/22/00 6:42	27.61	9.78	8.85	7.17	9.58	0.16	0.29	0.13	0.25
221	5/26/00 6:42	31.61	8.87	8.95	9.25	9.51	0.26	0.30	0.12	0.25
251	5/31/00 6:42	36.61	9.09	10.04	9.94	10.23	0.27	0.29	0.16	0.23
281	6/5/00 6:42	41.61	9.38	9.21	9.30	9.51	0.22	0.25	0.15	0.18
293	6/7/00 6:42	43.61	8.11	9.68	10.52	10.69	0.22	0.22	0.17	0.19
299	6/8/00 6:42	44.61	5.38	9.36	9.59	10.59	0.24	0.24	0.09	0.22

Table C-9. Continued

Time for evap. corr. (d)	**Measured effluent NO_3^- conc. ($mg\ L^{-1}$)**				**Influent NO_3^- concentration ($mg\ L^{-1}$)**				**Effluent NO_3^- conc. (corrected for evaporation and normalized to influent NO_3 conc.)**			
	NC1	**NC2**	**N1**	**N2**	**NC1**	**NC2**	**N1**	**N2**	**NC1**	**NC2**	**N1**	**N2**
0.08	3100	3020	3080	3095	3045	3045	3035	3035	1.02	0.99	1.01	1.02
0.63	3160	3110	3120	n.a.	3045	3045	3035	3035	1.02	1.00	1.01	0.00
2.00	3225	3225	3190	3255	3059	3059	3070	3070	1.01	0.99	1.01	1.01
0.17	3105	3065	3145	3155	3059	3059	3070	3070	1.01	1.00	1.02	1.02
0.08	3170	3060	3150	3110	3092	3092	3105	3105	1.02	0.99	1.01	1.00
0.13	3075	3110	3130	3155	3095	3095	3098	3097	0.99	1.00	1.01	1.02
0.13	3045	3095	3100	3150	3079	3079	3065	3065	0.99	1.00	1.01	1.03
0.13	3125	3115	3105	3095	3079	3079	3065	3065	1.01	1.01	1.01	1.01
0.17	3200	3120	3195	3140	3079	3079	3065	3065	1.03	1.01	1.04	1.02

Table C-10. pH values measured during column experiments. Missing values represent sample vials that contained no water or insufficient water (e.g., < 5 ml) for measurement of pH.

Effluent Sample				Column				
Vial ID	NC1	NC2	C1	C2	N1	N2	B1	B2
35	7.84	7.69	8.44	n.m.	8.04	7.77	8.36	8.44
38	7.64	7.77	8.44	n.m.	8.01	8.08	8.63	9.34
40	7.68	7.67	8.42	8.10	7.89	7.72	8.36	8.47
43	7.65	7.74	8.48	8.24	7.98	8.07	8.90	8.73
45	7.57	7.54	8.42	8.23	7.90	7.76	8.35	8.50
48	7.59	7.73	8.54	8.28	8.08	8.06	8.92	8.72
55	7.63	7.10	7.61	8.12	7.64	7.93	7.94	8.00
60	8.37	7.21	7.73	7.63	7.89	8.15	8.13	8.26
65	8.42	7.82	7.75	7.70	7.99	8.18	8.13	8.26
70	8.13	7.95	7.81	8.05	8.03	8.13	8.12	8.27
75	8.40	7.73	8.15	7.82	8.07	8.16	8.17	8.30
80	8.51	7.30	8.17	8.16	8.10	8.20	8.18	8.28
85	8.21	8.31	8.09	8.10	8.10	8.19	n.m.	8.26
90	8.50	8.14	8.19	8.09	8.08	8.25	n.m.	8.25
95	8.61	8.57	7.92	8.19	8.12	8.37	n.m.	8.39
100	8.56	8.58	8.26	8.25	8.17	8.41	n.m.	8.43
105	8.55	8.59	8.23	8.25	8.17	8.40	n.m.	8.42
110	8.53	8.59	8.22	n.m.	8.15	8.38	n.m.	8.38
115	8.50	8.45	8.34	8.23	8.10	8.33	n.m.	n.m.
120	8.67	8.39	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
125	8.33	8.37	7.65	7.95	8.03	8.08	n.m.	8.12
130	8.34	8.49	8.02	7.98	8.06	8.25	n.m.	8.32
135	8.44	8.29	8.00	7.78	8.10	8.25	n.m.	8.29
140	8.60	8.58	8.22	8.11	8.22	8.35	n.m.	8.40
145	8.57	8.53	8.28	8.23	8.23	8.32	n.m.	8.34
150	8.57	8.54	8.28	8.21	8.17	8.33	n.m.	8.34
155	8.55	8.46	8.32	8.22	8.15	8.29	n.m.	8.36
160	8.55	8.42	8.29	8.25	8.19	8.28	n.m.	8.29
165	8.47	8.23	8.21	8.01	8.32	8.68	n.m.	8.60
170	8.41	8.42	8.26	7.83	8.36	8.67	8.45	8.47
175	8.67	8.62	8.29	8.26	8.26	n.m.	8.39	8.51
180	8.64	8.49	8.34	8.16	8.38	8.45	8.52	8.55
185	8.63	8.59	8.37	8.42	8.37	8.40	8.41	8.35
190	8.69	8.63	8.56	8.51	8.28	8.40	8.54	8.50
195	8.69	8.55	8.36	8.50	8.38	8.41	8.36	8.43
200	8.61	8.41	8.01	8.42	8.37	8.40	8.30	8.35
205	8.72	8.67	8.25	8.28	8.35	8.37	8.31	8.36
210	8.72	8.61	8.39	8.14	8.28	8.41	8.28	8.35
215	8.74	8.57	8.07	8.38	8.30	8.40	8.30	8.36
220	8.57	8.55	8.35	8.35	8.37	8.24	8.28	8.36
225	8.67	8.61	8.40	n.m.	8.32	8.38	8.33	8.45
230	8.67	8.33	8.39	8.39	8.31	8.33	8.30	8.36
235	8.61	8.60	8.37	8.47	8.27	8.35	8.26	8.31
240	8.58	8.62	8.45	n.m.	8.39	8.48	8.48	8.54
245	8.54	8.41	8.48	n.m.	8.27	8.35	8.40	8.36

Table C-10. Continued.

250	8.30	8.31	8.41	8.21	8.26	8.24	8.26	8.38
255	8.70	8.64	8.69	n.m.	8.31	8.41	8.37	8.38
260	8.62	8.60	8.75	8.15	8.30	8.36	8.34	8.25
265	8.74	8.70	8.85	8.58	8.53	8.43	8.41	8.42
270	8.69	8.67	8.83	8.54	8.41	8.38	8.43	8.40
275	8.63	8.61	8.87	8.47	8.41	8.39	8.33	8.42
280	8.74	8.62	8.82	8.64	8.38	8.42	8.38	8.43
285	8.17	8.64	8.58	8.53	8.40	8.40	8.43	8.43
290	8.13	7.92	8.58	8.13	8.44	8.37	8.41	8.42
295	8.58	7.74	8.52	8.37	8.39	8.40	8.39	8.42
300	8.61	8.34	8.57	7.95	8.37	8.40	8.40	8.49

Preparation date of Influent batch				**Column**				
	NC1	**NC2**	**C1**	**C2**	**N1**	**N2**	**B1**	**B2**
4/24/00	7.04	6.47	7.59	7.19	8.18	8.18	8.26	8.24
4/27/00	8.32	8.41	8.58	8.58	8.39	8.34	8.40	8.80
5/5/00	6.50	7.17	7.09	7.06	8.32	8.31	8.16	8.13
5/8/00	6.53	7.78	8.02	7.74	8.29	8.36	8.27	8.28
5/11/00	7.31	7.81	7.91	7.69	8.36	8.33	8.42	8.40
5/13/00	7.08	7.11	7.76	7.81	8.34	8.39	8.30	8.36
5/15/00	7.33	7.23	8.18	7.47	8.58	8.64	8.59	8.66
5/23/00	7.26	7.26	7.71	7.76	8.64	8.62	8.68	8.62
5/24/00	8.12	8.16	8.37	8.21	8.48	8.63	8.59	8.60
6/4/00	7.22	7.35	7.82	7.94	8.50	8.45	8.62	8.36

Table C-11. Normalized effluent tritium concentrations and pore volume data for first tracer experiment performed prior to addition of Cr(VI) and nutrients.

Column NC1		**Column NC2**		**Column C1**	
time (pore volumes)	**normalized tritium conc.**	**time (pore volumes)**	**normalized tritium conc.**	**time (pore volumes)**	**normalized tritium conc.**
0.065	0.000	0.075	0.000	0.051	0.000
0.179	0.003	0.216	0.001	0.145	0.007
0.275	0.002	0.333	0.006	0.232	0.003
0.364	0.007	0.436	0.002	0.317	0.009
0.448	0.006	0.531	0.008	0.395	0.015
0.531	0.014	0.621	0.010	0.473	0.013
0.615	0.037	0.706	0.046	0.549	0.041
0.707	0.120	0.790	0.141	0.623	0.113
0.803	0.259	0.879	0.274	0.699	0.235
0.897	0.393	0.967	0.356	0.775	0.377
0.990	0.548	1.056	0.576	0.848	0.500
1.082	0.632	1.143	0.631	0.917	0.596
1.174	0.715	1.229	0.724	0.986	0.663
1.257	0.718	1.310	0.755	1.051	0.700
1.375	0.793	1.424	0.830	1.121	0.788
1.498	0.809	1.558	0.869	1.206	0.806
1.588	0.833	1.671	0.866	1.293	0.819
1.672	0.848	1.772	0.886	1.374	0.848
1.748	0.831	1.871	0.874	1.452	0.830
1.820	0.853	1.966	0.898	1.521	0.829
1.895	0.864	2.058	0.873	1.592	0.788
1.971	0.796	2.146	0.758	1.663	0.769
2.045	0.640	2.230	0.609	1.730	0.626
2.122	0.496	2.317	0.437	1.797	0.475
2.197	0.360	2.396	0.309	1.862	0.374
2.267	0.305	2.475	0.248	1.924	0.247
2.335	0.240	2.553	0.170	1.978	0.182
2.395	0.190	2.616	0.141		
2.440	0.171	2.655	0.137		

Table C-11. Continued.

Column N1		Column B1		Column B2	
time (pore volumes)	normalized tritium conc.	time (pore volumes)	normalized tritium conc.	time (pore volumes)	normalized tritium conc.
0.060	0.000	0.087	0.000	0.080	0.000
0.174	0.002	0.227	0.002	0.213	0.004
0.277	0.002	0.321	0.005	0.312	0.005
0.370	0.004	0.399	0.006	0.400	0.005
0.455	0.004	0.469	0.006	0.480	0.006
0.532	0.007	0.534	0.006	0.554	0.007
0.607	0.007	0.595	0.006	0.624	0.009
0.680	0.010	0.657	0.006	0.696	0.027
0.753	0.043	0.720	0.008	0.773	0.081
0.824	0.115	0.783	0.021	0.851	0.184
0.896	0.239	0.845	0.055	0.925	0.378
0.965	0.411	0.906	0.112	0.994	0.478
1.031	0.502	0.965	0.184	1.060	0.557
1.095	0.595	1.020	0.260	1.124	0.626
1.181	0.752	1.093	0.368	1.202	0.704
1.283	0.816	1.178	0.457	1.292	0.724
1.372	0.868	1.253	0.541	1.373	0.824
1.457	0.851	1.323	0.624	1.453	0.815
1.542	0.881	1.389	0.674	1.531	0.826
1.623	0.887	1.453	0.711	1.606	0.868
1.703	0.865	1.515	0.758	1.678	0.882
1.782	0.898	1.578	0.762	1.751	0.873
1.858	0.859	1.640	0.847	1.826	0.836
1.931	0.840	1.698	0.815	1.903	0.768
2.001	0.713	1.755	0.826	1.979	0.671
2.069	0.593	1.811	0.782	2.055	0.528
2.135	0.458	1.865	0.663	2.129	0.456
2.199	0.343	1.913	0.679	2.196	0.388
2.248	0.263	1.947	0.604	2.247	0.346
2.279	0.226			2.276	0.298

Table C-12. Normalized effluent tritium concentrations and pore volume data for second tracer experiment performed after 38 days of Cr(VI) and nutrient additions.

Column NC1		Column NC2		Column N1	
time (pore volumes)	**normalized tritium conc.**	**time (pore volumes)**	**normalized tritium conc.**	**time (pore volumes)**	**normalized tritium conc.**
0.053	0.004	0.066	0.004	0.114	0.008
0.183	0.003	0.204	0.003	0.356	0.007
0.325	0.005	0.351	0.010	0.610	0.019
0.451	0.024	0.502	0.079	0.878	0.256
0.580	0.097	0.653	0.178	1.157	0.657
0.721	0.241	0.800	0.325	1.422	0.847
0.847	0.385	0.939	0.425	1.667	0.887
0.974	0.516	1.072	0.524	1.912	0.917
1.103	0.634	1.204	0.609	2.165	0.913
1.211	0.676	1.349	0.652	2.423	0.622
1.333	0.647	1.503	0.608	2.683	0.262
1.474	0.572	1.641	0.534	2.927	0.078
1.589	0.506	1.765	0.441	3.144	0.033
1.696	0.441	1.890	0.393	3.363	0.016
1.825	0.306	2.017	0.294	3.597	0.015
1.934	0.226	2.154	0.219	3.846	0.011
2.033	0.174	2.301	0.143	4.104	0.011
2.165	0.125	2.434	0.107	4.346	0.009
2.287	0.087	2.563	0.081	4.587	0.008
2.394	0.064	2.692	0.065	4.837	0.007
2.517	0.051	2.818	0.046	5.077	0.006
2.618	0.042	2.935	0.037	5.285	0.008
2.711	0.029	3.047	0.024	5.419	0.007
2.842	0.023	3.164	0.023	5.564	0.005
2.975	0.018	3.291	0.013	5.794	0.005
3.084	0.015	3.428	0.010	6.053	0.004

Table C-12. Continued.

Column N2		Column B2	
time (pore volumes)	**normalized tritium conc.**	**time (pore volumes)**	**normalized tritium conc.**
0.139	0.007	0.129	0.005
0.424	0.006	0.393	0.005
0.717	0.039	0.660	0.087
1.012	0.354	0.938	0.436
1.307	0.708	1.225	0.702
1.597	0.852	1.500	0.838
1.880	0.905	1.760	0.897
2.155	0.912	2.023	0.941
2.424	0.896	2.293	0.859
2.703	0.613	2.569	0.525
2.984	0.251	2.841	0.246
3.246	0.105	3.089	0.125
3.488	0.064	3.310	0.063
3.733	0.036	3.531	0.033
3.985	0.024	3.774	0.021
4.246	0.016	4.018	0.012
4.512	0.013	4.260	0.009
4.765	0.012	4.499	0.008
5.021	0.011	4.746	0.007
5.281	0.010	5.005	0.006
5.533	0.008	5.255	0.005
5.798	0.006	5.519	0.004
6.074	0.004	5.795	0.004
6.334	0.004	6.051	0.004
6.592	0.004	6.315	0.001
6.869	0.004	6.600	0.002

Table C-13. Results of XRF analyses for total Cr in column sediments.

Sample ID	**run**	**total Cr (ug g^{-1})**	**Mean total Cr (ug g^{-1})**	**standard deviation of measurements**
NC1-top	1	92.4	92.4	2.9
NC1-middle	1	88.5	88.5	1.3
NC1-bottom	1	97.6	97.6	2.3
mean for column NC1			**92.8**	
NC2-top	1	107.8	107.8	0.9
NC2-middle	1	90.7		1.8
NC2-middle	2	89.6		2.6
NC2-middle	3	92.3	90.9	4.1
NC2-bottom	1	89	89	2.8
mean for column NC2			**95.9**	
C1-top	1	73.9	73.9	2.8
C1-middle-a	1	62.6		0.5
C1-middle-a	2	60.5		1.4
C1-middle-b	1	51.5		2.1
C1-middle-b	2	52.3		2
C1-middle-c	1	54.2	56.2	1.3
C1-bottom	1	80.1	80.1	0.1
mean for column C1			**70.1**	
C2-top	1	72.4	72.4	2.1
C2-middle	1	55.4	55.4	3.3
C2-bottom	1	54	54	3.7
mean for column C2			**60.6**	
N1-top	1	52.7	52.7	2.3
N1-middle	1	36.3	36.3	2.3
N1-bottom	1	42.6	42.6	2.9
mean for column N1			**43.9**	
N2-top	1	40.8	40.8	1.8
N2-middle-a	1	38.8		3.4
N2-middle-a	2	35.7		3.6
N2-middle-b	1	30.8		1.5
N2-middle-b	2	30.3	33.9	3.3
N2-bottom	1	36.7	36.7	2.1
mean for column N2			**37.1**	
B1-top	1	35.5	35.5	2.4
B1-middle	1	40	40	1.9
B1-bottom	1	36.5	36.5	2.9
mean for column B1			**37.3**	
B2-top-a	1	48.8		0.7
B2-top-a	2	47.6		0.8
B2-top-b	1	29.2		3.4
B2-top-b	2	31.5	39.3	2.4
B2-middle	1	32.6	32.6	2.5
B2-bottom	1	31.5	31.5	0.4
mean for column B2			**34.5**	

Table C-14. Mass balance for total Cr accumulated in column sediments ($\mu g\ g^{-1}$).

Column	**Estimated Immobilized Cr**	**Aqueous Cr remaining in pore water**	**Background Cr in sediment**	**Sorbed Cr**	**Calculated total mass Cr**	**Total Cr measured with XRF**	**Mass balance difference (%)**
NC1	27	10	37	2	76	93	18
NC2	37	10	37	2	86	96	10
C1	2	24	37	2	65	70	7
N1	-2	5	37	2	42	44	5
N2	1	5	37	2	45	37	-22
B2	-2	5	37	2	42	35	-20

Table C-15. Total Cr concentrations ($\mu g\ g^{-1}$) by grain size for untreated sediment and sediment from columns NC2 and B2, measured with XRF.

Grain size (mm)	**Untreated sediment**	**Column B2**	**Column NC2**	**Ratio NC2/B2**
< 0.125 **(very fine sand, silt, and clay)**	391	586	581	0.99
0.125-0.250 **(fine sand)**	95	182	228	1.25
0.250-0.500 **(medium sand)**	22	28	109	3.89
0.500-1.00 **(coarse sand)**	28	32	76	2.38
> 1.00 **(very coarse sand)**	35	34	70	2.06
Unsieved (bulk)	36	30	108	3.60

Figure C-1. Breakthrough curve for first tritium tracer test in column NC1.

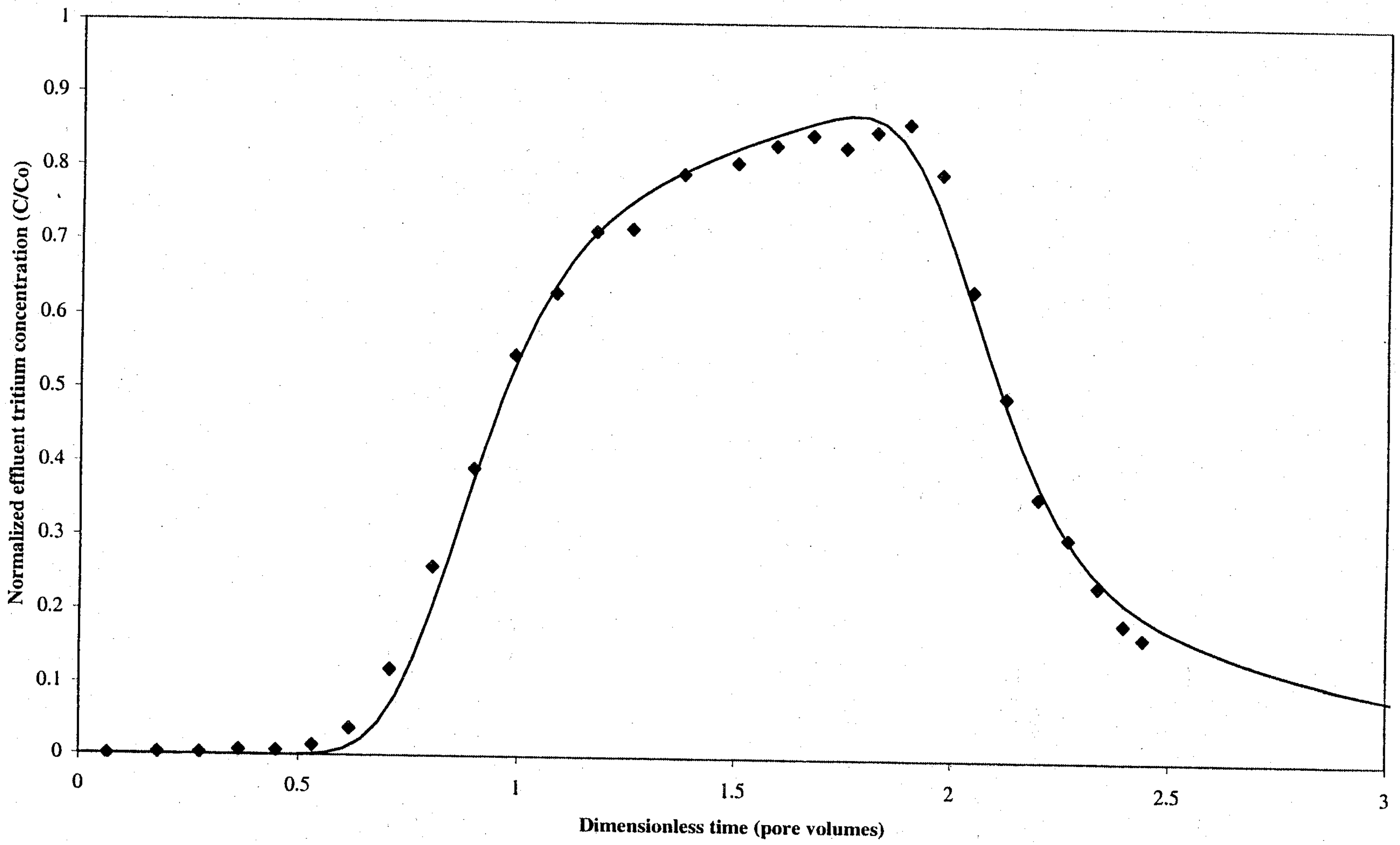
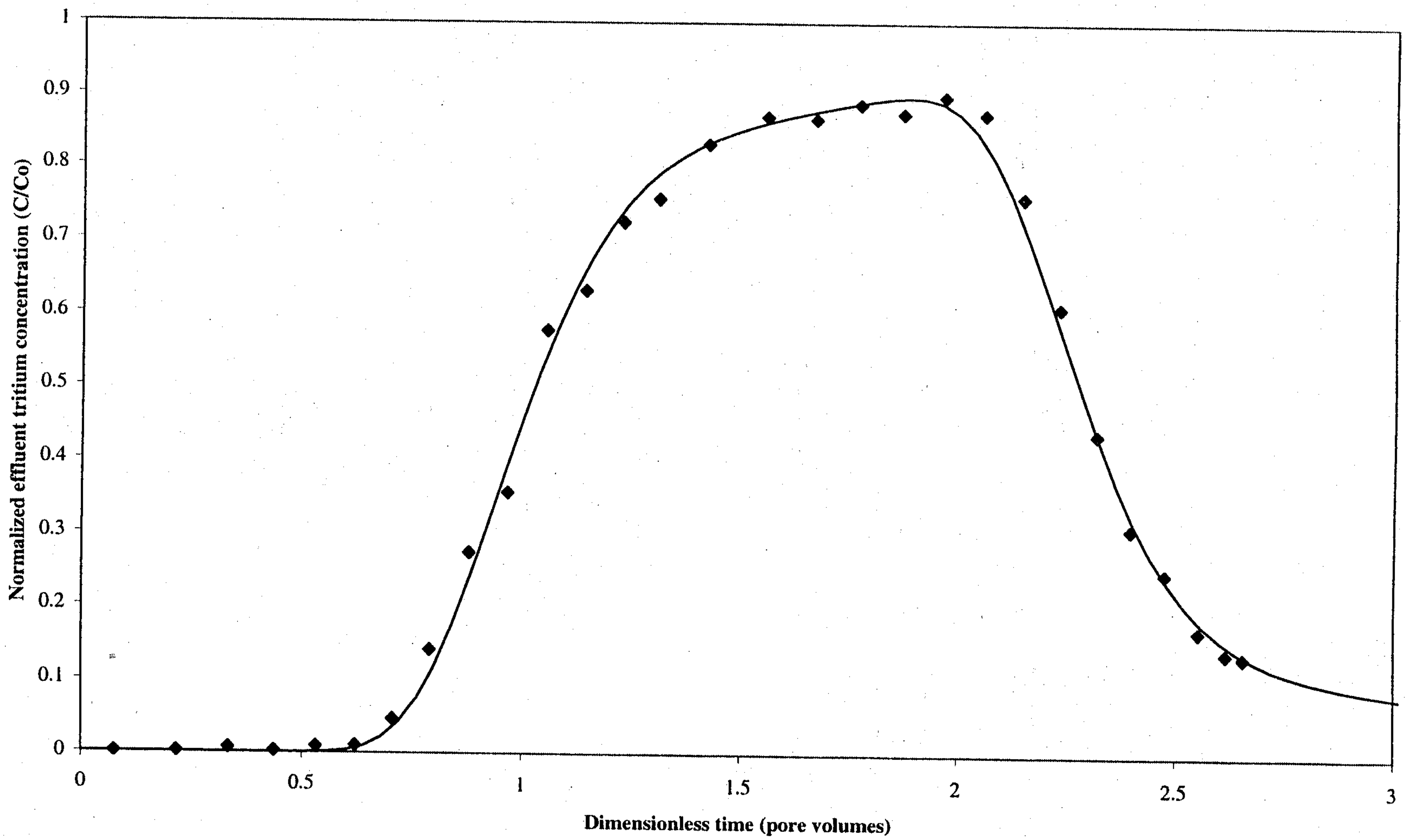


Figure C-2. Breakthrough curve for first tritium tracer test in column NC2.



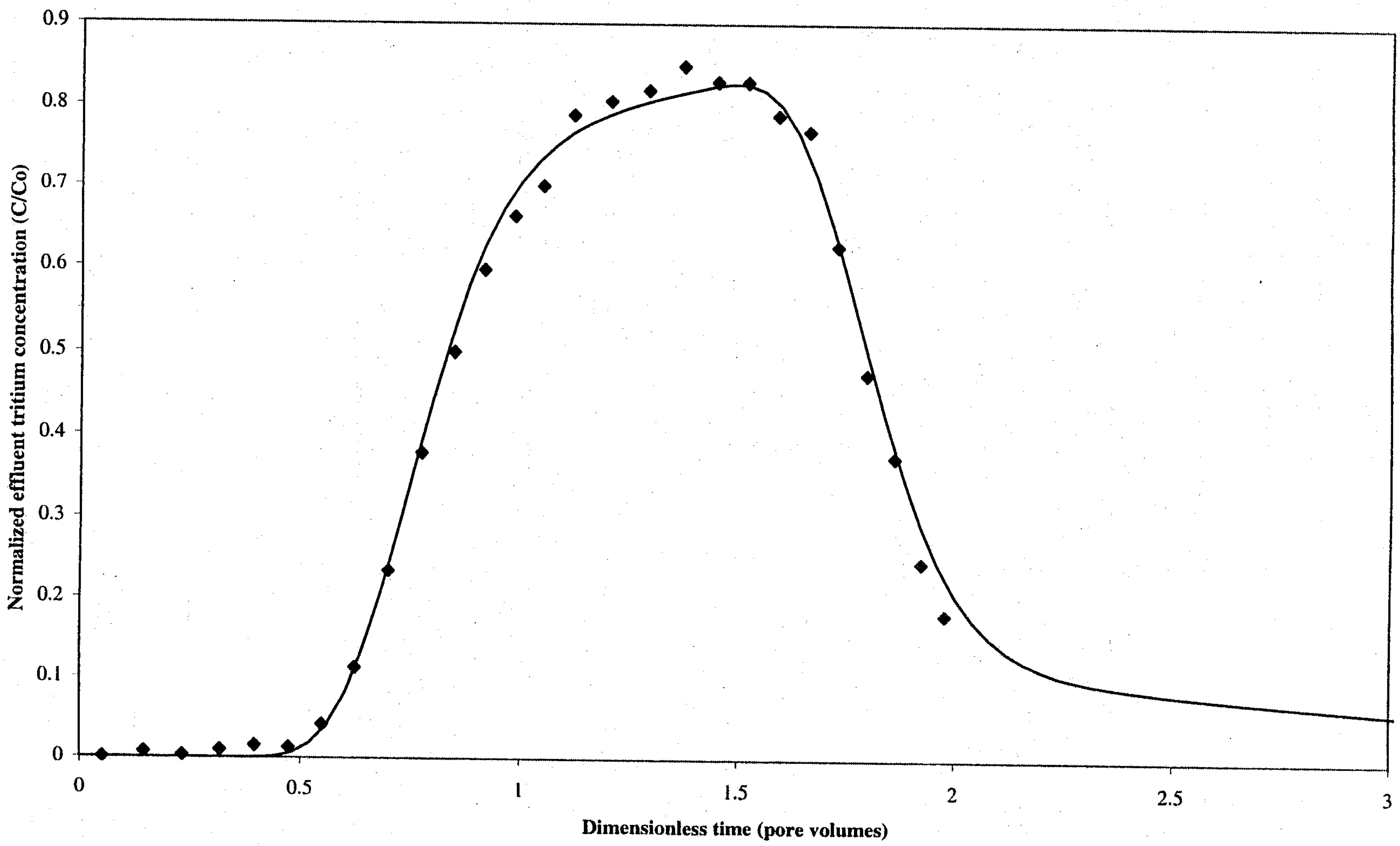


Figure C-3. Breakthrough curve for first tritium tracer test in column C1.

Figure C-4. Breakthrough curve for first tritium tracer test in column N1.

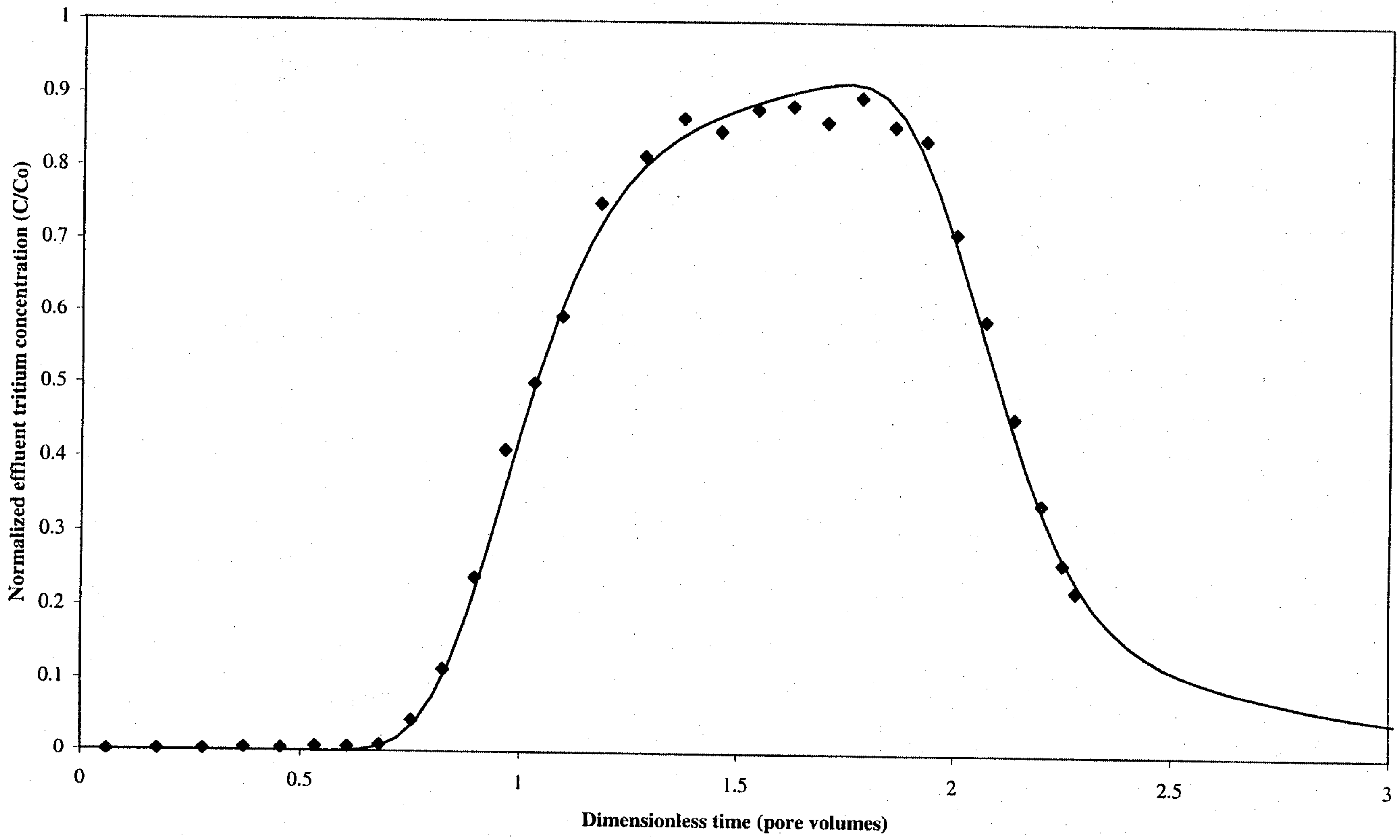


Figure C-5. Breakthrough curve for first tritium tracer test in column B2.

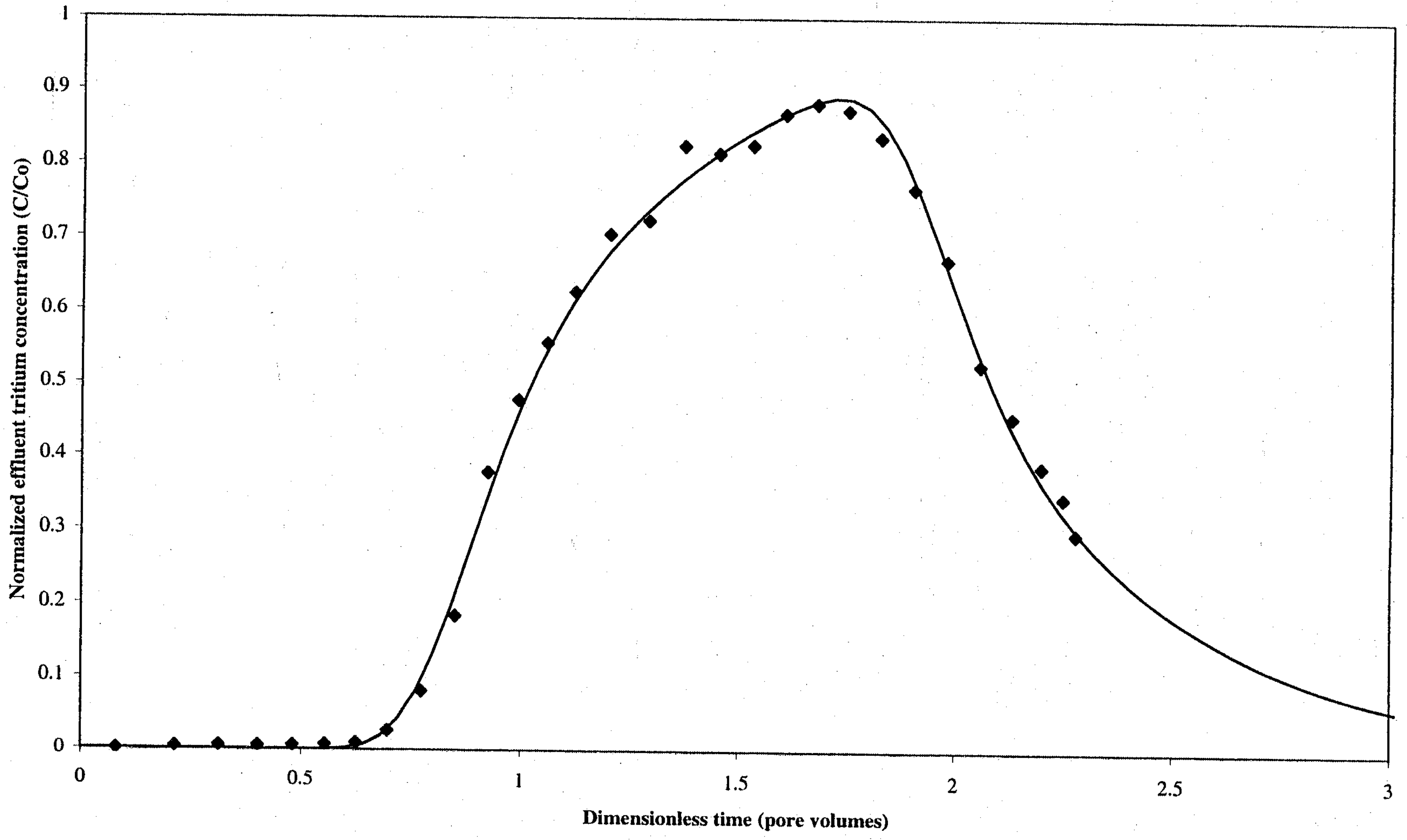


Figure C-6. Breakthrough curve for second tritium tracer test in column NC1.

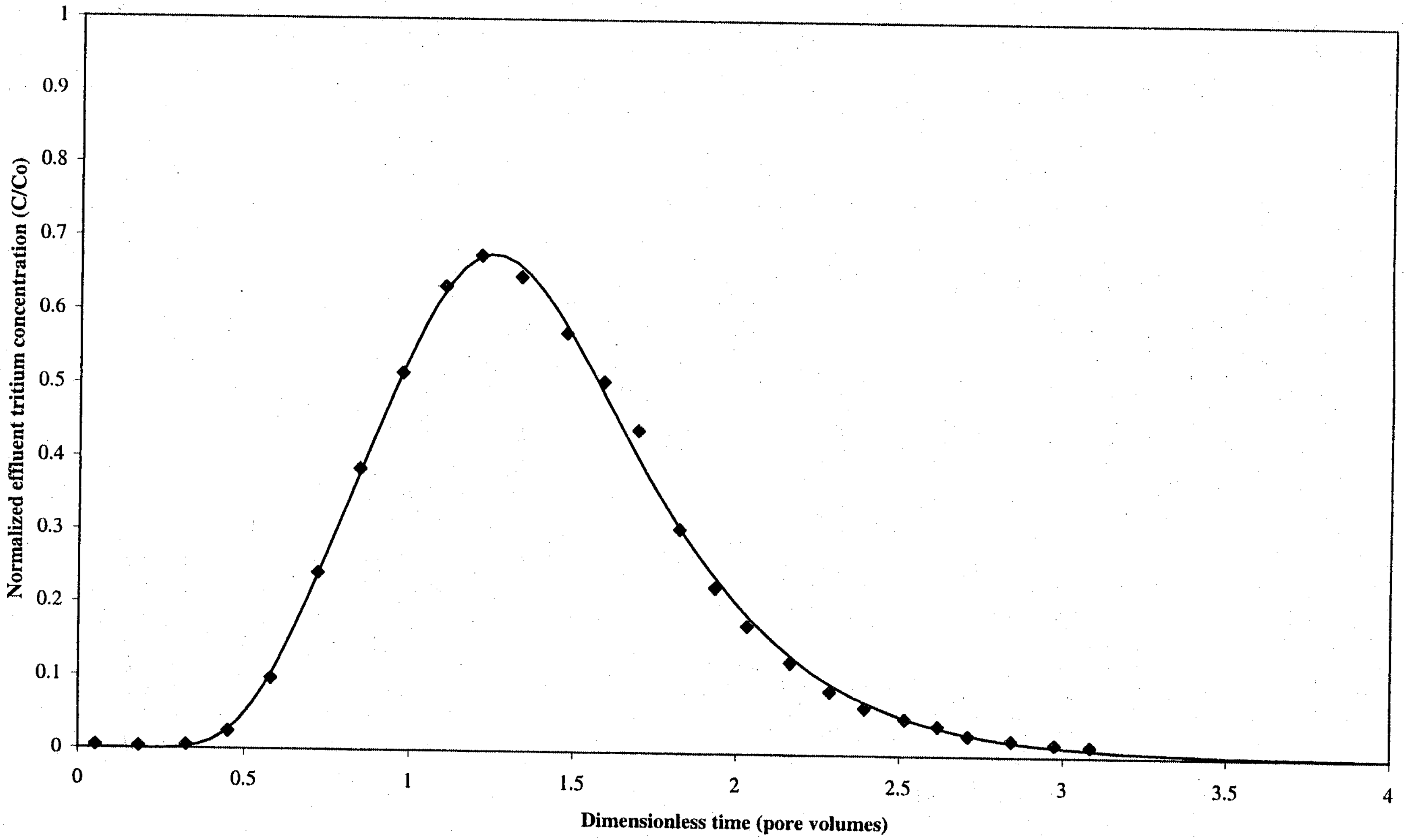


Figure C-7. Breakthrough curve for second tritium tracer test in column NC2.

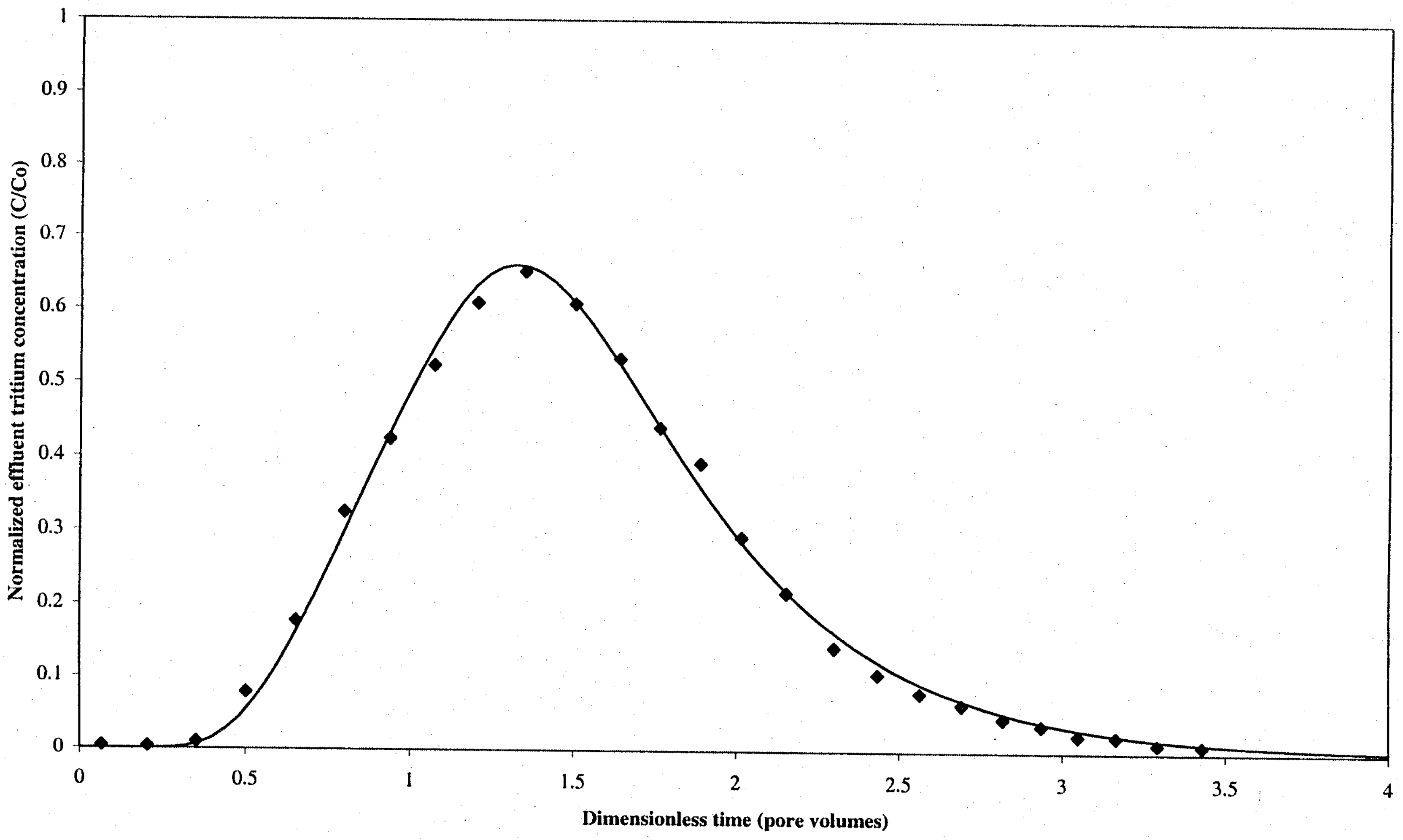


Figure C-8. Breakthrough curve for second tritium tracer test in column N1.

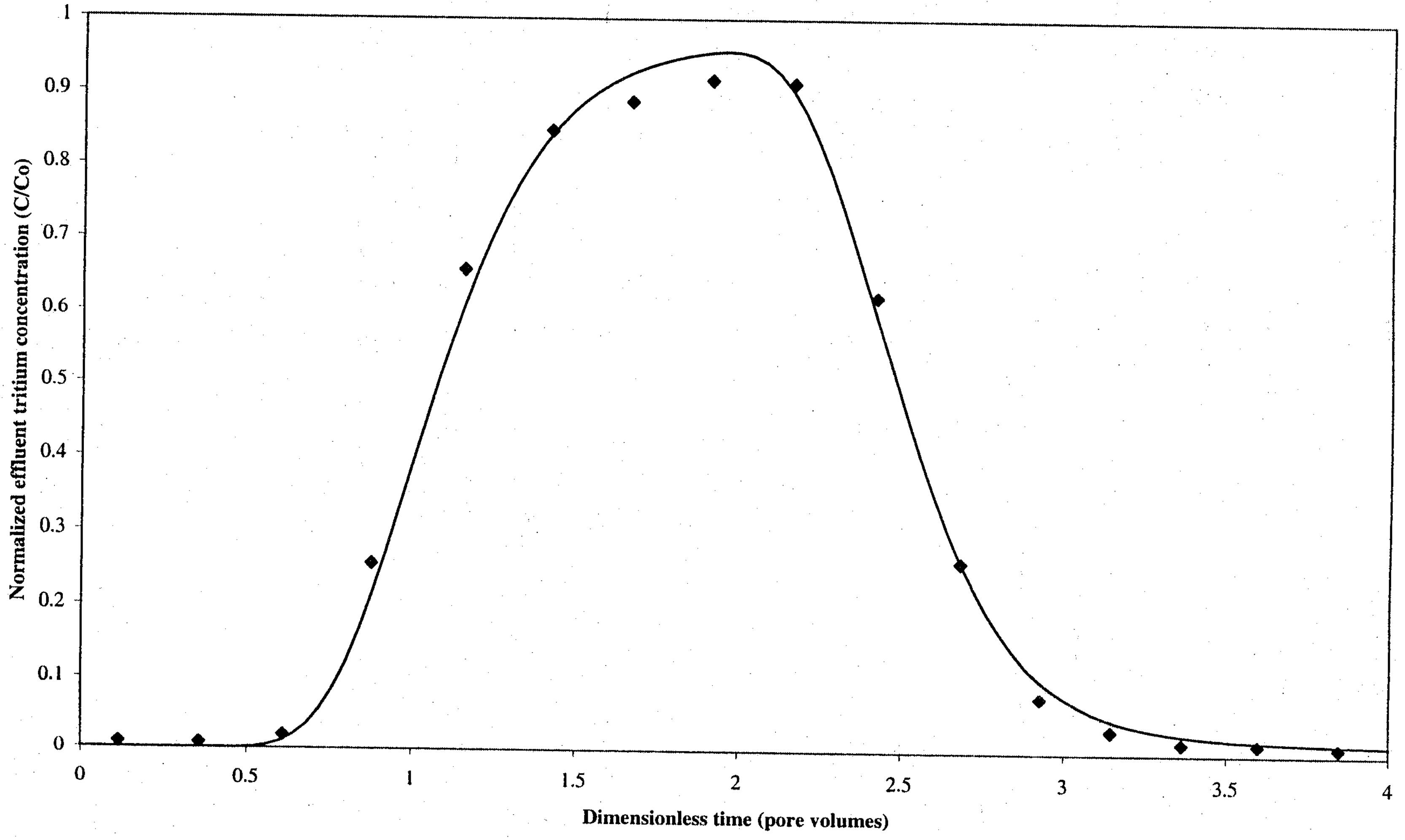


Figure C-9. Breakthrough curve for second tritium tracer test in column N2.

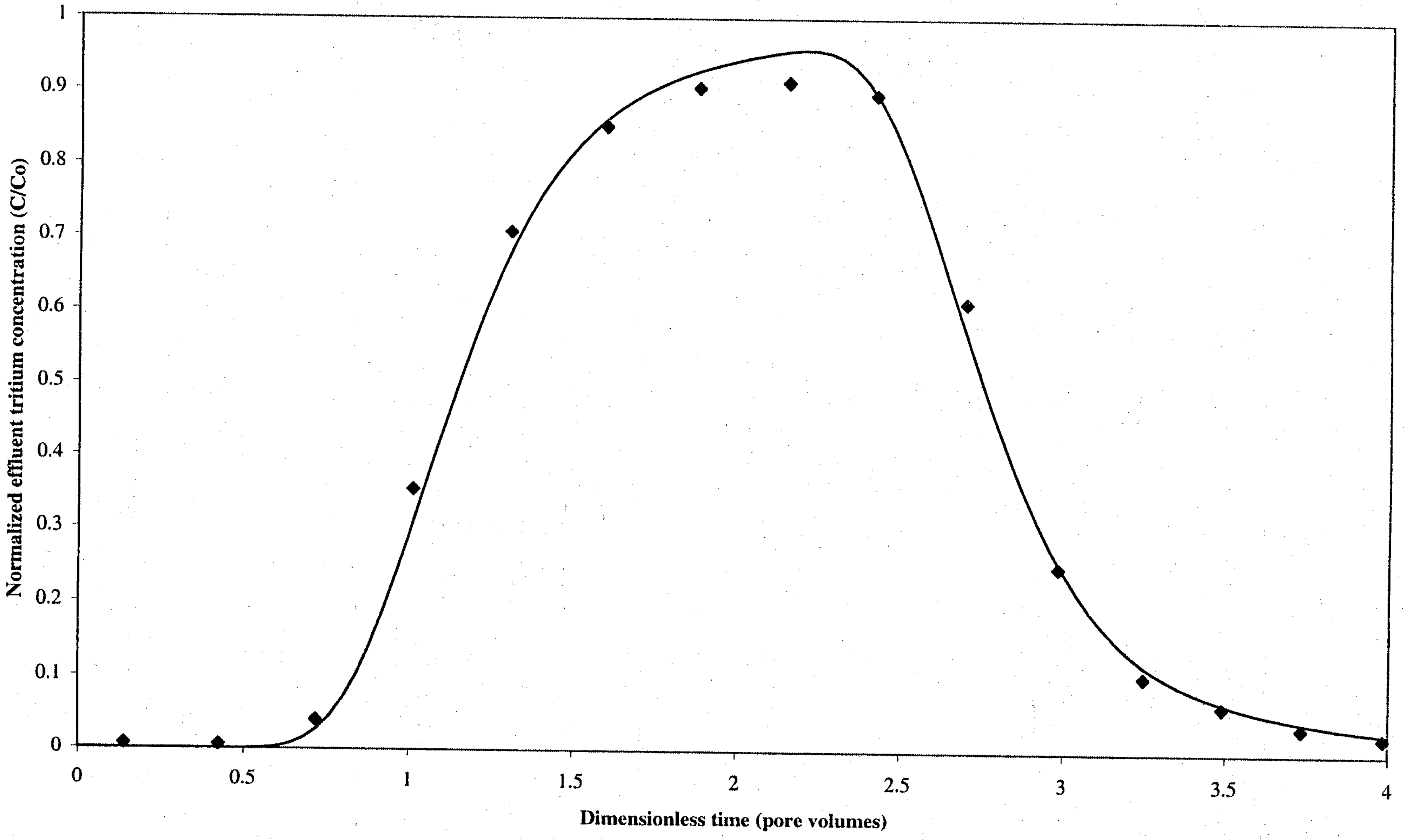


Figure C-10. Breakthrough curve for second tritium tracer test in column B2.

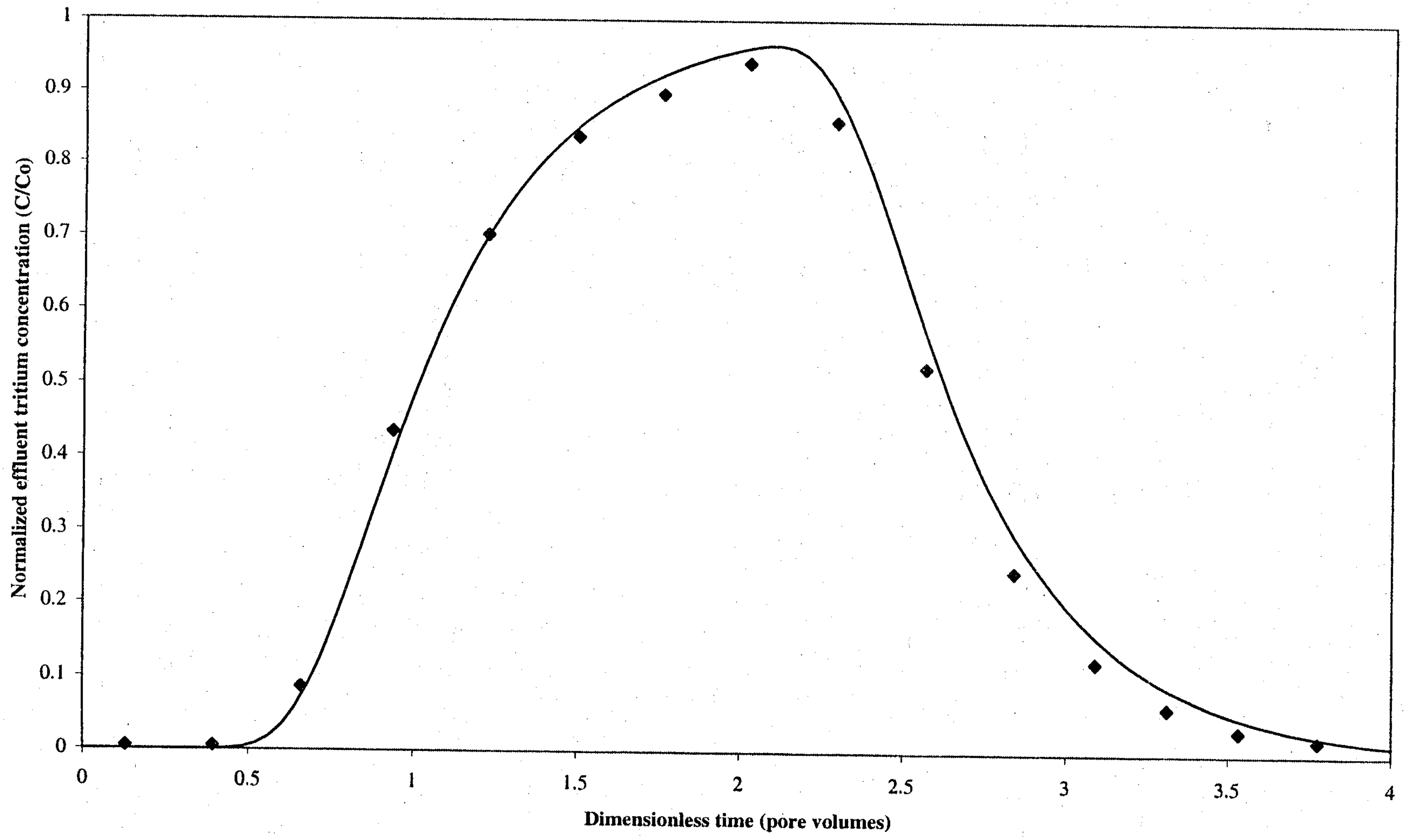


Figure C-11. Cr K-edge XANES for sediment from the middle of column NC2.

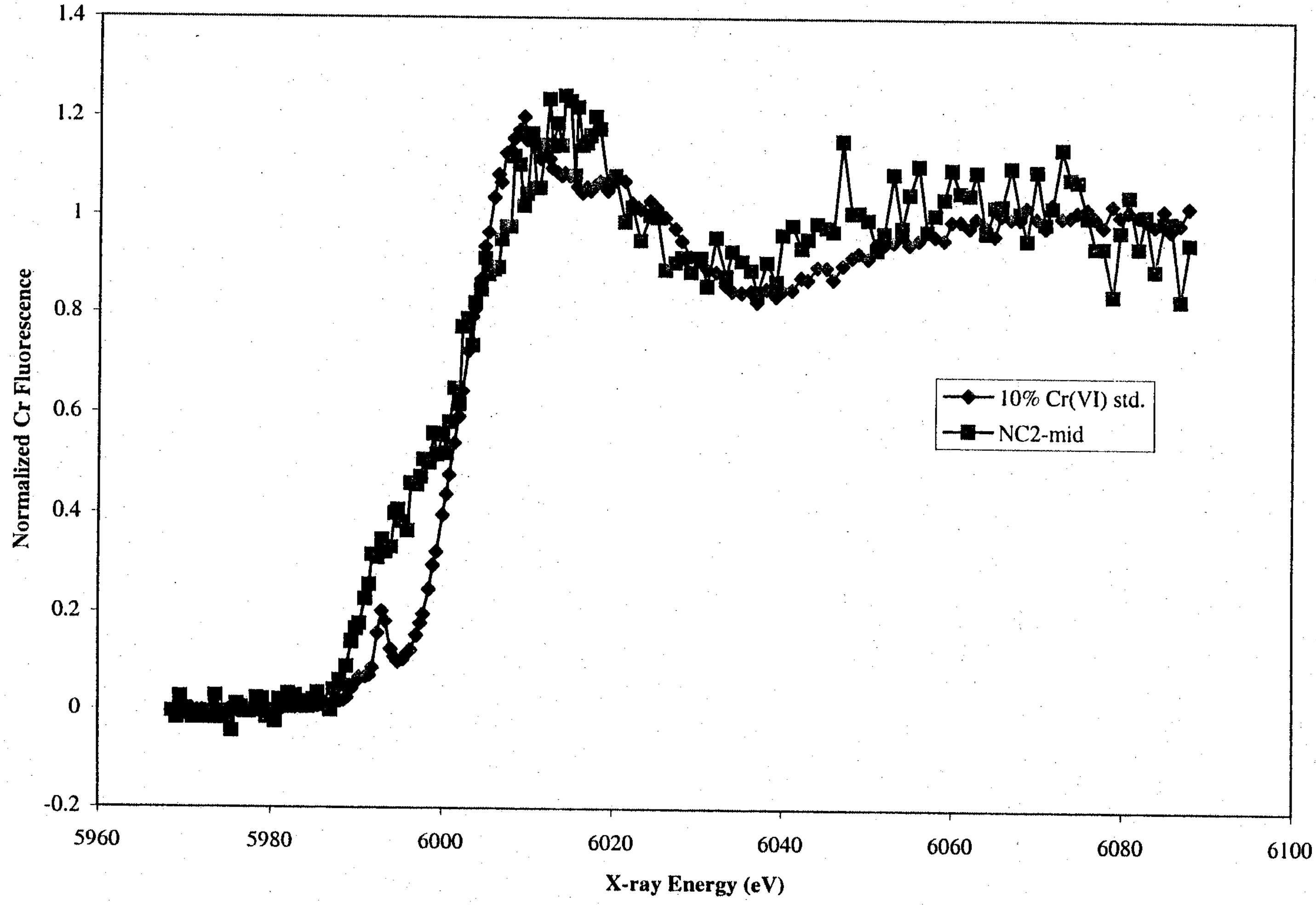


Figure C-12. Cr K-edge XANES for sediment (0.42-0.84 mm) from the bottom of column NC2.

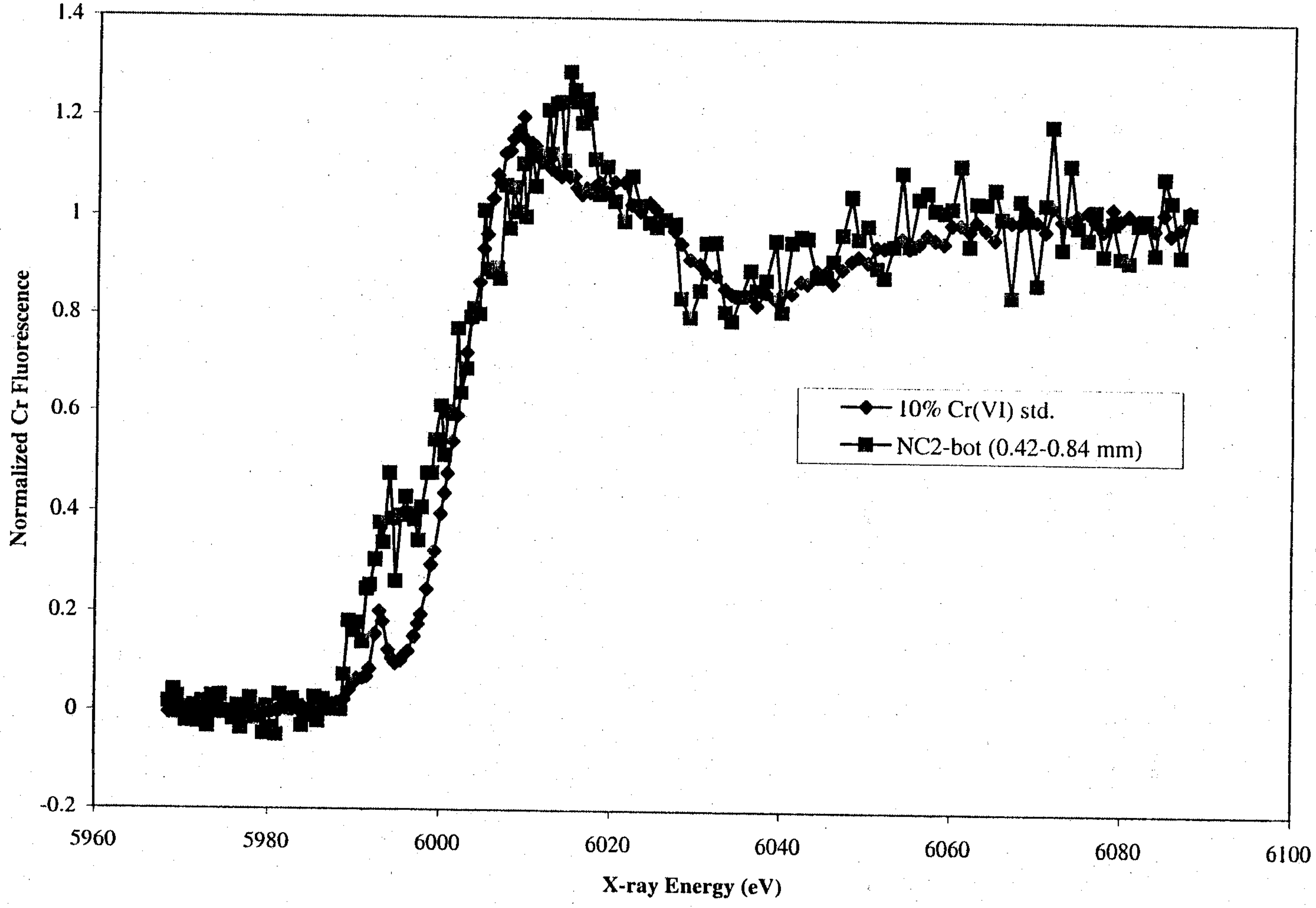


Figure C-13. Cr K-edge XANES for sediment (0.15-0.42 mm) from the bottom of column NC2.

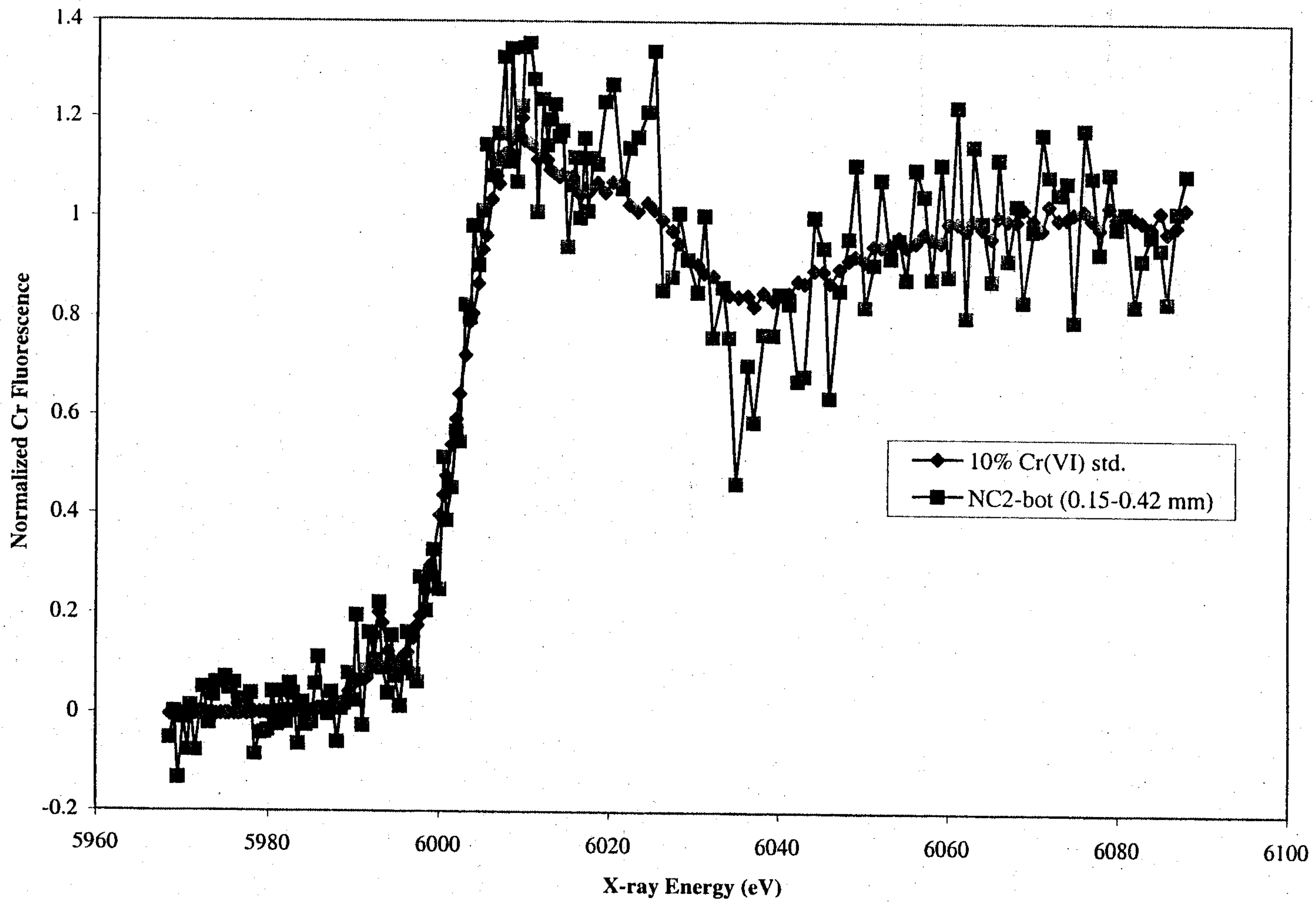


Figure C-14. Cr K-edge XANES for sediment (<0.15 mm) from the bottom of column NC2.

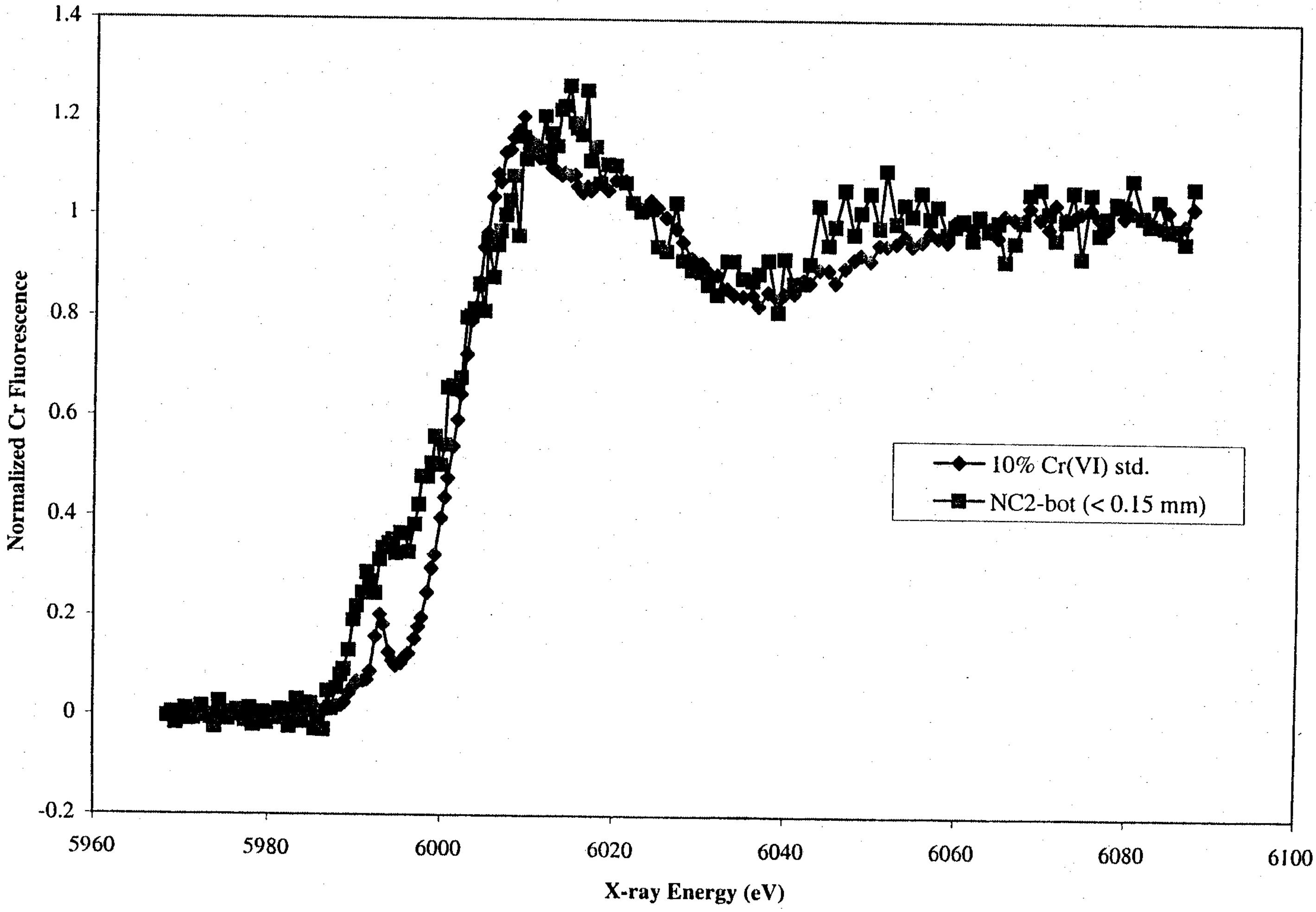


Figure C-15. Cr K-edge XANES for sediment (0.42-0.84 mm) from the top of column B2.

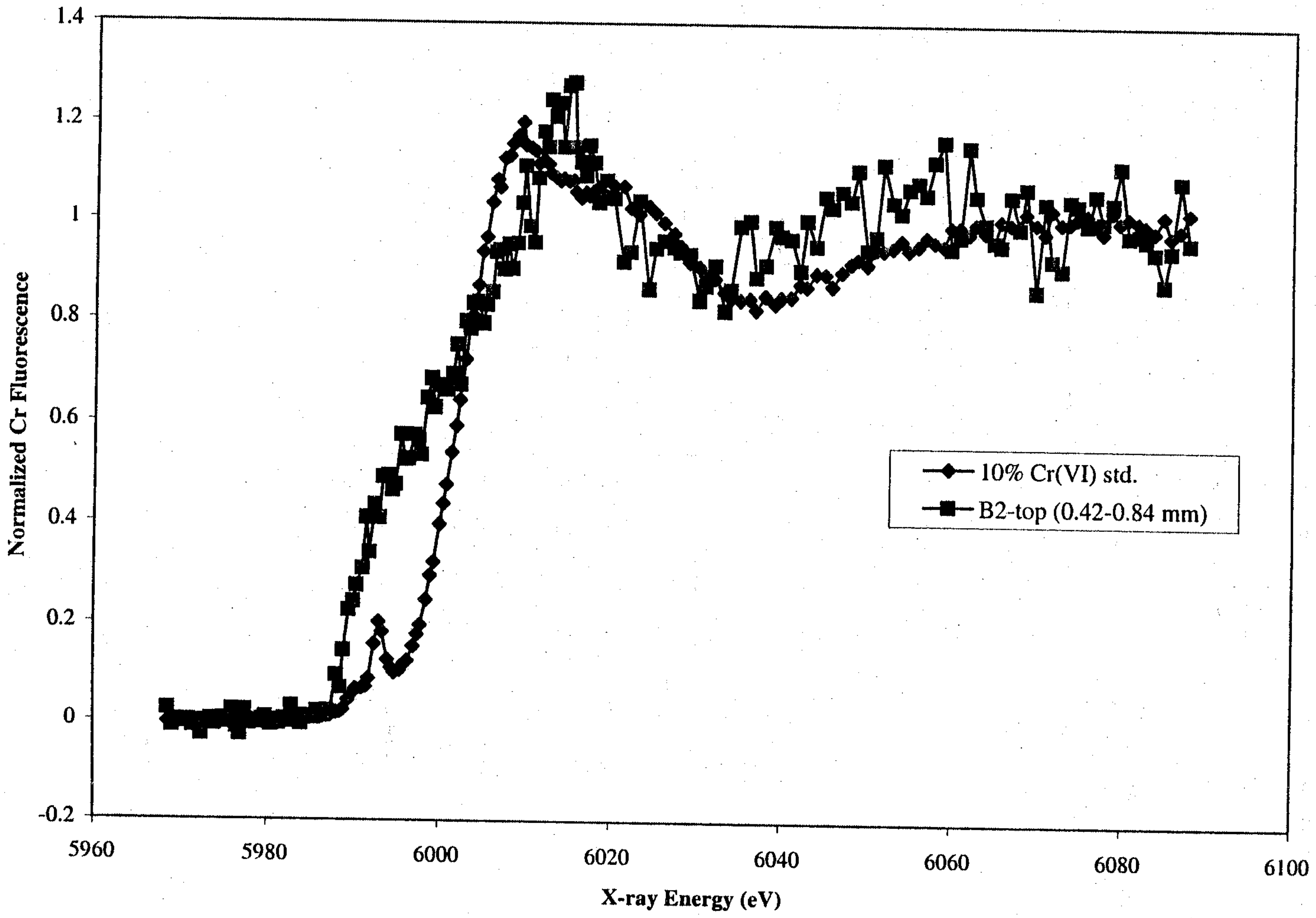


Figure C-16. Cr K-edge XANES for sediment (0.15-0.42 mm) from the top of column B2.

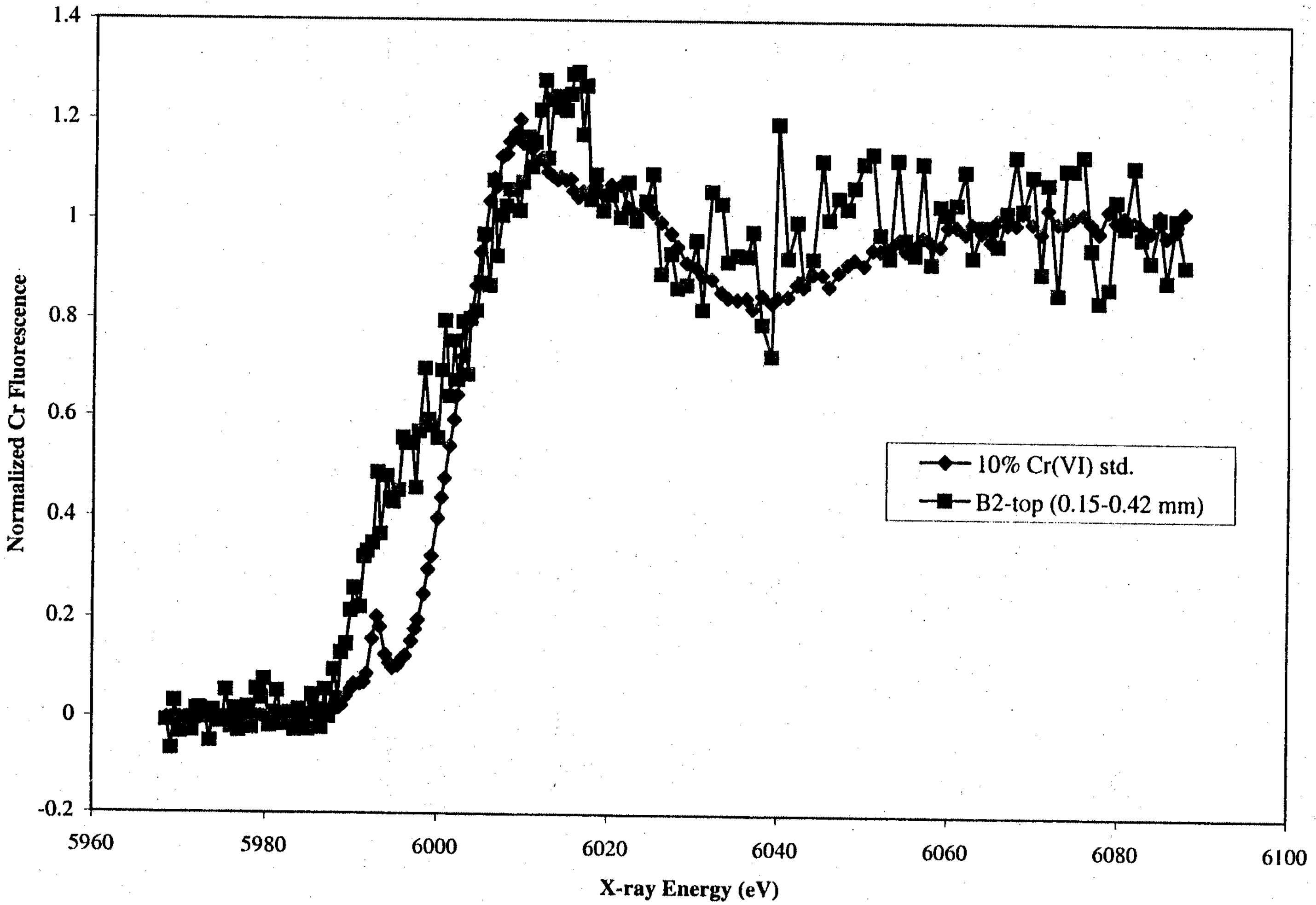
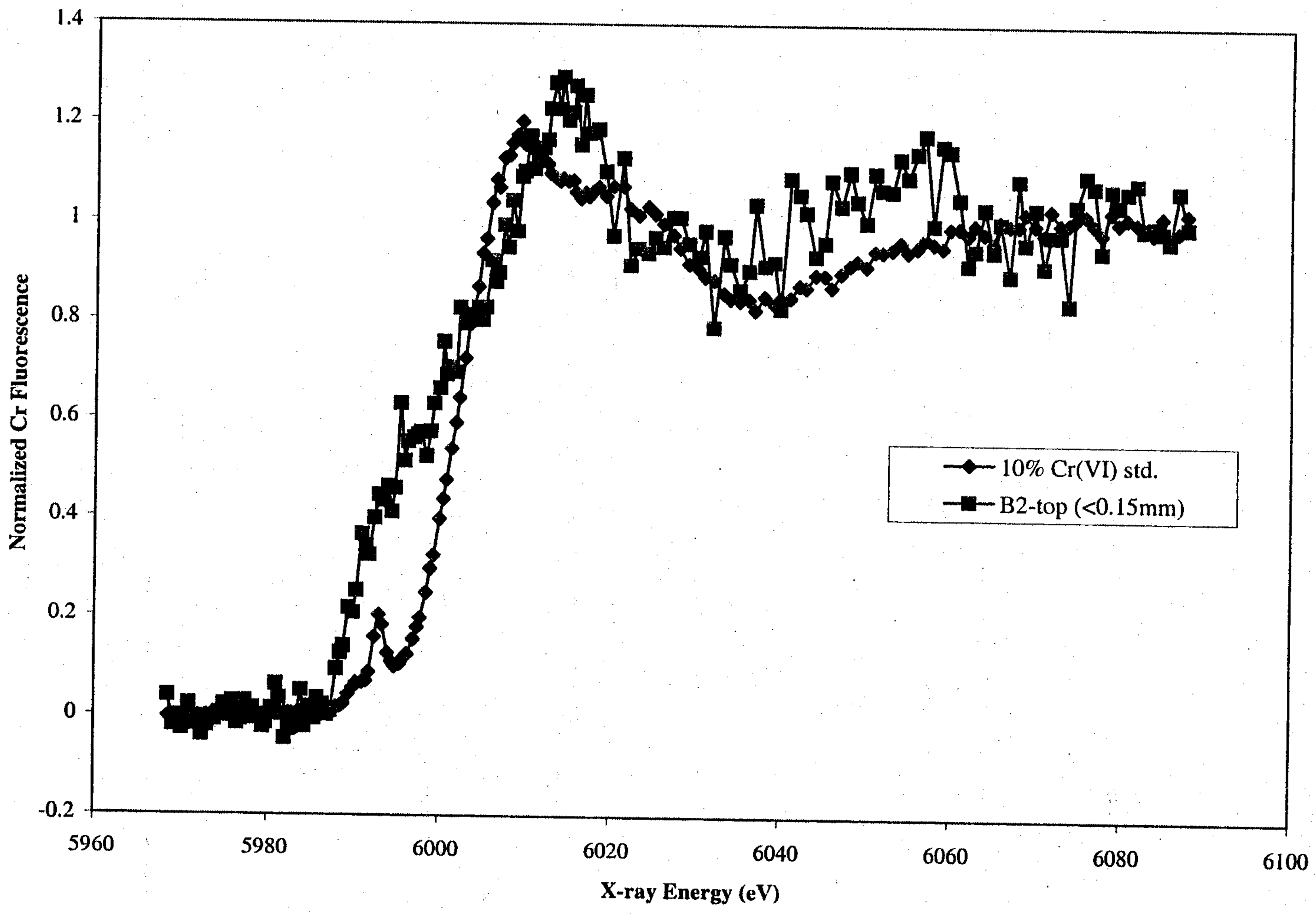


Figure C-17. Cr K-edge XANES for sediment (<0.15 mm) from the top of column B2.



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