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Metal fluxes across the sediment-water interface in Terrace Reservoir, Colorado

by

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Executive Summary

Product: U.S. Geological Survey Open-File Report 96-040, 1996:
Metal fluxes across the sediment-water interface in Terrace Reservoir, Colorado

The exchange or flux of dissolved metals across the sediment-water interface was examined at three sites in Terrace Reservoir, Conejos County, Colorado during June, July, August, September 1994 and June 1995. This report presents the approaches used for determining dissolved fluxes across the sediment-water interface, field sampling and laboratory methods, analytical results, and results of flux calculations. In addition, there are discussions addressing the direction and magnitude of dissolved copper (Cu), zinc (Zn), cobalt (Co), and manganese (Mn) fluxes in Terrace Reservoir, the significance of those fluxes relative to transport of dissolved metal by inflowing or outflowing Alamosa River water, and the influence of sorption of dissolved metal by iron oxyhydroxide surfaces and pH variations within the reservoir on the direction and magnitude of those fluxes.

Form of Product: USGS Open-File Report 96-040, Typed Report, 8½ x 11 inches, 92 pages, including 17 tables and 28 figures.

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Conversion Factors

Measurement values in the International (metric) System (meter/kilogram units) used in this report may be converted to the U.S. Customary System (inches/pounds units) by using the following factors:

To convert from	To	Multiply by
centimeter (cm)	inch (in)	0.3937
meter (m)	foot (ft)	3.281
	yard (yd)	1.094
kilometer (km)	mile (mi)	0.6214
kilometer^2 (km^2)	mile^2 (mi^2)	0.3861
gram (g)	ounce avoirdupois (oz avdp)	0.03527
kilogram (kg)	pound avoirdupois (lb avdp)	2.205
liter (L)	quart (qt)	1.057

Degree Celsius (°C) is converted to degree Fahrenheit (°F) as follows: °F = 1.8(°C) + 32

Abbreviations

The following terms and abbreviations also are used in this report:

day (d)
hour (hr)
micrograms per liter (µg/L)
micrometer or micron (µm)
milligrams per liter (mg/L)
millimeter (mm)
parts per billion (ppb) is the same as µg/L
parts per million (ppm) is the same as mg/L
rpm (revolutions per minute)
year (y)

Chemical elements or species are as follows:

aluminum (Al)
ammonia (NH_4)
arsenic (As)
antimony (Sb)
boron (B)
barium (Ba)
beryllium (Be)
calcium (Ca)
cadmium (Cd)
cesium (Cs)
chloride (Cl)
chromium (Cr)
cobalt (Co)
copper (Cu)
iron (Fe)
lead (Pb)
lithium (Li)
magnesium (Mg)
manganese (Mn)
mercury (Hg)
molybdenum (Mo)
nickel (Ni)
nitrate (NO_3)
potassium (K)
silicon (Si)
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sodium (Na)
sulfate (SO_4)
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titanium (Ti)
vanadium (V)
zinc (Zn)

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Introduction

Underground workings and past open-pit mining activities at the Summitville Mine in the San Juan mountains of southwestern Colorado have produced highly acidic, metal-enriched drainage. The studies of Plumlee and others (1995a) during 1990 to 1994 (i.e., before and during remediation of the mine site) indicate that pH values of waters draining adits, waste dumps, or seeps near the mining pit were between 1.7 and 3.8. Dissolved concentrations of metals in these waters ranged from hundreds to thousands of mg/L for Fe and Al, tens to hundreds of mg/L for Cu and Zn, and hundreds of µg/L to tens of mg/L for As, Cd, Cr, Co, Ni, and rare earth elements. Plumlee and others (1995b) have suggested that the geology and associated geochemistry of the Summitville area can account, in part, for present and future environmental problems. Critical geochemical factors contributing to environmental problems in the Summitville area include the abundance of acid-generating sulfide minerals such as pyrite, the formation and dissolution of soluble metal salts such as iron and copper sulfates, the low buffering capacity of the host rocks, and the alteration and permeability of the deposit.

Some of the water draining the Summitville mine site flows into the Wightman Fork, which in turn, enters the Alamosa River (Fig. 1a). Other tributaries draining highly mineralized areas both above and below the confluence of the Alamosa River and Wightman Fork also contribute to the acidic, metal-enriched drainage carried by the Alamosa River (Kirkham and others, 1995; Bove and others, 1995).

Terrace Reservoir is the only reservoir on the mainstem of the Alamosa River. It is located about 19 km downstream of the confluence of the Wightman Fork and Alamosa River at an elevation of about 2610 m above sea level (Fig. 1a). It was constructed in 1912 by damming the Alamosa River canyon. The reservoir is approximately 2.9 km long and varies from 45 to 430 m in width (Fig. 1b). The Alamosa River enters the reservoir at the northwest end. The level of the water in the reservoir is regulated by inflow due to runoff and by controlled release through a bottom-draining dam at the southeast end. Depths are deepest in the spring and shallowest in the fall.

Terrace Reservoir is a repository for metal-enriched sediments carried by the Alamosa River. Surface sediments in Terrace Reservoir contain many elements (Al, As, Cd, Cu, Fe, Hg, Pb, Sb, and Zn) that are enriched relative to background samples in the United States (Horowitz and Elrick, 1995; Horowitz and others, in review). The water in Terrace Reservoir is primarily used for the irrigation of alfalfa, barley, and wheat and is a source of drinking water for sheep and cattle in the southwestern part of the San Luis Valley. Recent work indicates that Cu concentrations of soils irrigated with water from Terrace Reservoir are statistically higher than control samples, but within the range of geochemical baselines observed in other soils from the western United States (Erdman and others, 1995; Stout and Emerick, 1995). In addition, levels of Cu and Mn in alfalfa grown in fields irrigated with Terrace Reservoir water and used as cattle feed are higher than in control samples, but below the maximum tolerable levels for cattle (Erdman and others, 1995).

Virtually nothing is known about the transport and cycling of metals in Terrace Reservoir. In 1994, the U. S. Environmental Protection Agency funded the U.S. Geological Survey to collect basic data concerning metal distributions in the water and sediment column, define the transport of dissolved metals between the water column and porewater of the sediment, estimate the volume of sediments, and provide information about processes controlling metal distributions in the Reservoir. Primary constituents of concern in the Alamosa River, as identified by Morrison and Knudsen Corporation (1994), are Al, Cd, Cu, Fe, Mn, and Zn. Information from the Terrace Reservoir study will be used by others to develop remediation plans for the reservoir.

This report addresses one component of the Terrace Reservoir study; specifically, the transport of dissolved metals between the water column and the porewater of the sediment. The direction of this transport is needed to assess whether the sediments supply dissolved metals to the water column or remove them from the water column. The magnitude of this transport is necessary for assessing how important the exchange of metals across the sediment-water interface is relative to other processes affecting metal distributions in the reservoir (e.g., loading caused by inflow of metal-enriched Alamosa River water). In addition, this report examines pH dependent sorption of dissolved metals by Fe oxyhydroxide phases as a possible mechanism for controlling the exchange of dissolved metals between porewater and the water column in Terrace Reservoir. Information about other components of this study can be found in Edelmann and Ferguson (in review), Horowitz and others (in review), Stogner and Edelmann (in review), and Watts, (in review).

Theory of determining dissolved metal fluxes across the sediment-water interface

This section discusses two approaches for determining the flux or exchange of dissolved metals across a sediment-water interface. The first approach calculates the flux using Fick's First Law whereas the second approach directly measures the flux using a benthic flux chamber. Both approaches were used in this study to provide information about the mechanism of transport (i.e., diffusion versus bioturbation and irrigation) and because each method has its own advantages and disadvantages as outlined below. In addition, generalized cases concerning the direction of metal fluxes are presented. Note that the specific details of sample collection and analyses used to determine fluxes in Terrace Reservoir are discussed in the Methods section and Appendix I.

Fluxes calculated from Fick's First Law

The determination of fluxes from Fick's First Law is quite simple in theory. Fick's First Law defines the exchange of dissolved elements across the sediment-water interface by molecular diffusion; i.e.,

$$J_s = -\Phi D_s [\partial C/\partial x] \qquad (1)$$

where J_s is the flux (g cm^{-2} d^{-1}), Φ is the porosity at the sediment-water interface, D_s is the diffusion coefficient for the element in the sediment (cm^2 d^{-1}), and $\partial C/\partial x$ is the concentration gradient of the element across the sediment-water interface (g cm^{-4}) (Berner, 1980). The diffusion coefficient in the sediment (D_s) is related to the molecular diffusion coefficient in water (D_0) as follows:

$$D_s = D_0/(\Phi F) \qquad (2)$$

where F is the sediment resistivity and, for high porosity sediments, can be approximated as Φ^3 (Ullman and Aller, 1982). Values of D_0 at infinite dilution for a variety of ions are tabulated in Li and Gregory (1974). These values are temperature corrected using the Stokes-Einstein relationship (Li and Gregory, 1974). Thus, one needs to measure the porosity of the sediments and the concentration gradient of elements across the sediment-water interface.

The fluxes are then calculated from these data and using temperature corrected literature values for the diffusion coefficients.

The gradient is determined by measuring the dissolved concentration of an element in the water column and in porewater just below the sediment-water interface (Fig. 2). Ideally, one needs to measure the concentration of elements in the porewater within millimeters both above and below the sediment-water interface for an accurate diffusive flux calculation. In reality, the concentration gradient can be difficult to determine because of limits in sampling resolution across the interface. Other potential concerns with determining this gradient are:

1) disturbing the sediment-water interface during sampling. Care must be taken to maintain the integrity of the interface during sample collection.

2) extracting porewater from the sediments. Several methods can be used to separate porewater from sediments (Hesslien, 1976; Murray and Grundmanis, 1980; Bender and others, 1987; Jahnke, 1989). These methods include pressure squeezing the core, slicing sediment sections and centrifuging them to separate sediment and porewater, in-situ dialysis using peepers, and in-situ suction using harpoons. Small sample volumes result from these methods when fine resolution near the sediment-water interface is required.

3) maintaining in-situ redox conditions. These conditions are required to maintain the in-situ speciation of elements (e.g.; to eliminate possible oxidation of ferrous Fe (Fe^{2+}) and precipitation of Fe oxyhydroxides). In-situ redox conditions can be maintained by performing all sample manipulations in a glove bag with an oxygen free environment.

Fluxes determined from benthic flux chambers

Benthic flux chambers, commonly known as landers, are designed to directly measure changes in the concentrations of dissolved elements across the sediment-water interface as a function of time. These chambers eliminate problems with determining concentration gradients across the interface. In addition, fluxes determined from these chambers account for enhanced fluxes (i.e., greater than those due to molecular diffusion) caused by bioturbation and irrigation by benthic organisms.

The design and operation of benthic flux chambers are discussed in Smith and others (1976) and Devol (1987). Briefly, a benthic flux chamber consists of a box that isolates a volume of water in contact with the sediments (Fig. 3). A known amount of an inert tracer (e.g., KCl, CsCl, or tritium) is added to determine the volume of the trapped water. This isolated water is gently stirred and sampled using spring actuated syringes as a function of time. Sampling is electronically controlled with a multi-event programmable timer (i.e., tattletale) in a pressure case and is accomplished using "dissolving link" releases. The need for highly specialized electronics and long deployment times are the main disadvantages of benthic flux chambers.

Temporal changes in the dissolved concentration of an element in the box and the area and volume of the chamber are used to calculate the flux of the element across the sediment-water interface:

$$J_s = [V/A][\partial C/\partial t] \qquad (3)$$

where J_s is the flux (g cm^{-2} d^{-1}), V is the volume of the benthic flux chamber box (L), A is the area of the box (cm^2), and $\partial C/\partial t$ is the change in concentration of the element in the box as a function of time (g L^{-1} d^{-1}). Comparisons of fluxes calculated from Fick's First Law and measured by benthic flux chambers in environments devoid of benthic organisms are in good agreement suggesting that:

1) diffusion, not bioturbation or irrigation, is the primary mechanism of transport of ions across the interface in environments with no benthic organisms;

2) benthic flux chamber measurements are determining exchange across the sediment-water interface rather than processes only occurring in the trapped water, and

3) the method of isolating water overlying the sediment does not appear to significantly influence the exchange of elements across the interface (Devol, 1987).

Flux direction and magnitude: Generalized cases

The driving force for the exchange of elements across the sediment-water interface is the difference in concentration of the element in the porewater and in the water column. Ions diffuse from higher concentrations to lower concentrations. Thus, the direction of the flux depends on the relative magnitude of the concentrations on either side of the interface. The magnitude of the flux depends on the difference in concentration across the interface; the larger the difference, the greater the flux.

There are three scenarios for the direction of fluxes across the sediment-water interface. Each of the three cases and the associated water column/porewater or benthic flux chamber observations are discussed below.

Case I (positive flux): Dissolved metal is transferred from the porewater to the water column when metal concentrations in the porewater are greater than those in the water column. In this case the sediments act as a source for dissolved metal. The field observations are that water column concentrations are lower than in the porewater and that concentrations in the benthic flux chamber increase as a function of time (Fig. 4a,d).

Case II (negative flux): Dissolved metal is transferred from the water column to the porewater when metal concentrations in the water column are greater than those in the porewater. In this case the sediments act as a sink for dissolved metal. The field observations are that metal concentrations in the porewater are less than those in the water column and that concentrations in the benthic flux chamber decrease as a function of time (Fig. 4b,e).

Case III (no flux): No dissolved metal is transferred between the porewater and the water column when the concentrations of metal in the porewater and water column are equal. The sediments do not act as either a source or a sink for dissolved metal. The field observations for this case are that the concentration of metal in the porewater is the same as in the water column and that concentrations in the benthic flux chamber do not change as a function of time (Fig. 4c,f).

Methods

Field sites

Three sites in Terrace Reservoir were established for sampling the water and sediment column (Fig. 1b). One site (T5; 37°22.13'N 106°18.31'W) was located in the upstream portion or riverine zone of the reservoir. This site was the shallowest; water depths ranged from 1.2 to 11.3 m during our samplings. The second site (T2B; 37°21.46'N 106°17.50'W) was located about mid-reservoir. Depths at this site varied from 12.5 to 22.2 m. The deepest site (T1A; 37°21.43'N 106°17.9'W) was located near the dam at depths of 20.1 to 30.5 m. Flux determinations and water column measurements were made at these sites during the weeks of

June 13, July 18, August 15, September 26, 1994, and June 5, 1995.

Water column sampling

The profiling and water column sampling and results are discussed in detail elsewhere (Stogner and Edelmann, in review). Briefly, each site was profiled for pH, temperature, dissolved oxygen, and specific conductance using an in-situ multimeter prior to collection of three to four water column samples. One of the water column samples was collected as close as possible to the bottom of the reservoir without disturbing the bottom sediments. These deepest samples will be referred to as bottom water (BW) samples throughout the remainder of this report. Only the results from the dissolved (<0.4 μm) bottom water samples are presented in this report as they are used to calculate fluxes.

Water column samples were collected with a 4 L, non-metallic hydrobottle, transferred into plastic churns, and transported to a field-based laboratory that was located about 3.2 km upstream of the reservoir. At the laboratory, portions of the water samples were filtered through 0.45 μm filters into acid-cleaned plastic bottles. The samples were then acidified to pH < 2 using concentrated nitric acid and kept on ice during transport to the analytical laboratory.

Of particular interest to the flux study is that oxygen was present in the bottom water samples during all collection times and that the underflow from the Alamosa River appeared to act as a river in itself within the Reservoir. Thus, there are both vertical and horizontal gradients of temperature and pH within the reservoir.

Sediment and porewater sampling

Three sediment cores were collected at each site after the water column profiling and sampling were completed. The sediment cores were collected in pre-washed, acid-cleaned 10.2 cm diameter, acrylic butyrate core liners placed in a gravity corer. The gravity corer was slowly lowered into the sediment to avoid disturbance of the sediment-water interface. Visual examination of the interface upon retrieval of the cores indicated that there was very little, if any, disturbance. The lengths of the cores varied from about 0.3 to 0.9 m. The cores were kept upright and carefully transported to the field-based laboratory.

Two cores were sectioned for sediment and associated porewater within 8 to 24 hours of collection while the third was reserved as a backup. For the cores that were sectioned, the water overlying the sediment was first siphoned off to within 1 to 10 cm of the interface using tygon tubing. A sample of this overlying water was then taken with a 10 mL plastic syringe. These samples are referred to as overlying water (OW) throughout the remainder of this report. Note that they are distinct from the bottom water samples collected with the hydrobottle. The cores were extruded and sectioned into 0.5 cm (0-2 cm), 1 cm (2-4 cm), and 2 cm (4-6 cm) intervals in a nitrogen-filled glove bag. The glove bag was used to eliminate any possible oxidation of the porewater samples. Because only the very surface sediment and associated porewater were needed for flux determinations, only the upper 6 cm, at most, were extruded and sectioned. The individual core sections were then placed in nitrogen-filled 50 mL centrifuge tubes. For one core, subsamples of sediment were also placed into pre-weighed glass vials for the determination of water content. The centrifuge tubes were removed from the glove box and centrifuged at 1500 rpm for 20 minutes to separate porewater and sediment. The tubes were then returned to the glove box. Porewater then was extracted with pre-cleaned 10 mL plastic syringes and filtered through 10 mm or 25 mm, 0.4 μm Nuclepore filters. All filters, except those used in June 1994, were loaded into pre-cleaned Swinnex holders in a laminar flow clean hood at the School of Oceanography, University of Washington in Seattle, Washington before the sampling trip. Filters used in June 1994 were loaded at the field laboratory during the sampling trip. Porewater volumes ranged from 6 to 21 mL depending on the interval size and porosity of the sediment. One mL portions of unfiltered porewater were placed into 5 mL polystyrene test tubes for pH measurements while 5 mL filtered portions were placed into acid-cleaned 30 mL polyethylene bottles for metal determinations. During the June 1995 sampling, 1 mL portions of porewater were also taken for alkalinity and anion determinations, if there was sufficient volume. The porewater samples were removed from the glove box and pH measurements were immediately made using an Orion model 290A meter and Orion semi-micro combination electrode standardized with pH buffers of 4.0, 7.0, and 10.0. The porewater metal samples were acidified to pH < 2 with re-distilled, concentrated nitric acid. Alkalinity samples collected during June 1995 were determined in the field by Gran titrations using 0.01 N hydrochloric acid (Stumm and Morgan, 1981). Porewater and associated sediment samples were then packed for transport to the analytical laboratory. The third core was typically extruded in the open air onto a plastic sheet and split open length wise. There was no sulfide smell in any of the extruded cores.

Benthic flux chamber

The benthic flux chamber used in this study consisted of a teflon-coated, stainless-steel box with an area of 412 cm^2 and a hinged lid. A magnetically coupled, solid state motor in the lid stirred the trapped water at 60 rpm. Four 50 mL spring-actuated plastic syringes were used to sample the trapped water. In addition, a spring-actuated glass syringe was used to inject a known volume of a 90 mM KCl tracer. This tracer was used to determine the volume of water in the box. Total volumes trapped by the box were between 1.9 and 3.2 L. The six "dissolving link" releases sequentially closed the lid, sampled the box for the initial metal concentrations, injected the tracer, and then sampled the box at 5, 10, and 15 hour intervals. Because of problems with the electronics, the benthic flux chamber samples were obtained only in July and August, 1994 and for 0 and 5 hours in June, 1995.

The sample volumes from the benthic flux chamber ranged from 33 to 41 mL. Unfiltered portions were taken for pH (1 mL) and filtered (47 mm, 0.4 μm Nuclepore filter) portions were collected for anions (5-10 mL), nutrients (15 mL), and metals (5-10 mL) determinations. Measurements of pH were done immediately upon arrival at the field-based laboratory. Nutrient samples were placed on ice for transport to the analytical laboratory. Metal samples were acidified to pH < 2 using redistilled, concentrated nitric acid and packaged along with anion samples for transport to the analytical laboratory.

Laboratory Analyses

As noted above, the volumes of the porewater samples were very small (6-21 mL). The 0.5 cm intervals typically had the lowest volumes. This problem was anticipated before the project began and a priority for analyses of porewater was established. Determination of metals in the porewater was the highest priority. Because of costs, these metal analyses were done by inductively coupled plasma-atomic emission spectrometry (ICP-AES) versus inductively coupled plasma-mass spectrometry (ICP-MS). The tradeoff was that the ICP-AES analyses required a volume of at least 5 mL. The second priority was pH and these measurements required 1 mL. The third and fourth priorities were sulfide and alkalinity, respectively. Each of these analyses required 1 mL. There was insufficient volumes, especially for the upper 0.5 cm sections, to do more than metal and pH determinations. Although data concerning other constituents in the porewater (e.g., oxygen, dissolved ferrous Fe (Fe^{2+}) and ferric Fe (Fe^{3+}), nutrients) would have added to our understanding of processes occurring in the sediments of Terrace Reservoir, there were insufficient volumes of porewater to do these analyses.

The dissolved concentrations of 24 major ions and metals were determined in all water samples by inductively coupled plasma-atomic emission spectrometry (ICP-AES). The samples were not concentrated prior to analysis. Detection limits for the ICP-AES analyses are given in Table 1. Sulfate and chloride were determined by ion chromatography. Metal and anion concentrations in overlying water, porewater, and benthic flux chamber samples were determined by the U.S. Geological Survey, Geologic Division, Analytical Chemistry Services Group in Denver, Colorado (Arbogast and others, 1990) whereas the metal concentrations in the bottom water samples were determined by the Environmental Protection Agency, ESD laboratory in Denver, Colorado. Nutrient (i.e., ammonia and the sum of nitrate and nitrite) concentrations were determined by Quanterra Laboratory in Denver, Colorado using standard aquatic colorimetric methods (Strickland and Parsons, 1972).

Total metal contents of sediment samples from one core per site per sampling (specifically, core 2) were determined using modifications of the methods of Horowitz and others (1989). Briefly, dried sediment was digested in a combination of HF, $HClO_4$, and aqua regia in Teflon beakers at 200^0C. The resulting salts were dissolved in 2% HCl and analyzed for 11 elements by ICP-AES. Determinations of As and Sb concentrations were made on similarly digested sediment. However, the resulting salts were dissolved in 50% HCl. As and Sb were determined by hydride generation atomic absorption spectrometry (HG-AAS) after addition of urea and oxalic acid/hydroxylamine solutions and reduction by KI. Hg was determined by cold vapor HG-AAS after the dried sediment was digested by aqua regia at 100^0C. Standard reference materials were included with the samples and one duplicate per core was done. Sediment analyses were done in the U.S Geological Survey Sediment-Trace Element Laboratory, Water Resources Division, in Atlanta, Georgia. Water content for core 2 was determined as the difference between wet and dried (100 ^0C) weights. Porosity was calculated assuming a water density of 1 g cm^{-3} and a dried sediment density of 2.65 g cm^{-3}, a value close to that of average crustal material and used by Pedersen (1983) in a lacustrine mine tailings deposit.

A partial chemical extraction was done on the surface sediments in Terrace Reservoir in order to estimate the reactive fraction of metals. These geochemical partitioning data were needed to assess the importance of sorption as a process for controlling metal fluxes across the interface. Wet surface sediments (0-0.5 cm) from core 1 at all sites and for all sampling times were leached with 1 M HCl for 16 hours at room temperature following the procedure of Huerta-Diaz and Morse (1990). This operationally defined reactive fraction likely contains iron monosulfides, amorphous and crystalline iron oxyhydroxides, manganese oxides, carbonates, and hydrous aluminosilicates (Huerta-Diaz and Morse, 1992). The leach solution was analyzed for Co, Cu, Fe, Mn, and Zn by atomic absorption spectrometry (AAS) in a laboratory at the School of Oceanography, University of Washington in Seattle, Washington.

Chain-of-custody procedures were followed during the collection, transport, analysis, and storage of all samples. In addition to the quality assurance (QA) and quality control (QC) procedures of the individual laboratories, the field study quality control included the submission of procedural blanks, duplicates (if there was sufficient volume), and control samples (i.e., two previously collected river samples) for each batch of overlying water, porewater, and benthic flux chamber samples from a given sampling time. Procedural blanks for the cores were treated the same as overlying water and porewater and consisted of distilled, de-ionized water that was put into 50 mL centrifuge tubes, suctioned with 10 mL plastic syringes, passed through 0.4 μm Nuclepore filters into 30 mL polyethylene bottles, and then acidified to pH < 2 using redistilled, concentrated nitric acid. Blanks for the benthic flux chamber samples consisted of distilled, de-ionized water placed in 50 mL syringes, passed through a 0.4 μm Nuclepore filters into 30 mL polyethylene bottles, and then acidified to pH <2 using redistilled, concentrated nitric acid.

Results

Water column and porewater

Bottom water, overlying water, and porewater data are tabulated for each site and each sampling time in Tables 2 through 6. The samples are coded with the station identification preceded by a 1, 2, 3, 4, or 5 (e.g., 2T5 or 4T1A) that represents the consecutive sampling trips (i.e., 1 = June 1994, 2 = July 1994, 3 = August 1994, etc.). The number 1 or 2 after the station identification (e.g., T51 or T1A2) indicates the specific core from each site. Note that the upper 2.5 cm of core 1 is sectioned into 0.5 cm intervals whereas the upper 6 cm of core 2 is sectioned into intervals of 0.5 cm (0-2 cm), 1 cm (2-4 cm), and 2 cm (4-6 cm). The porewater data indicate that major and only a few minor (Co, Cu, Fe, Mn, and Zn) elements are present at concentrations above the detection limits of the ICP-AES.

Concentrations of elements in blank samples processed during the sampling of porewater are also presented in Tables 2 through 6. In general, 1 or 2 blanks were done with each set of cores from a given site. These blank samples include contamination from centrifuge tubes, syringes, filters and acid. The concentrations of most elements in these blanks are below the detection limits of the ICP-AES indicating no contamination. The exceptions are discussed by sampling date as follows:

- June 1994: Measurable concentrations (i.e., above the ICP-AES detection limits) in the blanks associated with the processing of certain cores are observed for Fe, Mn, Si, and Zn. Fe concentrations in the blank for T5 cores are < 2% of the measured Fe concentrations in the porewater. For the T2B blank, Fe concentrations in the overlying water and 0-0.5 cm interval for core 2 are lower or slightly above the blank levels indicating contamination; the other data indicate that the Fe blank is < 6.1% for the overlying water and < 2.5% of the porewater concentrations. Blank concentrations of Mn for the T5 cores are < 1% of either the overlying water or porewater. The Si blanks for all cores are < 1.6% of the overlying and porewater concentrations. The Zn blanks for all cores collected during June 1994 are high.

Although the porewater data show downcore trends that are consistent with data from other sampling times when Zn blank concentrations were below the ICP-AES detection limits, the porewater Zn data from June 1994 are not included in the flux calculations due to the high Zn concentrations in the blank.

- July 1994: Measurable concentrations of Ba, Fe, Mn, and Si are observed in the blanks for this sampling time. The porewater Ba data for T2B and T1A cores is questionable because the blank concentrations are either higher than or at most one third of most of the porewater concentrations. Fe concentrations in blanks are < 2.8% of the overlying water or porewater concentrations. The Mn and Si concentrations in the blank for T2B cores are, respectively, < 1.4% and < 1% of the overlying water or porewater concentrations.

- August 1994: Measurable concentrations of Al, Ca, Fe, Mn, Na, and Si are observed in the blanks. Most of the Al concentrations in the porewater, except in the T51 core, are at or near the blank levels. However, these blank concentrations are only 1.5 to 2.9 times the detection limits of the ICP-AES. The Ca, Mg, Na, and Si concentrations in the blanks are, respectively, < 2.1%, < 2.2%, < 5.9%, and < 1.6% of the overlying or porewater concentrations. Blank concentrations of Mn are < 2.4% of the overlying water or porewater for cores T5 and T2B. Only one of the Mn blank concentrations for core T1A was significant and amounted to about one half of the overlying water concentration. Fe concentrations in blank samples for T5 indicate that the overlying water and 0-0.5 cm porewater data for Fe in core 1 are questionable. The Fe data for T1A indicate that one blank concentration is about equal to or greater than the overlying water samples and most of the porewater data for core 1.

- September 1994: Measurable concentrations of Al, Ca, Fe, Mn, Na, and Si also are observed in the blanks for this sampling time. Most of the Al concentrations in porewater are either at or within a factor of 4 of the blank concentrations. The Ca, Mg, Mn, Na, and Si concentrations in the blanks are, respectively, < 1.3%, < 1.9%, < 4.4%, < 4%, and < 1.8% of the overlying or porewater concentrations. Fe concentrations in the blanks are < 7.3% of the overlying water and porewater for cores T5 and T1A. One blank sample for T2B has a high Fe concentration while the other one is < 2.8% of all Fe data for overlying water and porewater, except the 0-0.5 cm sample for core 1.

- June 1995: There are no measurable concentrations of elements in any of the blank samples for this sampling time.

Benthic flux chamber

Data from the benthic flux chamber samples and associated procedural blanks are summarized in Table 7. Once again, only major ions and a few minor elements (Co, Cu, Fe, Mn, and Zn) are present at concentrations above the detection limits of the ICP-AES. Concentrations of most elements in the blanks are below instrumental detection limits indicating no contamination. The exceptions for July 1994 are Fe and Mn. Blanks for Fe and Mn are, respectively, < 17% and < 4.8% of the concentrations in the benthic flux chamber. The exceptions for August 1994 are Al, Fe, Mn, and Si. Concentrations of Al, Fe, Mn, and Si account for, respectively, up to 30%, < 20%, < 1%, and < 1.2% of the concentrations in the benthic flux chamber. Subtraction of these blank values from the benthic flux chamber data makes no difference on the flux calculations because it is the slope or change in concentration as a function of time that is used to determine the fluxes.

Control samples

Water samples collected in June 1993 from the Wightman Fork and from the Alamosa River about 2 km upstream of Terrace Reservoir were used as control samples. These samples were submitted to the laboratory with the overlying water and porewater samples for each sampling period. Although they are not standard reference materials, the results provide an indication of the consistency of the data over the long term. The major ion and metal data for these control samples are presented in Table 8. Better detection limits were obtained when these samples were analyzed during the Terrace Reservoir study as compared to when they were originally submitted to the laboratory in June 1993 as part of a wetland study (Balistrieri and others, 1995a,b). Precision of the analyses is presented in Table 8 for elements whose concentrations are above the detection limits of the ICP-AES. Precision is generally poor when the concentration of an element is close to the detection limits of the ICP-AES (e.g., Al and Fe for sample 1SWG1FA). In general, the long term precision for minor elements (Co, Cu, Fe, Mn, and Zn) at concentrations much greater than the detection limits of the ICP-AES is between 4.1 and 10%.

Sediment

The porosity and metal content of the sediments from core 2 at each site and for each sampling are presented in Tables 9 through 13.

The 1 M HCl leach data for selected metals in the surface sediments of Terrace Reservoir are summarized in Table 14.

Discussion

The discussion will focus on the behavior of minor elements whose concentrations in the porewater and benthic flux chamber samples were above the detection limits of the ICP-AES. These elements include Co, Cu, Fe, Mn, and Zn. Four of these elements (Cu, Zn, Fe, and Mn) have been identified as primary constituents of concern in the Alamosa River (Morrison and Knudsen Corporation, 1994).

Comparison of dissolved Cu, Zn, Co, and Mn fluxes determined from Fick's First Law and benthic flux chamber data

Details concerning the flux calculations from water column and porewater data using Fick's First Law and from the benthic flux chamber data are presented in Appendix I. Fluxes calculated from core data can be used to predict changes in dissolved metal concentrations as a function of time. These predicted changes reflect transport due to molecular diffusion because they are based on fluxes calculated from Fick's First Law. These predictions can be compared to measured concentration changes observed in the benthic flux chamber. Recall that benthic flux chamber measurements include transport due to diffusion and any other operating processes (e.g., benthic irrigation). Thus, a comparison of these two approaches provides information about the mechanism of transport across the sediment-water interface.

In general, both the direction and magnitude of dissolved metal fluxes in Terrace Reservoir are in good agreement for the two methods (Figs. 5 through 8). These comparisons indicate that transport of dissolved metals across the sediment-water interface in Terrace Reservoir occurs primarily by diffusion. Benthic activity, if present, does not appear to influence exchange of dissolved metals across the sediment-water interface.

There are some exceptions to the good agreement between fluxes calculated from Fick's First Law and derived from benthic flux chamber data. For example, data from core 2 at the mid-lake site (T2B) indicate that the sediment is a source for dissolved Cu while data from core 1 and the flux chamber indicate that the sediment is a sink (Fig. 5). The same can be said for dissolved Zn data at site T1A in July 1994 and the second deployment of the flux chamber in June 1995 where core and flux chamber data indicate opposite directions for the flux (Fig. 6). These variations might be explained by observed horizontal gradients in pH and metal concentrations within the reservoir and the heterogeneity of the sediments. These differences are compounded by the difficulty of re-occupying exactly the same spot at each site.

Direction and magnitude of dissolved Cu, Zn, Co, and Mn fluxes

The direction and magnitude of dissolved metal fluxes at each site as a function of time are summarized in Table 15 and Figures 9 through 12. The direction of the dissolved Cu fluxes at site T5 were generally (4 out of 5 measurements) from the water column into the sediment porewater during June and July 1994 (Fig. 9). All Cu fluxes at site T5 after that time were out of the sediment porewater and into the water column. At sites T2B and T1A, the sediment acted as a sink for Cu (16 out of 19 measurements) in the summer and early fall of 1994. The flux of Cu at these sites changed direction, i.e., the sediment acted as a source, in June 1995. Values of most (87%) of the dissolved Cu fluxes from the porewater at all sites ranged from 100 to 510 µg cm^{-2} y^{-1}, while the magnitude of all fluxes into the porewater varied from 160 to 690 µg cm^{-2} y^{-1}. Fluxes of dissolved Zn at sites T5 and T1A followed a similar pattern to those of Cu, especially with respect to the timing of the changes in direction (Fig. 10). At site T2B, 4 out of 6 measurements from cores and overlying water indicated that the sediment is a source of dissolved Zn. The single benthic flux chamber determination at this site in August 1994 indicated no flux of Zn. Almost all (92%) of the dissolved Zn fluxes from the porewater were between 17 to 300 µg cm^{-2} y^{-1}, while all fluxes into the porewater ranged from 4 to 280 µg cm^{-2} y^{-1}. Twenty three out of 28 determinations of flux for dissolved Co and 35 out of 36 for Mn indicated that the sediment was a source for these elements (Figs. 11 and 12). The magnitude of dissolved Co and Mn fluxes from the porewater was between 0.8 to 30 µg cm^{-2} y^{-1} and 0.1 to 6.8 mg cm^{-2} y^{-1}, respectively. The magnitude of dissolved Co and Mn fluxes out of the porewater into the water column tended to decrease from the shallow site (T5) to the deep site (T1A).

How does the direction and magnitude of fluxes across the sediment-water interface in Terrace Reservoir compare with similarly determined fluxes in other mining impacted areas? Several previous studies have determined the flux of dissolved Cu and Zn across the sediment-water interface in aquatic systems impacted by mining activities (Pedersen, 1983; Carignan and Tessier, 1985; Carignan and Nriagu, 1985; Tessier and others, 1989; Pedersen and others, 1993; Williamson and Parnell, 1994). The sites in these studies either received acid mine drainage or mining tailings from nearby mining activities or atmospheric deposition from nearby smelters. Most of the flux determinations in these studies were based on a few cores from a single lake where the pH in the water column did not vary. The exception being the study by Tessier and others (1989) that examined cores from 40 lakes with a pH range from 4 to 8.4. In contrast, flux determinations in Terrace Reservoir were based on multiple determinations at three sites during 5 sampling times when the pH in the water column ranged from 4.2 to 7.2. The dissolved Cu and Zn fluxes determined in previous studies are compared with those in Terrace Reservoir in Table 16. Most previous studies in mining impacted areas indicated that the sediments acted as a sink for dissolved Cu and Zn and that the magnitudes of these fluxes were < 5.1 and < 16 μg cm^{-2} y^{-1}, respectively. Pacheta Lake was the exception because the sediment porewater acted as a source of dissolved Cu and Zn (Williamson and Parnell, 1994). Fluxes of dissolved Cu and Zn in Terrace Reservoir indicated that the sediment acted as a sink for these elements; however, at other times the sediment porewater acted as a source for dissolved Cu and Zn. Fluxes across the sediment-water interface in Terrace Reservoir tended to be from the porewater to the water column when the pH of the water column was > 5.5 and into the porewater from the water column when the pH of the water column was < 5.5. Similar observations were made by Tessier and others (1989) in their study of 40 Canadian lakes. In addition, the magnitude and range of Cu and Zn fluxes in Terrace Reservoir were much greater than in the other systems. This latter observation is likely due to much greater dissolved metal concentrations in the water column of Terrace Reservoir as compared to the other sites.

Significance of dissolved Cu, Zn, and Mn fluxes

The importance of dissolved metal fluxes from the porewater to the water column in Terrace Reservoir can be evaluated by considering the magnitude of other fluxes that contribute to dissolved metal concentrations in the water column. A box model that defines the fluxes of dissolved metal into and out of the water column of an aquatic system is illustrated in Figure 13. This model and our corresponding calculations assume that the reservoir is well mixed. This assumption is clearly an oversimplification as there were strong thermal gradients in the reservoir from mid-May through August, 1994 (Stogner and Edelmann, in review). A more complex model that incorporates this stratification needs to be developed in future work. The fluxes that add dissolved metal to aquatic systems include wet and dry atmospheric deposition, inflow from rivers, and transport from the porewater to the water column. The fluxes that remove dissolved metal from the water column include outflow by rivers, transport from the water column to the porewater, and transformations of dissolved to particulate phases (e.g., precipitation or sorption). Although all fluxes that contribute to metal concentrations in Terrace Reservoir were not evaluated during the Terrace Reservoir study (e.g., atmospheric deposition or transformations from dissolved to particulate phases), data from other components of the study can be used to calculate the flux of dissolved metal due to inflow from the Alamosa River and outflow through the dam. These values then can be compared with dissolved metal fluxes from and to the sediment porewater.

The fluxes of dissolved metal in Terrace Reservoir due to inflow and outflow are calculated using the loading data for dissolved Cu, Zn, and Mn presented in Edelmann and Ferguson (in review) and the bathymetry of the reservoir (Watts, in review). Data for Co loadings are not summarized in the work of Edelmann and Ferguson (in review); hence, fluxes are not presented for this element. The inflow and outflow flux calculations are based on metal concentrations and streamflow at Alamosa River sites located upstream (site

AR34.5) and downstream (site AR31.0) of the reservoir and the surface area of the reservoir during sampling.

$$J_{flow} = L_{Me}/A \qquad (4)$$

where J_{flow} is the flux due to inflow or outflow (g cm^{-2} d^{-1}), L_{Me} is the loading of dissolved metal (g d^{-1}), and A is the surface area of the reservoir at the time of sampling (cm^2). These flux calculations are done for each day during the same 5 weeks we determined the transport of dissolved metal across the sediment-water interface.

The significance of the sediment porewater as a source of dissolved metal to the reservoir relative to the supply of dissolved metal by inflowing Alamosa River water is illustrated in Figure 14. These comparisons indicate that the porewater source of both Cu and Zn was < 28% of the supply from inflowing Alamosa River water during the summer and early fall of 1994. The porewater source of dissolved Mn, however, was more significant (up to 72%) during this period. The significance of the sediments as a sink for dissolved Cu, Zn, and Mn relative to outflow from the reservoir is presented in Figure 15. The loss of dissolved Cu, Zn, and Mn to the sediments is at most 20% of the loss due to outflow from the reservoir. Thus, the supply (or loss) of dissolved Cu and Zn due to exchange across the sediment-water interface is not as important as the supply (or loss) of these metals due to inflow (or outflow). The supply of dissolved Mn from the porewater to the water column, however, can be significant relative to inflow from the Alamosa River.

It should be noted that these comparisons are done for time periods (June through September 1994) when the water column in Terrace Reservoir was acidic and had high dissolved metal concentrations. These conditions imply large loadings of dissolved metals to the reservoir from the Alamosa River. The loading data for June 1995 at the upstream Alamosa River site, when the reservoir was nearer to neutral and had lower dissolved metal concentrations in water overlying the cores (Table 6), are not currently available. The lower dissolved metal concentrations at that time imply lower dissolved metal loadings from the Alamosa River. The dissolved Cu and Zn fluxes from the sediment porewater during June 1995 do not appear to be significantly smaller than during other sampling times (Figs. 9 and 10). Thus, the significance of the sediment porewater as a source of dissolved Cu and Zn relative to inflow from the Alamosa River may be greater when the pH of the reservoir is near neutral as compared to acidic.

Sorption on Fe oxyhydroxides as a process affecting dissolved metal fluxes across the sediment-water interface

A review by Santschi and others (1990) examines the various physical, microbiological, and chemical processes that affect the partitioning of elements between the sediment and water column. It is the coupling of such processes that result in the flux of elements across the sediment-water interface. Physical processes include diffusion, bioturbation by benthic organisms, re-suspension and settling of particles, coagulation, and aggregation. Microbiological processes primarily involve transformations of carbon, oxygen, nitrogen, Mn, Fe, and sulfur during early diagenesis (i.e., oxidation) of organic matter. Chemical processes include sorption, complexation by dissolved ligands, precipitation-dissolution, and abiotic oxidation-reduction. The following discussion will focus on two of these processes. First we will examine the behavior of Fe in the surface sediments of Terrace

Reservoir. Then we will discuss how sorption of dissolved metals by Fe oxyhydroxides and changes in the pH of the water column relative to the porewater of Terrace Reservoir influence the flux of dissolved Cu, Zn, and Co across the sediment-water interface.

Decomposition or oxidation of particulate organic matter primarily occurs at the sediment-water interface and within the sediments. Studies of diagenesis of organic matter in a variety of environments, including areas impacted by mining activities, indicate that organic matter oxidation proceeds using a thermodynamically predicable sequence of oxidants - oxygen, nitrate, Mn oxyhydroxides, Fe oxyhydroxides, and sulfate (Froelich and others, 1979; Berner, 1980; Pedersen and Losher, 1988; Sherman and others, 1994). The signatures of these reactions in the porewater of sediments are the sequential disappearance of oxygen and nitrate and the appearance of dissolved Mn, Fe, and sulfide as a function of depth (Fig. 16). Oxygen is the oxidant for organic matter decomposition in the oxic zone. Suboxic conditions exist when oxygen concentrations are very low. Organic matter decomposition within this zone primarily occurs by the reduction of nitrate, Mn oxyhydroxides, and Fe oxyhydroxides. The anoxic region is characterized by no oxygen and oxidation of organic matter by sulfate. The reduction of sulfate by organic matter results in the production of sulfide. This sulfide either appears in the porewater or is precipitated as a metal sulfide if there are sufficient dissolved metal (primarily Fe) concentrations. The depth scale over which these reactions occur can be large (meters) or small (millimeters to centimeters) depending on environmental conditions (e.g., sedimentation rate or supply of organic matter). Increases in dissolved Mn and Fe concentrations as a function of depth in the porewater of Terrace Reservoir indicate that reduction of Mn and Fe oxyhydroxide phases during organic matter diagenesis and the transition between oxic and suboxic conditions occur within a few centimeters below the sediment-water interface (Figs. 17 and 18). The behavior of Fe across this transition zone is critical to understanding how Fe cycling affects the flux of dissolved metals across the sediment-water interface.

Iron exists as ferric Fe (Fe^{3+}) in oxic environments. This ion is highly insoluble and forms solid phase Fe oxyhydroxides (FeOOH). Ferrous Fe (Fe^{2+}) is the dominant form of iron in suboxic environments. This ion is soluble, i.e., dissolved, except in the presence of sulfide. The behavior of Fe in the upper centimeters of Terrace Reservoir sediments is governed by transitions between ferric and ferrous Fe (i.e., oxidation and reduction reactions). The reduction of solid phase Fe (Fe^{3+}) oxyhydroxides during organic matter diagenesis in the suboxic region produces dissolved Fe (Fe^{2+}) and alkalinity, if calcium carbonate does not precipitate:

$$\text{organic matter} + \text{FeOOH} \rightarrow Fe^{2+} \text{ and alkalinity} \qquad (5)$$

The production of dissolved Fe in the suboxic zone and low dissolved Fe concentrations in the oxic region produce a concentration gradient across the oxic-suboxic interface. Dissolved Fe^{2+} diffuses from the suboxic to the oxic region, is oxidized to Fe^{3+} by oxygen, and then precipitated as Fe oxyhydroxides. The net effect of these reactions is the production of solid phase Fe oxyhydroxides and protons:

$$Fe^{2+} + \text{oxygen} \rightarrow \text{FeOOH} + \text{protons} \qquad (6).$$

The above series of reactions and the resulting chemical signatures in the porewater and sediment are depicted in Figure 19 using data collected in Terrace Reservoir at site T5 during June 1995. Dissolved concentrations of Fe are low in the oxygenated water column and increase in the porewater just below the sediment-water interface (Fig. 19a). The corresponding increase in alkalinity in the porewater suggests that dissolved Fe is produced by the reduction of Fe oxyhydroxides during organic matter diagenesis in the suboxic region (Fig. 19b,c). These observations indicate that the transition from oxic to suboxic conditions occurs just below the sediment-water interface (Fig. 19c). The gradient or change in dissolved Fe^{2+} concentrations with depth in the sediments results in the diffusion of dissolved Fe^{2+} from depth towards the interface. The increase in solid phase Fe (coupled with observations of a red orange floc in the surface sediments) and decrease in pH just below the sediment-water interface indicates the oxidation of Fe^{2+} diffusing from depth and precipitation of Fe oxyhydroxides (Fig. 19). Thus, the pH of porewater just below the interface tends to be more acidic than pH values deeper in the sediment column and is likely controlled by the precipitation of Fe oxyhydroxides. These Fe oxyhydroxides tend to have large surface areas and strong sorption capacities for metal ions (Davis and Leckie, 1978; Dzombak and Morel, 1990).

It is now widely recognized that sorption reactions play an important role in regulating the concentrations of certain trace elements in aquatic systems (e.g., Schindler, 1975; Balistrieri and others, 1981; Sigg, 1987; Honeyman and Santschi, 1992), including mining impacted environments (Tessier and others, 1985, 1989; Johnson, 1986; Smith and others, 1992). Sorption of metals by particles is dependent on pH, the concentration and type of particles and metal, and the composition of the solution. Metal oxides, in particular Fe and Mn oxyhydroxides, have been shown to have a strong affinity for trace elements (e.g., Benjamin and Leckie, 1981; Balistrieri and Murray, 1982; Catts and Langmuir, 1986; Dzombak and Morel, 1990). Various mathematical models have been developed to describe this complexation between metals and surfaces of metal oxides (Davis and Kent, 1990; Dzombak and Morel, 1990).

The sorption of a dissolved divalent metal (Me^{2+}) by an oxide surface site (S-OH) can be defined by the following reaction (e.g., Benjamin and Leckie, 1981; Balistrieri and Murray, 1983):

$$\text{S-OH}_x + \text{Me}^{2+} \rightleftharpoons \text{S-OMe}^+ + x\text{H}^+ \qquad (6)$$

where x is the number of protons (H^+) released per metal ion sorbed and S-OMe^+ is the surface bound metal. The equilibrium constant (K) describing the above reaction is defined as:

$$K = (\{\text{S-OMe}^+\}(\text{H}^+)^x)/(\{\text{S-OH}_x\}[\text{Me}^{2+}]) \qquad (7)$$

where { } indicate concentration in moles g^{-1}, ( ) indicate activity of the proton in moles L^{-1}, and [ ] indicate concentration in moles L^{-1}. This constant is an apparent overall equilibrium constant because it depends on the solution composition and assumes an average binding energy for the heterogeneous surface sites on the oxide.

Tessier and co-workers (Tessier and others, 1985; Tessier and others, 1989) and Johnson (1986) have used a simplified version of the above apparent equilibrium constant to describe the regulation of metals by sorption onto Fe oxyhydroxides phases in lakes and in a river system impacted by acid mine drainage. We will use their approach to examine the partitioning of Cu, Zn, and Co between the dissolved phase and surface sediments in Terrace Reservoir.

An apparent constant ($K_{Fe\text{-}Me}$) dependent on pH can be defined from equation 6 as:

$$K_{Fe\text{-}Me} = K/(H^+)^x = \{S\text{-}OMe^+\}/(\{S\text{-}OH_x\}[Me^{2+}]) \qquad (8).$$

If Fe oxyhydroxides dominate the composition of surface sediments in Terrace Reservoir and the number of free surface sites ($S\text{-}OH_x$) is approximately equal to the number of total surface sites (i.e., $S\text{-}OH_x >>$ sites bound by metals or other ions), then:

$$\{S\text{-}OH_x\} = n^*\{Fe_p\} \qquad (9)$$

where $\{Fe_p\}$ is the moles of particulate Fe oxyhydroxides per g of surface sediment and n is the moles of surface sites per mole of particulate Fe oxyhydroxides. Substituting equation 9 into equation 8 results in:

$$K_{Fe\text{-}Me} = (n^*K)/(H^+)^x = \{S\text{-}OMe^+\}/(\{Fe_p\}[Me^{2+}]) \qquad (10).$$

A plot of log $K_{Fe\text{-}Me}$ versus pH should yield a straight line with a slope of x and an intercept of log(n*K).

Values of $K_{Fe\text{-}Me}$ for Cu, Zn, and Co interactions with Terrace Reservoir surface sediments were calculated by:

1) assuming that dissolved Cu^{2+}, Zn^{2+}, and Co^{2+} ions in the water column of the Reservoir interact with the very surface sediment,

2) determining the free Cu, Zn and Co (i.e., Cu^{2+}, Zn^{2+}, and Co^{2+}) concentrations from the measured dissolved concentrations in the bottom water of the Reservoir using the total composition of the bottom water (Tables 2-6) and the chemical speciation computer program, HYDRAQL (Papelis and others, 1988) (see Table 14 for summary of free metal concentrations), and

3) assuming that $\{S\text{-}OMe^+\}$ and $\{Fe_p\}$ are equal to the metal concentrations obtained from the 1 N HCl leach of the surface sediments of Terrace Reservoir (Table 14).

Technically, we should use the dissolved Cu, Zn, and Co concentrations in the porewater recovered from the 0-0.5 cm interval rather than the bottom water in the Reservoir. However, we are interested in the interaction of metals with the very surface sediments and the 0-0.5 cm interval is too coarse. In addition, we are also interested in the ability to predict consequences (i.e., adsorption or desorption) based on changes in the composition of the bottom water in the Reservoir. Metal concentrations in the water overlying the cores were used for the June 1995 calculations because data for the bottom water are not yet available. Dissolved Co concentrations in the overlying water were below detection limits for the June 1995 sampling. Upper limits for these values were estimated to be 70% of the detection limits for the calculations of $K_{Fe\text{-}Me}$.

The speciation calculations considered the formation of metal complexes with hydroxyl (OH^-), chloride (Cl^-), and sulfate (SO_4^{2-}) anions and the effect of ionic strength. The concentrations of anions were not measured in the bottom waters of the Reservoir, but were determined in selected porewater samples. Good correlations ($r^2 > 0.93$) were found between measured dissolved concentrations of major ions (Ca^{2+}, Mg^{2+}, Sr^{2+}, K^+, and Na^+) and sulfate in porewaters for $[SO_4^{2-}] < 200$ ppm. Because the best relationship was between potassium and sulfate, dissolved concentrations of sulfate for the bottom waters of the Reservoir were estimated from the relationship with potassium ($[SO_4^{2-}](\text{ppm}) = ((85\pm6)^*[K^+](\text{ppm})) - (17\pm13)$; $r^2 = 0.96$; $n = 12$; for $[SO_4^{2-}] < 220$ ppm)(Fig. 20a). A good correlation was also found between measured dissolved chloride and sulfate concentrations in porewaters (i.e., $[Cl^-](\text{ppm}) = ((0.0123\pm0.0004)^*[SO_4^{2-}](\text{ppm})) + (0.11\pm0.45)$; $r^2 = 0.98$; $n = 15$) (Fig. 20b), and was used to estimate dissolved concentrations of chloride in the bottom waters of the Reservoir.

Values of log $K_{Fe\text{-}Me}$ describing sorption of Cu, Zn, and Co on the Fe oxyhydroxides in surface sediments of Terrace Reservoir are plotted versus pH in Figure 21. The apparent constants ($K_{Fe\text{-}Me}$) for the metals become larger as pH increases; i.e., the affinity of the metal for the surface sediment increases as the pH increases. In addition, binding of Cu by the surface sediment is greater than that for either Zn or Co at a given pH. Both observations are consistent with laboratory experiments that examine the sorption of cations on well-defined Fe oxyhydroxide phases (e.g., Dzombak and Morel, 1990). Thus, strong correlations between log $K_{Fe\text{-}Me}$ and pH, patterns of increasing $K_{Fe\text{-}Me}$ with increasing pH, and the relative affinity of the surface for Cu, Zn, and Co suggest that dissolved concentrations of these elements in Terrace Reservoir may, in part, be controlled by sorption reactions with Fe oxyhydroxides at the sediment-water interface.

The question now arises as to how the measured fluxes of dissolved Cu, Zn, and Co across the sediment-water interface are influenced by sorption reactions. As noted above, sorption is highly pH dependent. The calculated apparent constants ($K_{Fe\text{-}Me}$) indicate that there is more dissolved metal at lower pH values than at higher pH values. If the pH of the porewater in a small interval just below the sediment-water interface is less than the pH of the water column, then there should be higher concentrations of dissolved metal in sorptive equilibrium in that porewater relative to the water column. For these conditions, this difference or gradient in dissolved metal concentrations across the interface results in a flux of dissolved metal from the porewater to the water column; i.e., the sediment acts as a source of metal. Conversely, if the pH of the porewater is greater than the pH of the water column, then dissolved metal concentrations in the porewater are less than in the water column and the gradient or flux is from the water column to the porewater. In this case, the sediment acts as a sink for dissolved metal.

To illustrate the above points, we can examine variations in the ratio of the concentration of dissolved free metal, $[Me^{2+}]$, to the concentration of sorbed metal, $\{S\text{-}OMe^{+}\}$, as a function of pH. Equation 10 can be re-arranged to obtain the ratio of dissolved free metal to sorbed metal concentrations in terms of the apparent constant and "reactive" particulate Fe concentration:

$$[Me^{2+}]/\{S\text{-}OMe^{+}\} = 1/(K_{Fe\text{-}Me}*\{Fe_p\}) \qquad (11).$$

This ratio is a function of pH because $K_{Fe\text{-}Me}$ is a function of pH (Fig. 21). Using the relationships between log $K_{Fe\text{-}Me}$ and pH for Cu, Zn, and Co (Fig. 21) and assuming an average "reactive" particulate Fe concentration of 880 μmoles Fe/g of sediment (the actual average of measured values in 1 M HCl leaches of core 1; Table 14), we can determine the concentration ratio for pH values measured in the bottom water and porewater at 0-0.5 cm in Terrace Reservoir. These ratios increase with decreasing pH or, in other words, there is more dissolved metal relative to sorbed metal at low pH values (Fig. 22). Differences between the concentration ratios at pH values of the bottom water and porewater are plotted versus the difference in pH values across the interface in Fig. 23. The differences in the ratios reflect the direction and magnitude of the dissolved concentration gradients, or fluxes, across the interface. When the pH in the bottom water is greater than in the porewater just below the interface, then there is more dissolved metal in the porewater relative to the dissolved metal in the water column. Thus, this gradient in dissolved metal results in a flux of dissolved metal from the porewater to the water column. The case is reversed when the pH in the porewater just below the sediment-water interface is greater than in the bottom water. Then the bottom water has more dissolved metal than in the porewater just below the interface. The corresponding gradient of dissolved metal produces a flux from the water column to the porewater.

The measured fluxes of dissolved Cu, Zn, and Co in Terrace Reservoir are plotted versus the difference in pH between the bottom water and porewater at 0-0.5 cm in Fig. 24. These plots generally are in agreement with the plots derived from the sorption model(Fig. 23). Fluxes for dissolved Cu, Zn, and Co tend to be out of the sediment when the pH of the bottom water is greater than the pH of the porewater just below the interface and into the sediment (Cu and Zn) or near zero (Co) when the relative pH values of bottom water and porewater are reversed. The magnitude of the fluxes for Co are smaller than those for Cu or Zn because of less dependence of Co sorption on pH; i.e., large changes in pH do not have as significant an effect on the partitioning of Co between dissolved and particulate phases as they do for Cu or Zn (Fig. 22).

Thus, fluxes of dissolved Cu, Zn, and Co across the sediment-water interface are closely tied to the behavior of Fe. The cycling of Fe across the oxic-suboxic boundary in the upper surface sediments of Terrace Reservoir influences the pH of the porewater just below the sediment-water interface while sorption of dissolved metals by Fe oxyhydroxides regulates metal concentrations in the porewater. The pH of the water column in the reservoir is, in part, regulated by the acidity of inflowing Alamosa River water while sorption and solubility reactions influence the magnitude of the concentrations of dissolved metals in the water column (Stogner and Edelmann, in review). Therefore, pH is the master variable and sorption reactions play a role in influencing the concentration of dissolved metals in both the water column and porewater. Differences in pH between the water column and porewater just below the sediment-water interface were large during our sampling times (Fig. 25). It is these large pH differences, coupled with sorption reactions that are highly pH dependent, that result in the observed direction and magnitude of fluxes across the sediment-water interface in Terrace Reservoir. These processes are summarized in Figure 26.

Conclusions

1) Fluxes of dissolved Cu, Zn, Co, and Mn were determined at three sites in Terrace Reservoir during 1994 and 1995 using porewater measurements (i.e., Fick's First Law calculations) and benthic flux chamber determinations. These methods were generally in good agreement and suggested that diffusion was primarily responsible for transport of these elements across the sediment-water interface.

2) The direction of dissolved Cu and Zn fluxes depended on the sampling location within the reservoir and the time of sampling. In general, the sediments tended to act as a source of dissolved Cu and Zn at site T5 for most sampling times, while at site T1A the sediment tended to act as a sink for most times. There was a distinct change in direction for both dissolved Cu and Zn fluxes at site T1A in June 1995 when the pH of the reservoir increased to near neutral values. At site T2B, flux direction was variable for dissolved Cu while fluxes of dissolved Zn tended to be from the porewater to the water column. Both dissolved Co and Mn fluxes tended to be near zero or out of the sediment at all sites and for almost all times. The magnitude of exchange of dissolved Cu and Zn between the sediment

and water column is larger in Terrace Reservoir relative to observations in other systems impacted by mining activities or smelters.

3) The significance of the magnitude of dissolved Cu, Zn, and Mn fluxes across the sediment-water interface relative to transport into and out of Terrace Reservoir by the Alamosa River was evaluated for conditions when the water column was acidic. During these periods the supply of dissolved Cu and Zn to the water column was < 28% of the supply by inflowing Alamosa River water. Dissolved Mn fluxes from the sediment, however, could account for up to 72% of the supply by inflowing river water. The significance of the supply of dissolved metal to the water column by transport across the sediment-water interface needs to be evaluated for neutral pH conditions. In addition, a more detailed model that incorporates thermal stratification should be developed.

4) Sorption reactions between dissolved Cu, Zn, and Co and Fe oxyhydroxide phases and differences in pH between the water column and porewater just below the sediment-water interface control the concentration gradients and, hence, directions and magnitudes of dissolved metal fluxes across the interface.

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Appendix I

The details of the flux calculations from core data and benthic flux chamber measurements in Terrace Reservoir are presented in this section.

Core data

Fick's First Law defines the exchange of dissolved elements across the sediment-water interface by molecular diffusion; i.e.,

$$J_s = -\Phi D_s\,[\partial C/\partial x] \qquad \text{(A1)}$$

where J_s is the flux (g cm^{-2} d^{-1}), Φ is the porosity at the sediment-water interface, D_s is the diffusion coefficient for the element in the sediment (cm^2 d^{-1}), and $\partial C/\partial x$ is the concentration gradient of the element across the sediment-water interface (g cm^{-4}) (Berner, 1980).

Estimates of porosity of the sediment were determined from direct measurements of the water content of the sediment. Wet sediment samples were placed in pre-weighed glass vials and sealed to prevent evaporation. Total wet weight (vial and wet sediment) was measured in the laboratory and the samples were then dried at 100°C. Total dry weight (vial and dry sediment) then was determined. The calculations are as follows:

total wet weight - vial weight = wet weight (g) (A2)
total dry weight - vial weight = dry weight (g) (A3)
wet weight - dry weight = water weight (g) (A4)
dry weight/ρ_{sed} = cm^3 dry sediment (A5)
water weight/ρ_{water} = cm^3 water (A6)
Φ = porosity = [cm^3 water/(cm^3 water + cm^3 dry sediment)]*100 (A7)
where:
ρ_{sed} = sediment density = 2.65 g cm^{-3} (Pedersen, 1983)
ρ_{water} = water density = 1.0 g cm^{-3}.

Diffusion coefficients in the sediment (D_s) are related to molecular diffusion coefficients in water (D_0) as follows:

$$D_s = D_0/(\Phi F) \qquad \text{(A8)}$$

where F is the sediment resistivity. For high porosity sediments, as in Terrace Reservoir, F can be approximated as Φ^3 (Ullman and Aller, 1982). Therefore,

$$D_s = D_0/\Phi^2 = D_0\Phi^2 \qquad \text{(A9)}$$

Values of D_0 at infinite dilution for a variety of ions are tabulated in Li and Gregory (1974). Inorganic speciation calculations indicate that the dominant species for the dissolved metals of interest in the water column of Terrace Reservoir are the free metal ions (Cu^{2+}, Zn^{2+}, Co^{2+}, and Mn^{2+}). The D_0 values for Cu^{2+}, Zn^{2+}, Co^{2+}, and Mn^{2+} at 25°C are, respectively, 0.633, 0.618, 0.604, and 0.594 cm^2 d^{-1} (Li and Gregory, 1974). The Stokes-Einstein relationship is used to temperature correct the diffusion coefficients to in-situ conditions as follows:

$$(D_0\eta^0/T)_{T1} = (D_0\eta^0/T)_{T2} \qquad \text{(A10)}$$

where η^0 is the viscosity of water and T is absolute temperature (T°C + 273.15). The temperature dependence on the viscosity of water is tabulated in Dorsey (1940). The temperature at the base of the water column in Terrace Reservoir during our sampling times is summarized in Table A1.

The concentration gradient across the sediment-water interface is calculated as:

$$\partial C/\partial x = [(Me^{2+})_{BW} - (Me^{2+})_{PW(0\text{-}0.5\ cm)}]/\Delta d \qquad \text{(A11)}$$

where $\partial C/\partial x$ is the dissolved concentration gradient (g cm^{-4}), $(Me^{2+})_{BW}$ is the concentration of the dissolved metal (Me^{2+}) in the bottom water (BW) (g cm^{-3} or g L^{-1}), $(Me^{2+})_{PW(0\text{-}0.5\ cm)}$ is the concentration of dissolved metal in the porewater at a depth of 0-0.5 cm below the sediment-water interface (g cm^{-3} or g L^{-1}), and Δd is the distance between the location of the bottom water and porewater sample (cm).

Recall that during our Terrace Reservoir study we measured dissolved element concentrations in both the bottom water (BW) collected with the hydrobottle near the sediment-water interface and the water within the core barrel that was overlying the core (OW). During our 1994 samplings we tried to collect OW as close as possible to the sediment-water interface, i.e., within 1-2 cm. Unfortunately, most of that data indicate that the composition of the OW sample is probably a combination of porewater from the 0-0.5 cm interval and bottom water as demonstrated by dissolved Cu data from site T1A (Fig. A1). This mixture probably occurred during sampling. Therefore, we have used bottom water data for the 1994 gradient calculations. During June 1995, we collected the overlying water (OW) at about 10 cm above the sediment-water interface to avoid the mixing of porewater and bottom water. Because the water column data for that sampling is not yet completed, we used data for OW data for our 1995 gradient calculations.

We assumed that the composition of water just above the sediment-water interface was either bottom water (1994) or overlying water (1995) and that the location of the porewater sample for the 0-0.5 cm interval was 0.25 cm. Thus, the distance between the locations of the porewater and bottom water (or overlying water) samples (Δd) was 0.25 cm in our calculations.

Benthic flux chamber data

Fluxes from the benthic flux chamber were calculated as follows:

$$J_s = [V/A][\partial C/\partial t] \qquad (A12)$$

where J_s is the flux (g cm^{-2} d^{-1}), V is the volume of the benthic flux chamber box (L), A is the area of the box (cm^2), and $\partial C/\partial t$ is the change in concentration of the element in the box as a function of time (g L^{-1} d^{-1}). The area of the box for the Terrace Reservoir study was 412 cm^2.

The volume of the chamber is determined by adding a known volume and concentration of an element and then determining the diluted concentration of that element in the box. The concentration of the element should be low or below detection limits before its addition and the element should be chemically inert. We used KCl in our study. The calculations are as follows:

$$V_f = (C_o/C_f)^* V_o \qquad (A13)$$

where V_f is the volume in the flux chamber (L), C_o is the dissolved concentration added to the box (mg L^{-1}), C_f is the dissolved concentration in the box after the addition of the element (mg L^{-1}). A glass, spring-actuated syringe was used to add a known volume (2-3 mL) of 90 mM KCl after the lid on the benthic flux chamber was closed. The dissolved K and Cl concentrations in the first sample from the benthic flux chamber were used to calculate the volume of the chamber.

The change in the concentration of dissolved metals in the chamber as a function of time ($\partial C/\partial t$) was determined by linear regression of the flux chamber data. The slope of the line of a dissolved concentration versus time plot is the $\partial C/\partial t$ term (Fig. A2). No temperature corrections are needed for these fluxes as the data are collected in-situ.

Table 1. Analytical detection limits for elements in porewater and overlying water analyzed by inductively coupled plasma-atomic emission spectrometry (ICP-AES).

Element	Detection limit
Aluminum (Al)	100 ppb
Barium (Ba)	7 ppb
Beryllium (Be)	10 ppb
Boron (B)	20 ppb
Cadmium (Cd)	10 ppb
Calcium (Ca)	1 ppm
Chromium (Cr)	10 ppb
Cobalt (Co)	10 ppb
Copper (Cu)	30 ppb
Iron (Fe)	90 ppb
Lead (Pb)	30 ppb
Lithium (Li)	20 ppb
Magnesium (Mg)	1 ppm
Manganese (Mn)	9 ppb
Molybdenum (Mo)	20 ppb
Nickel (Ni)	30 ppb
Potassium (K)	1 ppm
Silicon (Si)	10 ppb
Sodium (Na)	1 ppm
Strontium (Sr)	4 ppb
Vanadium (V)	10 ppb
Zinc (Zn)	20 ppb

Table 2. Data for bottom water (BW), overlying water (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during June 1994. Depth intervals in cores are in units of centimeters.

	pH	diss Al	diss B	diss Ba	diss Be	diss Ca	diss Cd	diss Co
1T51		ppm	ppb	ppb	ppb	ppm	ppb	ppb
BW at 37'	5.51	0.216		<20	<2	13.1	1.6	11.8
OW	4.88	0.8	210	52	<10	66	<10	44
0-0.5	4.79	0.7	130	56	<10	76	<10	60
0.5-1	4.28	0.3	350	50	<10	82	<10	54
1-1.5	4.19	0.7	350	60	<10	93	<10	57
1.5-2	4.45	0.2	520	48	<10	97	<10	41
2-2.5	4.75	0.2	570	48	<10	100	<10	41
1T52								
OW	4.83	0.3	230	46	<10	47	<10	37
0-0.5	4.77	0.2	440	54	<10	75	<10	48
0.5-1	4.76	0.3	450	75	<10	88	<10	53
1-1.5	5.18	0.4	770	55	<10	94	<10	47
1.5-2	5.43	0.1	720	36	<10	97	<10	52
2-3	6.31	0.1	1200	26	<10	110	<10	130
3-4	6.11	0.2	1300	32	<10	130	10	160
4-6	6.20	insufficient sample						
1T2B1								
BW at 73'	5.32	0.21		20.1	<2	14.6	1.5	12.6
OW	4.73	0.3	130	25	<10	25	<10	23
0-0.5	4.82	0.2	500	29	<10	45	<10	29
0.5-1	5.92	insufficient sample						
1-1.5	5.88	<0.1	1100	19	<10	67	<10	46
1.5-2	5.80	0.2	1200	17	<10	69	<10	48
2-2.5	5.93	<0.1	1100	10	<10	58	<10	40
1T2B2								
OW	5.36	0.3	<20	36	<10	19	<10	15
0-0.5	5.05	0.6	<20	81	<10	34	<10	47
0.5-1	4.31	0.6	320	36	<10	44	<10	35
1-1.5	5.59	0.2	630	20	<10	53	<10	33
1.5-2	5.42	insufficient sample						
2-3	5.33	<0.1	1100	18	<10	61	<10	43
3-4	5.29	0.2	990	12	<10	50	<10	36
4-6	5.29	insufficient sample						
1T1A1								
BW at 100'	5.24	0.214		20.9	<2	15	1.4	12.4
OW	5.86	0.2	<20	26	<10	16	<10	15
0-0.5	5.76	0.2	<20	37	<10	21	<10	14
0.5-1	5.71	0.2	21	30	<10	26	<10	26
1-1.5	5.57	<0.1	49	24	<10	29	<10	28
1.5-2	5.60	0.1	82	21	<10	30	<10	28
2-2.5	5.63	<0.1	89	19	<10	31	<10	32
1T1A2								
OW	5.41	0.3	<20	26	<10	15	<10	17
0-0.5	5.69	0.2	<20	52	<10	21	<10	26
0.5-1	5.80	0.2	21	53	<10	21	<10	12
1-1.5	5.86	<0.1	<20	43	<10	21	<10	15
1.5-2	5.83	0.2	<20	29	<10	17	<10	15
2-3	5.25	0.3	<20	30	<10	23	<10	14
3-4	5.22	0.5	<20	28	<10	25	<10	18
4-6	5.23	0.2	47	24	<10	30	<10	23
1T5 Blk		<0.1	<20	<7	<10	<1	<10	<10
1T2B Blk		<0.1	<20	<7	<10	<1	<10	<10
1T1A Blk		<0.1	<20	<7	<10	<1	<10	<10

Table 2 (continued). Data for bottom water (BW), overlying water (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during June 1994. Depth intervals in cores are in units of centimeters.

	diss Cr	diss Cu	diss Fe	diss K	diss Li	diss Mg	diss Mn
1T51	ppb	ppb	ppm	ppm	ppb	ppm	ppm
BW at 37'	<4	819	2.47	1.19		2.11	0.373
OW	<10	990	29	2.3	<20	11	7.6
0-0.5	<10	1300	15	2.6	<20	12	9
0.5-1	<10	590	43	2.7	<20	13	10
1-1.5	<10	980	48	3.1	<20	15	11
1.5-2	<10	270	72	3.1	<20	16	11
2-2.5	<10	230	81	3.5	<20	17	12
1T52							
OW	<10	290	32	1.9	<20	7.6	4.9
0-0.5	<10	390	59	2.8	<20	13	9.2
0.5-1	<10	340	61	3.2	<20	14	10
1-1.5	<10	350	96	3.6	<20	16	11
1.5-2	<10	100	100	4.1	<20	16	12
2-3	<10	32	160	4.6	<20	19	14
3-4	<10	<30	180	5	<20	22	16
4-6	insufficient sample						
1T2B1							
BW at 73'	<4	704	1.62	<0.65		2.48	0.399
OW	<10	190	18	<1	<20	3.6	1.6
0-0.5	<10	54	70	1.8	<20	6.4	3.8
0.5-1	insufficient sample						
1-1.5	<10	43	160	2.8	<20	9.6	6.1
1.5-2	<10	37	170	3	<20	9.9	6.7
2-2.5	<10	43	160	2.3	<20	8.7	6
1T2B2							
OW	<10	750	1.6	<1	<20	3	0.85
0-0.5	<10	840	0.2	1.5	<20	4.9	2.5
0.5-1	<10	320	44	1.9	<20	6.2	3.4
1-1.5	<10	44	89	2.3	<20	7.3	4.3
1.5-2	insufficient sample						
2-3	<10	190	150	2.9	<20	8.8	5.9
3-4	<10	150	140	2.2	<20	7.5	5.2
4-6	insufficient sample						
1T1A1							
BW at 100'	<4	720	1.58	<0.65		2.54	0.418
OW	<10	540	0.1	<1	<20	2.6	0.46
0-0.5	<10	290	<0.09	1.1	<20	3.2	0.69
0.5-1	<10	190	1.7	1.5	<20	4	1.1
1-1.5	<10	93	0.7	1.6	<20	4.4	1.5
1.5-2	<10	81	11	1.7	<20	4.6	2
2-2.5	<10	45	12	1.9	<20	4.7	2.4
1T1A2							
OW	<10	670	1	<1	<20	2.6	0.43
0-0.5	<10	390	0.09	1.4	<20	3.2	0.64
0.5-1	<10	230	0.3	1.3	<20	3.3	0.71
1-1.5	<10	130	0.4	1.2	<20	3.3	0.78
1.5-2	<10	180	0.4	1.3	<20	2.7	0.53
2-3	<10	670	0.3	1.4	<20	3.6	0.58
3-4	<10	870	1	1.5	<20	3.9	0.73
4-6	<10	320	5.7	1.5	<20	4.5	1.1
1T5 Blk	<10	<30	0.3	<1	<20	<1	0.039
1T2B Blk	<10	<30	1.1	<1	<20	<1	<0.009
1T1A Blk	<10	<30	<0.09	<1	<20	<1	<0.009

Table 2 (continued). Data for bottom water (BW), overlying water (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during June 1994. Depth intervals in cores are in units of centimeters.

	diss Mo	diss Na	diss Ni	diss Pb	diss Si	diss Sr	diss V	diss Zn
1T51	ppb	ppm	ppb	ppb	ppm	ppb	ppb	ppb
BW at 37'		4.76	<15	<1.4			<4	228
OW	<20	9.9	<30	<30	6.2	470	<10	270
0-0.5	<20	11	<30	<30	6	540	<10	300
0.5-1	<20	12	<30	<30	5.6	580	<10	210
1-1.5	<20	12	<30	<30	6.6	660	<10	260
1.5-2	<20	13	<30	<30	6.8	680	<10	170
2-2.5	<20	14	<30	<30	7.2	710	<10	89
1T52								
OW	<20	8.4	<30	<30	5.9	340	<10	190
0-0.5	<20	11	<30	<30	5.1	520	<10	160
0.5-1	<20	12	<30	<30	6.4	640	<10	190
1-1.5	<20	13	<30	<30	7.3	660	<10	110
1.5-2	<20	14	<30	<30	7	660	<10	53
2-3	<20	15	<30	<30	7.8	740	<10	<20
3-4	<20	16	<30	<30	7.4	860	<10	<20
4-6	insufficient sample							
1T2B1								
BW at 73'		5.47	<15	<1.4			<4	220
OW	<20	6.2	<30	<30	5.6	180	<10	200
0-0.5	<20	7.9	<30	<30	7.1	310	<10	90
0.5-1	insufficient sample							
1-1.5	<20	11	<30	<30	7.1	410	<10	52
1.5-2	<20	12	<30	<30	6.8	400	<10	52
2-2.5	<20	11	<30	<30	5.8	330	<10	43
1T2B2								
OW	<20	5.2	<30	<30	5.5	150	<10	330
0-0.5	<20	6.5	33	<30	9.2	270	<10	720
0.5-1	<20	8.5	<30	<30	9.3	320	<10	270
1-1.5	<20	10	<30	<30	8	360	<10	65
1.5-2	insufficient sample							
2-3	<20	12	<30	<30	7.2	390	<10	58
3-4	<20	11	<30	<30	5.5	310	<10	55
4-6	insufficient sample							
1T1A1								
BW at 100'		5.57	<15	<1.4			<4	217
OW	<20	5.1	<30	<30	5.1	130	<10	320
0-0.5	<20	6.3	<30	<30	7.7	180	<10	230
0.5-1	<20	8.1	<30	<30	8.2	220	<10	220
1-1.5	<20	9.5	<30	<30	7.4	240	<10	180
1.5-2	<20	11	<30	<30	7	240	<10	120
2-2.5	<20	12	<30	<30	6.6	250	<10	91
1T1A2								
OW	<20	4.9	<30	<30	4.8	120	<10	320
0-0.5	<20	5.5	<30	<30	7.4	180	<10	400
0.5-1	<20	5.8	<30	<30	8.6	190	<10	360
1-1.5	<20	5.8	<30	<30	8.6	190	<10	300
1.5-2	<20	5.6	<30	<30	8.6	150	<10	470
2-3	<20	6.7	<30	<30	8.1	200	<10	450
3-4	<20	7.9	<30	<30	8.5	220	<10	370
4-6	<20	10	<30	<30	7.5	240	<10	350
1T5 Blk	<20	<1	<30	<30	0.05	<4	<10	480
1T2B Blk	<20	<1	<30	<30	0.09	<4	<10	65
1T1A Blk	<20	<1	<30	<30	0.07	<4	<10	84

Table 3. Data for bottom water (BW), overlying water (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during July 1994. Depth intervals in cores are in units of centimeters.

	pH	diss Al	diss B	diss Ba	diss Be	diss Ca	diss Cd	diss Co
2T51		ppm	ppb	ppb	ppb	ppm	ppb	ppb
BW at 20'	5.20	0.584		30.4	<2	32.6	2.5	20.6
OW	5.42	0.2	390	47	<10	66	<10	29
0-0.5	5.49	0.2	520	70	<10	83	<10	37
0.5-1	5.86	<0.1	720	53	<10	99	<10	36
1-1.5	6.53	0.1	1200	37	<10	110	12	150
1.5-2	6.63	0.2	1400	38	<10	120	10	160
2-2.5	6.56	0.1	1400	24	<10	130	10	170
2T52								
OW	4.99	1.3	160	36	<10	45	<10	26
0-0.5	4.48	0.9	200	41	<10	51	<10	29
0.5-1	5.05	0.1	460	53	<10	64	<10	30
1-1.5	5.03	0.2	520	79	<10	77	<10	32
1.5-2	5.64	0.1	550	110	<10	88	<10	36
2-3	5.79	0.2	660	89	<10	100	11	51
3-4	5.89	0.1	780	53	<10	110	11	46
4-6	5.99	0.2	1000	31	<10	130	10	63
2T2B1								
BW at 54'	4.90	0.494		31.2	<2	28.2	3.8	17.6
OW	4.66	1.6	<20	38	<10	27	<10	23
0-0.5	4.61	2	<20	51	<10	34	<10	37
0.5-1	4.34	1.1	260	32	<10	39	<10	40
1-1.5	4.78	0.5	580	18	<10	44	<10	46
1.5-2	4.92	0.2	980	15	<10	52	10	40
2-2.5	5.23	0.2	1300	14	<10	57	<10	47
2T2B2								
OW	4.80	0.8	180	24	<10	27	<10	23
0-0.5	4.18	0.9	380	24	<10	35	<10	32
0.5-1	5.24	0.1	1300	10	<10	51	10	46
1-1.5	5.87	0.1	2000	14	<10	67	12	56
1.5-2	6.21	0.1	2200	21	<10	73	15	83
2-3	6.45	0.2	2600	17	<10	81	15	100
3-4	6.55	0.2	2800	16	<10	85	18	100
4-6	6.51	0.3	3000	16	<10	94	22	100
2T1A1								
BW at 81'	4.24	0.536		29.6	<2	26.5	2.2	19.9
OW	5.99	0.1	50	31	<10	22	<10	14
0-0.5	5.77	0.2	110	26	<10	27	<10	18
0.5-1	5.73	0.1	190	29	<10	33	<10	20
1-1.5	6.17	0.2	220	50	<10	34	<10	21
1.5-2	6.33	0.2	180	53	<10	35	<10	17
2-2.5	6.35	0.1	200	57	<10	35	<10	<10
2T1A2								
OW	6.27	<0.1	68	33	<10	23	<10	15
0-0.5	6.17	<0.1	140	26	<10	27	<10	12
0.5-1	6.11	<0.1	200	32	<10	30	<10	25
1-1.5	6.17	<0.1	220	41	<10	30	<10	17
1.5-2	6.15	<0.1	220	53	<10	32	<10	21
2-3	6.29	<0.1	230	59	<10	36	<10	21
3-4	6.32	0.2	230	63	<10	39	<10	20
4-6	6.32	<0.1	160	66	<10	41	<10	18
2T5 Blk		<0.1	<20	<7	<10	<1	<10	<10
2T2B Blk		0.1	<20	25	<10	<1	<10	<10
2T1A Blk		<0.1	<20	10	<10	<1	<10	<10

Table 3 (continued). Data for bottom water (BW), overlying water (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during July 1994. Depth intervals in cores are in units of centimeters.

	diss Cr	diss Cu	diss Fe	diss K	diss Li	diss Mg	diss Mn
2T51	ppb	ppb	ppm	ppm	ppb	ppm	ppm
BW at 20'	<4	1170	3.42	1.19		5.32	0.844
OW	<10	110	66	2.8	<20	11	7.9
0-0.5	<10	100	86	3.6	<20	14	11
0.5-1	<10	110	120	4.8	<20	17	13
1-1.5	<10	39	190	5.6	<20	19	14
1.5-2	<10	<30	230	6.3	<20	21	15
2-2.5	<10	<30	230	6.1	<20	22	15
2T52							
OW	<10	640	26	1.6	<20	7.6	4.6
0-0.5	<10	480	34	2	<20	8.8	6.4
0.5-1	<10	180	78	2.6	<20	11	10
1-1.5	<10	230	86	3.1	<20	14	13
1.5-2	<10	260	91	3.3	<20	15	14
2-3	<10	410	110	4	<20	17	14
3-4	<10	380	130	4.3	<20	19	14
4-6	<10	66	170	4.9	<20	21	16
2T2B1							
BW at 54'	4.6	1060	2.09	<0.65		4.58	0.734
OW	<10	1600	1	1.1	<20	4.3	1.3
0-0.5	<10	2300	0.3	1.2	<20	5.2	2.1
0.5-1	<10	1000	43	1.4	<20	6	3.2
1-1.5	<10	520	96	1.8	<20	6.8	4
1.5-2	<10	170	160	2.1	<20	8.1	5
2-2.5	<10	110	210	2.5	<20	9	5.8
2T2B2							
OW	<10	940	29	1	<20	4.3	1.6
0-0.5	<10	670	64	1.6	<20	5.4	2.8
0.5-1	<10	68	210	2.6	<20	8.3	5.6
1-1.5	<10	<30	330	4	<20	11	7.6
1.5-2	<10	<30	370	5	<20	12	8.1
2-3	<10	<30	440	5.6	<20	14	9.3
3-4	<10	50	470	6.7	<20	15	10
4-6	<10	59	510	8.1	<20	17	12
2T1A1							
BW at 81'	<4	1060	0.827	1.42		4.18	0.739
OW	<10	100	7.2	1.2	<20	3.4	1.3
0-0.5	<10	72	17	1.8	<20	4.1	1.5
0.5-1	<10	<30	32	2.2	<20	5	2.1
1-1.5	<10	<30	37	2.5	<20	4.9	3.1
1.5-2	<10	<30	29	2.9	<20	4.8	3.6
2-2.5	<10	<30	32	3.1	<20	4.9	3.7
2T1A2							
OW	<10	<30	11	1.7	<20	3.6	1.8
0-0.5	<10	<30	24	1.8	<20	4	1.4
0.5-1	<10	<30	32	2.3	<20	4.4	1.9
1-1.5	<10	<30	37	2.9	<20	4.3	2.4
1.5-2	<10	<30	36	3.1	<20	4.4	3
2-3	<10	<30	38	3.3	<20	4.9	3.9
3-4	<10	<30	37	3.7	<20	5.4	4.5
4-6	<10	<30	27	3.9	<20	5.8	5.1
2T5 Blk	<10	<30	0.09	<1	<20	<1	<0.009
2T2B Blk	<10	<30	<0.09	<1	<20	<1	0.018
2T1A Blk	<10	<30	0.2	<1	<20	<1	<0.009

Table 3 (continued). Data for bottom water (BW), overlying water (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during July 1994. Depth intervals in cores are in units of centimeters.

	diss Mo	diss Na	diss Ni	diss Pb	diss Si	diss Sr	diss V	diss Zn
2T51	ppb	ppm	ppb	ppb	ppm	ppb	ppb	ppb
BW at 20'		11.1	18.3	<1.4			<4	386
OW	<20	11	<30	<30	6.3	460	<10	120
0-0.5	<20	13	<30	<30	6.4	600	<10	82
0.5-1	<20	14	<30	<30	6.7	680	<10	71
1-1.5	<20	14	<30	<30	7.3	720	<10	<20
1.5-2	<20	15	<30	<30	7.4	770	<10	<20
2-2.5	<20	16	<30	<30	6.5	750	<10	<20
2T52								
OW	<20	9.7	<30	<30	6.9	350	<10	260
0-0.5	<20	9.8	<30	<30	5.9	400	<10	200
0.5-1	<20	9.9	<30	<30	5.7	510	<10	83
1-1.5	<20	11	<30	<30	7.5	610	<10	73
1.5-2	<20	11	<30	<30	8.8	710	<10	110
2-3	<20	12	<30	<30	8.2	770	<10	210
3-4	<20	13	<30	<30	7.3	770	<10	140
4-6	<20	14	<30	<30	8.9	800	<10	59
2T2B1								
BW at 54'		10.6	23.6	<1.4			<4	325
OW	<20	8.3	<30	<30	7.2	210	<10	530
0-0.5	<20	8.9	35	<30	8.9	260	<10	840
0.5-1	<20	9.3	<30	<30	10	290	<10	720
1-1.5	<20	10	<30	<30	8.5	310	<10	350
1.5-2	<20	10	<30	<30	6.7	330	<10	170
2-2.5	<20	11	<30	<30	5.6	340	<10	110
2T2B2								
OW	<20	7.8	<30	<30	6.2	190	<10	300
0-0.5	<20	8.3	<30	<30	7.3	240	<10	320
0.5-1	<20	9.9	<30	<30	5.8	280	<10	87
1-1.5	<20	11	<30	<30	5.6	340	<10	42
1.5-2	<20	11	<30	<30	5.8	380	<10	<20
2-3	<20	11	<30	<30	6.3	410	<10	<20
3-4	<20	11	<30	<30	6.2	400	<10	<20
4-6	<20	11	<30	<30	6.8	420	<10	21
2T1A1								
BW at 81'		10.1	16.7	<1.4			<4	486
OW	<20	8.3	<30	<30	5.7	180	<10	140
0-0.5	<20	9.8	<30	<30	6.3	220	<10	110
0.5-1	<20	11	<30	<30	6.3	270	<10	66
1-1.5	<20	14	<30	<30	8.5	290	<10	20
1.5-2	<20	16	<30	<30	9.9	290	<10	<20
2-2.5	<20	16	<30	<30	10	300	<10	58
2T1A2								
OW	<20	9	<30	<30	6.3	190	<10	87
0-0.5	<20	9.4	<30	<30	6.1	220	<10	38
0.5-1	<20	11	<30	<30	6.4	240	<10	50
1-1.5	<20	13	<30	<30	8.3	240	<10	<20
1.5-2	<20	14	<30	<30	9.5	270	<10	20
2-3	<20	16	<30	<30	10	310	<10	<20
3-4	<20	18	<30	<30	10	330	<10	24
4-6	<20	18	<30	<30	10	350	<10	39
2T5 Blk	<20	<1	<30	<30	<0.01	<4	<10	<20
2T2B Blk	<20	<1	<30	<30	0.02	<4	<10	<20
2T1A Blk	<20	<1	<30	<30	<0.01	<4	<10	<20

Table 4. Data for bottom water (BW), overlying water (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during August 1994. Depth intervals in cores are in units of centimeters.

	pH	diss Al	diss B	diss Ba	diss Be	diss Ca	diss Cd	diss Co
3T51		ppm	ppb	ppb	ppb	ppm	ppb	ppb
BW at 6'	4.96	0.803		47.7	<2	32.5	2.5	25.7
OW	4.67	1.7	33	46	<10	38	<10	43
0-0.5	4.09	4	24	44	<10	55	<10	82
0.5-1	3.81	3	100	41	<10	62	<10	88
1-1.5	4.21	1.6	79	46	<10	70	<10	92
1.5-2	4.17	2.1	37	43	<10	76	<10	100
2-2.5	3.97	4.7	67	41	<10	83	<10	120
3T52								
OW	4.50	1.4	76	38	<10	36	<10	29
0-0.5	4.33	1.7	290	50	<10	88	<10	67
0.5-1	4.63	0.36	780	62	<10	91	<10	54
1-1.5	4.77	0.25	920	83	<10	92	<10	50
1.5-2	4.97	0.25	1100	85	<10	98	<10	55
2-3	4.95	0.32	1200	59	<10	100	<10	66
3-4	5.28	0.32	1300	42	<10	110	<10	53
4-6	5.98	0.36	1800	35	<10	120	10	68
3T2B1								
BW at 47'	4.92	0.592		33.3	<2	30.5	2.5	20.6
OW	5.06	0.9	96	29	<10	30	<10	24
0-0.5	4.76	1	570	27	<10	51	<10	54
0.5-1	5.07	0.22	1100	19	<10	60	<10	55
1-1.5	5.52	0.16	1700	16	<10	61	13	54
1.5-2	5.68	0.22	2300	12	<10	64	13	61
2-2.5	6.03	0.18	2400	11	<10	65	11	59
3T2B2								
OW	4.73	1.5	99	29	<10	32	<10	34
0-0.5	4.50	1.4	370	28	<10	41	<10	48
0.5-1	4.99	0.41	1100	18	<10	51	<10	54
1-1.5	5.25	0.19	1800	15	<10	60	10	56
1.5-2	5.51	0.22	2200	12	<10	67	<10	59
2-3	6.14	0.22	2700	18	<10	75	10	100
3-4	6.41	0.19	3200	21	<10	84	13	130
4-6	6.42	0.25	3600	18	<10	91	15	150
3T1A1								
BW at 74'	4.70	0.727		33.8	<2	31.2	2.5	21.8
OW	5.49	0.52	<20	33	<10	27	<10	20
0-0.5	5.45	0.23	<20	29	<10	26	<10	22
0.5-1	5.45	0.71	64	33	<10	28	<10	35
1-1.5	5.50	0.32	26	35	<10	28	<10	38
1.5-2	5.62	0.22	35	39	<10	32	<10	47
2-2.5	5.82	0.16	53	38	<10	31	<10	43
3T1A2								
OW	5.40	0.44	26	36	<10	27	<10	19
0-0.5	5.51	0.22	96	24	<10	26	<10	21
0.5-1	5.66	0.12	180	23	<10	30	<10	17
1-1.5	5.84	0.52	330	27	<10	37	<10	26
1.5-2	6.31	0.48	340	32	<10	35	<10	21
2-3	6.52	0.16	380	51	<10	40	<10	30
3-4	6.58	0.25	360	77	<10	44	<10	24
4-6	no sample							
3T5 Blk1		0.22	<20	<7	<10	0.47	<10	<10
3T2B Blk1		0.15	<20	<7	<10	0.27	<10	<10
3T2B Blk2		0.16	<20	<7	<10	0.32	<10	<10
3T1A Blk1		0.29	<20	<7	<10	0.32	<10	<10
3T1A Blk2		0.19	<20	<7	<10	0.56	<10	<10

Table 4 (continued). Data for bottom water (BW), overlying water (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during August 1994. Depth intervals in cores are in units of centimeters.

	diss Cr	diss Cu	diss Fe	diss K	diss Li	diss Mg	diss Mn
3T51	ppb	ppb	ppm	ppm	ppb	ppm	ppm
BW at 6'	<4	628	4.78	0.993		5.28	1.59
OW	<10	1200	4.4	1.5	<20	6.2	2.3
0-0.5	<10	2600	2	2	<20	8.9	4.2
0.5-1	<10	1400	9.2	2.2	<20	9.4	4.8
1-1.5	<10	820	9.8	2.3	<20	11	5.2
1.5-2	<10	1300	3.3	2.3	<20	12	5.5
2-2.5	<10	2300	7.3	2.5	<20	12	6.5
3T52							
OW	<10	790	9.7	1.4	<20	5.9	2.3
0-0.5	<10	910	37	2.4	<20	11	8.1
0.5-1	<10	210	100	3.1	<20	13	12
1-1.5	<10	170	120	3.1	<20	15	14
1.5-2	<10	180	140	3.8	<20	17	15
2-3	<10	470	150	4	<20	18	15
3-4	<10	380	170	4.4	<20	19	15
4-6	<10	87	240	5.3	<20	21	17
3T2B1							
BW at 47'	<4	834	2.59	0.65		4.89	0.989
OW	<10	840	12	1.2	<20	4.8	1.4
0-0.5	<10	560	74	2.2	<20	7.7	4.5
0.5-1	<10	170	140	3	<20	9.3	6
1-1.5	<10	59	220	3.6	<20	9.9	7.2
1.5-2	<10	60	290	5.2	<20	12	8.5
2-2.5	<10	<30	310	5.8	<20	12	8.7
3T2B2							
OW	<10	1300	13	1.1	<20	5	1.7
0-0.5	<10	1300	48	1.6	<20	6.3	3.1
0.5-1	<10	210	140	2.1	<20	7.8	4.8
1-1.5	<10	110	230	3	<20	9.6	6.5
1.5-2	<10	52	280	3.5	<20	11	7.5
2-3	<10	<30	350	4.2	<20	12	8.5
3-4	<10	<30	410	5.4	<20	14	9.6
4-6	<10	<30	460	6.4	<20	16	11
3T1A1							
BW at 74'	<4	916	2.35	0.65		4.98	1.01
OW	<10	660	1.7	0.86	<20	4.3	0.89
0-0.5	<10	260	1.4	1.2	<20	4	0.91
0.5-1	<10	350	2	1.3	<20	4	0.96
1-1.5	<10	160	2	1.3	<20	4.2	1.2
1.5-2	<10	140	3.7	1.3	<20	4.7	1.4
2-2.5	<10	<30	5.4	1.2	<20	4.6	1.6
3T1A2							
OW	<10	500	2.9	0.87	<20	4.2	0.99
0-0.5	<10	110	13	1.5	<20	4	1.3
0.5-1	<10	66	23	1.9	<20	4.5	1.8
1-1.5	<10	81	43	2.7	<20	5.5	3.2
1.5-2	<10	<30	44	3.2	<20	5.1	3.5
2-3	<10	<30	49	3.9	<20	5.7	4.6
3-4	<10	<30	46	4.5	<20	6.2	5.9
4-6	no sample						
3T5 Blk1	<10	<30	0.69	<0.2	<20	0.07	0.056
3T2B Blk1	<10	<30	0.3	<0.2	<20	0.04	0.009
3T2B Blk2	<10	<30	0.26	<0.2	<20	0.07	0.031
3T1A Blk1	<10	<30	0.35	<0.2	<20	<0.04	0.011
3T1A Blk2	<10	<30	2	<0.2	<20	0.09	0.44

Table 4 (continued). Data for bottom water (BW), overlying water (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during August 1994. Depth intervals in cores are in units of centimeters.

	diss Mo ppb	diss Na ppm	diss Ni ppb	diss Pb ppb	diss Si ppm	diss Sr ppb	diss V ppb	diss Zn ppb
3T51								
BW at 6'		5.44	16.9	1.9			<4	430
OW	<20	6.2	<30	<30	8.3	290	<10	460
0-0.5	<20	7.8	34	<30	11	420	<10	820
0.5-1	<20	9.3	44	<30	10	490	19	690
1-1.5	<20	11	41	<30	9.8	580	<10	610
1.5-2	<20	12	41	<30	12	610	<10	690
2-2.5	<20	13	60	<30	15	630	<10	910
3T52								
OW	<20	6.2	<30	<30	7.8	270	<10	360
0-0.5	<20	11	33	<30	7.9	700	<10	460
0.5-1	<20	13	<30	<30	6.8	710	<10	140
1-1.5	<20	12	<30	<30	8	720	<10	140
1.5-2	<20	13	<30	<30	8.3	740	<10	180
2-3	<20	14	<30	<30	7.6	740	<10	170
3-4	<20	14	<30	<30	7.9	740	<10	130
4-6	<20	15	<30	<30	8.9	770	<10	54
3T2B1								
BW at 47'		9.54	<15	<1.4			<4	323
OW	<20	9.4	<30	<30	7	230	<10	310
0-0.5	<20	11	<30	<30	9.1	370	<10	340
0.5-1	<20	12	<30	<30	8.3	400	<10	150
1-1.5	<20	12	<30	<30	6.6	360	<10	88
1.5-2	<20	12	<30	<30	5.6	280	<10	42
2-2.5	<20	12	<30	<30	5.4	270	<10	<20
3T2B2								
OW	<20	9.5	<30	<30	7.5	250	<10	380
0-0.5	<20	10	<30	<30	8.6	300	<10	440
0.5-1	<20	11	<30	<30	7.6	330	<10	220
1-1.5	<20	12	<30	<30	5.8	350	<10	90
1.5-2	<20	12	<30	<30	5.3	360	<10	41
2-3	<20	13	<30	<30	6.7	410	<10	20
3-4	<20	12	<30	<30	6.8	450	<10	<20
4-6	<20	12	<30	<30	6.8	450	<10	32
3T1A1								
BW at 74'		9.3	<15	<1.4			<4	331
OW	<20	9.5	<30	<30	7	220	<10	300
0-0.5	<20	9.9	<30	<30	9.3	230	<10	240
0.5-1	<20	9.5	<30	<30	9.4	230	17	270
1-1.5	<20	9.5	<30	<30	9.4	240	<10	320
1.5-2	<20	9.6	<30	<30	9.3	260	<10	300
2-2.5	<20	9.1	<30	<30	9.5	260	<10	230
3T1A2								
OW	<20	9.5	<30	<30	6.8	220	<10	280
0-0.5	<20	10	<30	<30	6.9	210	<10	110
0.5-1	<20	11	<30	<30	6.4	240	<10	65
1-1.5	<20	13	<30	<30	6.7	300	<10	60
1.5-2	<20	14	<30	<30	8.4	290	<10	39
2-3	<20	16	<30	<30	11	340	<10	<20
3-4	<20	17	<30	<30	11	390	<10	<20
4-6	no sample							
3T5 Blk1	<20	0.37	<30	<30	0.07	<4	<10	<20
3T2B Blk1	<20	0.24	<30	<30	0.06	<4	<10	<20
3T2B Blk2	<20	<0.2	<30	<30	0.1	<4	<10	<20
3T1A Blk1	<20	0.38	<30	<30	0.06	<4	<10	<20
3T1A Blk2	<20	0.38	<30	<30	0.1	<4	<10	<20

Table 5. Data for bottom water (BW), overlying water (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during September 1994. Depth intervals in cores are in units of centimeters.

	pH	diss Al ppm	diss B ppb	diss Ba ppb	diss Be ppb	diss Ca ppm	diss Cd ppb	diss Co ppb
4T51								
BW at 3'	5.99	0.044		26.6	<1	46.25	1.5	17
OW	5.81	0.47	91	27	<10	52	<10	29
0-0.5	5.84	0.38	150	34	<10	68	<10	50
0.5-1	5.84	0.51	480	25	<10	83	<10	55
1-1.5	5.68	1.5	720	21	<10	92	10	52
1.5-2	5.52	1.1	720	24	<10	86	22	39
2-2.5	5.70	0.57	680	32	<10	93	<10	51
4T52								
OW	5.74	0.5	170	31	<10	69	<10	43
0-0.5	5.78	0.64	320	30	<10	78	<10	55
0.5-1	5.59	1.2	720	27	<10	86	<10	39
1-1.5	6.08	0.34	600	27	<10	87	<10	53
1.5-2	6.00	0.28	610	24	<10	94	<10	53
2-3	5.84	0.41	650	29	<10	100	<10	70
3-4	5.88	0.44	650	28	<10	110	<10	76
4-6	5.79	0.41	740	27	<10	120	<10	69
4T2B1								
BW at 41'	4.99	0.524		29.7	<1	33.23	2	18
OW	5.40	0.96	56	26	<10	33	<10	26
0-0.5	5.18	0.44	190	20	<10	34	<10	31
0.5-1	5.53	0.22	500	18	<10	38	<10	33
1-1.5	5.70	0.22	740	16	<10	43	<10	28
1.5-2	6.25	0.25	1000	18	<10	53	<10	40
2-2.5	6.35	0.22	1100	18	<10	60	<10	46
4T2B2								
OW	5.31	0.92	99	25	<10	38	16	26
0-0.5	4.53	0.87	400	22	<10	49	<10	52
0.5-1	5.42	0.35	1100	18	<10	60	10	64
1-1.5	5.64	0.19	1900	13	<10	61	13	52
1.5-2	5.72	0.22	2400	11	<10	66	11	57
2-3	5.94	0.25	2700	9	<10	68	39	64
3-4	6.13	0.34	2900	12	<10	74	11	73
4-6	6.29	0.28	3300	19	<10	79	14	130
4T1A1								
BW at 66'	4.96	0.525		30.1	<1	33.72	<3	19
OW	5.96	0.54	51	26	<10	33	<10	21
0-0.5	5.86	0.25	260	18	<10	32	<10	21
0.5-1	6.30	0.22	430	30	<10	43	<10	32
1-1.5	6.50	0.22	480	63	<10	47	<10	31
1.5-2	6.61	0.22	510	80	<10	52	<10	36
2-2.5	6.72	<0.1	490	88	<10	58	<10	31
4T1A2								
OW	7.13	0.32	73	25	<10	32	<10	18
0-1	5.82	0.41	260	18	<10	32	<10	22
1-2	5.90	0.22	260	21	<10	33	<10	20
1-2 DUP	5.90	0.19	270	21	<10	34	<10	28
2-2.75	5.87	0.25	400	17	<10	38	<10	24
2.75-3.5	6.03	0.22	460	24	<10	43	<10	31
3.5-4	6.40	0.19	460	28	<10	42	<10	30
4-5	6.49	0.22	510	46	<10	43	<10	34
5-6	6.65	0.19	540	62	<10	47	<10	34
4T51 Blk 1		0.19	<20	<7	<10	0.65	<10	<10
4T51 Blk 2		0.22	<20	<7	<10	<0.2	<10	<10
4T2B Blk 1		0.22	<20	<7	<10	0.32	<10	<10
4T2B Blk 2		0.19	<20	<7	<10	0.32	<10	<10
4T1A Blk 1		0.22	<20	<7	<10	0.4	<10	<10
4T1A Blk 2		0.19	<20	<7	<10	0.32	<10	<10

Table 5 (continued). Data for bottom water (BW), overlying water (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during September 1994. Depth intervals in cores are in units of centimeters.

	diss Cr ppb	diss Cu ppb	diss Fe ppm	diss K ppm	diss Li ppb	diss Mg ppm	diss Mn ppm
4T51							
BW at 3'	<4	337	1.913	1.5		6.12	0.725
OW	<10	640	10	1.5	<20	7.5	1.9
0-0.5	<10	740	17	2	<20	10	3.7
0.5-1	<10	610	55	2.1	<20	12	5.1
1-1.5	<10	370	85	2.2	<20	13	6.5
1.5-2	<10	400	86	2.3	<20	13	7.8
2-2.5	<10	150	79	2.8	<20	14	9.4
4T52							
OW	<10	1100	20	1.8	<20	10	3.8
0-0.5	<10	880	36	2.1	<20	11	4.9
0.5-1	<10	310	83	2.2	<20	13	7.8
1-1.5	<10	39	70	2.3	<20	14	9
1.5-2	<10	<30	71	2.5	<20	14	9.1
2-3	<10	<30	76	2.7	<20	14	9.1
3-4	<10	<30	76	2.6	<20	15	9.9
4-6	<10	<30	87	2.8	<20	16	10
4T2B1							
BW at 41'	<4	824	2.31	1.1		4.96	0.916
OW	<10	1000	120	0.98	<20	5.3	1.3
0-0.5	<10	610	0.85	1.6	<20	5.9	2.7
0.5-1	<10	210	22	2.3	<20	7	4.7
1-1.5	<10	98	59	3.2	<20	8.1	6.4
1.5-2	<10	<30	87	4.7	<20	10	10
2-2.5	<10	<30	120	5.5	<20	11	13
4T2B2							
OW	<10	730	0.24	1.1	<20	5.9	1.9
0-0.5	<10	330	11	1.7	<20	7.5	4
0.5-1	<10	180	46	2.4	<20	9.3	5.9
1-1.5	<10	150	130	3.8	<20	10	7.4
1.5-2	<10	75	230	4.8	<20	12	8.5
2-3	<10	66	280	5.8	<20	13	9.2
3-4	<10	73	320	6.4	<20	14	9.6
4-6	<10	41	330	7.7	<20	15	10
4T1A1							
BW at 66'	<4	847	2.375	1.3		5.07	0.924
OW	<10	740	380	0.89	<20	5.2	1.1
0-0.5	<10	110	5.7	1.9	<20	5.1	2.2
0.5-1	<10	<30	30	3.6	<20	6.4	4.9
1-1.5	<10	<30	50	4.6	<20	6.8	6.6
1.5-2	<10	<30	56	5.2	<20	7.5	8.2
2-2.5	<10	<30	59	5.6	<20	8.2	9.4
4T1A2							
OW	<10	320	8.4	1.1	<20	5.1	1.5
0-1	<10	120	28	1.6	<20	5	1.9
1-2	<10	54	31	1.8	<20	5.2	2.1
1-2 DUP	<10	61	31	1.7	<20	5.2	2.1
2-2.75	<10	50	46	2.8	<20	5.8	3
2.75-3.5	<10	<30	53	3.4	<20	6.5	4.2
3.5-4	<10	<30	53	3.8	<20	6.2	4.5
4-5	<10	<30	60	4.2	<20	6.4	5.2
5-6	<10	<30	64	4.6	<20	6.8	6.1
4T51 Blk 1	<10	<30	0.64	<0.2	<20	0.14	0.055
4T51 Blk 2	<10	<30	0.32	<0.2	<20	0.07	0.012
4T2B Blk 1	<10	<30	5.5	<0.2	<20	0.07	0.017
4T2B Blk 2	<10	<30	0.31	<0.2	<20	<0.04	0.015
4T1A Blk 1	<10	<30	0.61	<0.2	<20	0.07	0.049
4T1A Blk 2	<10	<30	0.43	<0.2	<20	0.05	0.019

Table 5 (continued). Data for bottom water (BW), overlying water (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during September 1994. Depth intervals in cores are in units of centimeters.

4T51	diss Mo ppb	diss Na ppm	diss Ni ppb	diss Pb ppb	diss Si ppm	diss Sr ppb	diss V ppb	diss Zn ppb
BW at 3'		23.1	<12	<1			<3	234
OW	<20	21	<30	<30	8.1	380	<10	300
0-0.5	<20	18	36	<30	7.6	500	<10	330
0.5-1	<20	15	55	<30	6.9	600	<10	270
1-1.5	<20	14	51	<30	4.7	680	<10	210
1.5-2	<20	15	37	<30	4.3	640	<10	200
2-2.5	<20	16	37	<30	6.7	680	<10	120
4T52								
OW	<20	19	41	<30	8.4	500	<10	430
0-0.5	<20	17	47	<30	8	570	<10	370
0.5-1	<20	14	38	<30	4.6	630	<10	180
1-1.5	<20	15	<30	<30	8.2	630	<10	140
1.5-2	<20	16	35	<30	9.4	670	<10	150
2-3	<20	18	38	<30	9.3	680	<10	180
3-4	<20	19	38	<30	8.9	740	<10	180
4-6	<20	19	<30	<30	8.6	810	<10	140
4T2B1								
BW at 41'		10.4	18	<1			<3	297
OW	<20	11	<30	<30	7.7	250	<10	350
0-0.5	<20	11	<30	<30	8.8	250	<10	320
0.5-1	<20	11	<30	<30	7.9	260	<10	150
1-1.5	<20	11	<30	<30	7.2	280	<10	68
1.5-2	<20	12	<30	<30	6.3	340	<10	34
2-2.5	<20	12	<30	<30	5.8	390	<10	<20
4T2B2								
OW	<20	11	<30	<30	7.8	290	<10	320
0-0.5	<20	12	<30	<30	9.2	370	<10	320
0.5-1	<20	12	<30	<30	8.9	410	<10	210
1-1.5	<20	13	<30	<30	6.5	320	<10	82
1.5-2	<20	13	<30	<30	5.1	270	<10	30
2-3	<20	13	<30	<30	5.7	250	<10	27
3-4	<20	13	<30	<30	6	300	<10	30
4-6	<20	13	<30	<30	7.1	360	<10	46
4T1A1								
BW at 66'		10.31	12	<1			<3	301
OW	<20	11	<30	<30	7.6	260	<10	330
0-0.5	<20	12	<30	<30	6.9	260	<10	110
0.5-1	<20	13	<30	<30	7.6	360	<10	40
1-1.5	<20	14	<30	<30	11	400	<10	<20
1.5-2	<20	15	<30	<30	11	470	<10	<20
2-2.5	<20	15	<30	<30	12	530	<10	<20
4T1A2								
OW	<20	11	<30	<30	7.7	260	<10	290
0-1	<20	11	<30	<30	7	250	<10	120
1-2	<20	11	<30	<30	6.7	260	<10	93
1-2 DUP	<20	12	<30	<30	6.7	260	<10	110
2-2.75	<20	12	<30	<30	6.3	300	<10	46
2.75-3.5	<20	13	<30	<30	6.5	350	<10	51
3.5-4	<20	13	<30	<30	8	350	<10	31
4-5	<20	14	<30	<30	9.5	360	<10	<20
5-6	<20	14	<30	<30	12	400	<10	<20
4T51 Blk 1	<20	0.43	<30	<30	0.08	4	<10	<20
4T51 Blk 2	<20	0.2	<30	<30	0.05	<4	<10	<20
4T2B Blk 1	<20	0.4	<30	<30	0.08	<4	<10	<20
4T2B Blk 2	<20	0.23	<30	<30	0.05	<4	<10	<20
4T1A Blk 1	<20	0.44	<30	<30	0.1	<4	<10	<20
4T1A Blk 2	<20	0.42	<30	<30	0.08	<4	<10	<20

Table 6. Data for bottom water (BW), water overlying the core (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during June 1995. Depth intervals in cores are in units of centimeters. Analyses for BW are not yet completed (2/96).

	pH	Alk meq/L	diss SO4 ppm	diss Cl ppm	diss Al ppm	diss B ppb	diss Ba ppb	diss Be ppb	diss Ca ppm
5T51									
BW at 37'									
OW1	7.20	no sample	no sample	no sample	<0.1	<20	25	<10	17
OW2	6.96	no sample	no sample	no sample	<0.1	<20	26	<10	16
0-0.5	5.21	no sample	no sample	no sample	0.74	33	34	<10	70
0.5-1	5.09	no sample	no sample	no sample	0.44	43	26	<10	73
1-1.5	no sample	no sample	no sample	no sample	0.63	49	26	<10	82
1.5-2	no sample	no sample	no sample	no sample	0.57	55	23	<10	81
2-2.5	no sample	no sample	no sample	no sample	<0.1	67	20	<10	91
5T52									
OW1	6.33	0.134	54	1.1	<0.1	<20	27	<10	17
0-0.5	5.15	0.075	219	2.7	0.39	20	81	<10	60
0.5-1	5.18	no sample	no sample	no sample	0.49	33	30	<10	74
1-1.5	5.67	no sample	no sample	no sample	0.24	48	25	<10	78
1.5-2	5.88	no sample	478	4.8	<0.1	57	24	<10	91
2-3	5.91	0.175	558	3.9	0.15	64	21	<10	93
3-4	5.97	0.398	722	4.1	<0.1	81	20	<10	100
4-6	5.80	0.403	857	3.9	0.18	100	19	<10	100
5T2B1									
BW at 66'									
OW1	6.72	no sample	no sample	no sample	<0.1	<20	24	<10	19
OW2	6.71	no sample	no sample	no sample	<0.1	<20	23	<10	19
0-0.5	4.90	no sample	no sample	no sample	0.52	<20	53	<10	33
0.5-1	5.15	no sample	no sample	no sample	0.16	25	15	<10	45
1-1.5	5.58	no sample	no sample	no sample	<0.1	39	14	<10	56
1.5-2	5.91	no sample	no sample	no sample	<0.1	54	14	<10	62
2-2.5	6.16	no sample	no sample	no sample	<0.1	69	13	<10	67
5T2B2									
OW1	6.07	0.103	59	0.75	<0.1	<20	27	<10	19
OW2	5.92	0.095	60	3.8	<0.1	<20	26	<10	18
0-0.5	4.37	0	178	2.2	0.82	<20	43	<10	38
0.5-1	5.17	0.058	327	3.3	0.51	35	19	<10	48
1-1.5	5.42	0.042	437	5.7	0.24	54	15	<10	56
1.5-2	5.49	0.042	544	7.4	<0.1	71	16	<10	64
2-3	5.67	0.061	627	8.4	<0.1	91	13	<10	69
3-4	5.71	0.063	813	10	0.34	110	14	<10	76
4-6	5.81	0.249	911	11	<0.1	130	10	<10	88
5T1A1									
BW at 95'									
OW1	6.81	no sample	no sample	no sample	<0.1	<20	24	<10	23
OW2	6.87	no sample	no sample	no sample	<0.1	<20	23	<10	22
0-0.5	5.69	no sample	no sample	no sample	0.25	<20	24	<10	30
0.5-1	5.53	no sample	no sample	no sample	0.22	<20	24	<10	31
1-1.5	5.48	no sample	no sample	no sample	0.12	<20	23	<10	34
1.5-2	5.50	no sample	no sample	no sample	<0.1	<20	24	<10	36
2-2.5	5.44	no sample	no sample	no sample	0.11	<20	27	<10	38
5T1A2									
OW1	6.45	0.157	65	1	<0.1	<20	23	<10	21
OW2	6.50	0.152	65	5.1	<0.1	<20	23	<10	21
0-0.5	5.74	0.056	103	3	0.14	<20	24	<10	30
0.5-1	5.57	0.09	117	2	<0.1	<20	21	<10	36
1-1.5	5.56	0.091	134	1.7	<0.1	<20	26	<10	40
1.5-2	5.66	no sample	177	1.9	<0.1	<20	41	<10	51
2-3	5.90	0.092	199	1.7	<0.1	<20	58	<10	54
3-4	6.18	0.136	no sample	no sample	<0.1	<20	59	<10	48
4-6	6.36	no sample	176	2.5	0.23	<20	65	<10	48
5T5 Blk 1					<0.1	<20	<10	<10	<0.2
5T2B Blk 1					<0.1	<20	<10	<10	<0.2
5T2B Blk 2					<0.1	<20	<10	<10	<0.2
5T1A Blk 1					<0.1	<20	<10	<10	<0.2
5T1A Blk 2					<0.1	<20	<10	<10	<0.2

Table 6 (continued). Data for bottom water (BW), water overlying the core (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during June 1995. Depth intervals in cores are in units of centimeters. Analyses for BW are not yet completed (2/96).

	diss Cd	diss Co	diss Cr	diss Cu	diss Fe	diss K	diss Li	diss Mg	diss Mn
5T51	ppb	ppb	ppb	ppb	ppm	ppm	ppb	ppm	ppm
BW at 37'									
OW1	<5	<10	<10	19	0.24	0.75	<20	2.7	0.48
OW2	<5	<10	<10	22	0.34	0.69	<20	2.8	0.52
0-0.5	6.4	55	<10	410	77	3.5	<20	11	8.7
0.5-1	5	52	<10	130	100	4.1	<20	12	10
1-1.5	<5	66	<10	81	120	4.9	<20	14	12
1.5-2	<5	71	<10	140	140	4.8	<20	14	13
2-2.5	<5	70	<10	37	170	5.1	<20	15	15
5T52									
OW1	<5	<10	<10	17	0.34	0.81	<20	2.8	0.5
0-0.5	<5	35	<10	290	12	2.8	<20	9	4.8
0.5-1	7.7	70	<10	130	60	4	<20	11	9.4
1-1.5	5.8	62	<10	23	81	4.4	<20	12	11
1.5-2	<5	71	<10	26	120	5.2	<20	14	13
2-3	6.1	75	<10	43	160	5.4	<20	15	15
3-4	8.5	72	<10	23	210	5.8	<20	16	18
4-6	12	87	<10	52	270	6.3	<20	18	21
5T2B1									
BW at 66'									
OW1	<5	<10	<10	11	0.18	0.96	<20	3	0.42
OW2	<5	<10	<10	11	0.18	0.88	<20	3	0.42
0-0.5	<5	12	<10	510	3.6	1.6	<20	4.7	1.2
0.5-1	<5	27	<10	240	57	1.9	<20	6.5	3
1-1.5	<5	35	<10	60	100	2.1	<20	8.4	4.3
1.5-2	7.9	44	<10	27	150	2.6	<20	9.1	5.3
2-2.5	8.4	46	<10	20	180	2.8	<20	10	6
5T2B2									
OW1	<5	<10	<10	11	0.7	0.93	<20	3	0.43
OW2	<5	<10	<10	12	0.72	0.95	<20	2.9	0.44
0-0.5	<5	32	<10	730	29	1.9	5.7	5.7	2.1
0.5-1	6.5	55	<10	390	90	2.2	<20	7.3	3.5
1-1.5	8.9	52	<10	200	150	2.6	<20	8.4	4.7
1.5-2	9.6	64	<10	240	190	2.8	<20	9.6	5.7
2-3	12	64	<10	120	250	3.3	<20	11	6.6
3-4	13	58	<10	210	320	3.7	<20	12	7.6
4-6	15	64	<10	22	390	4.2	<20	13	8.8
5T1A1									
BW at 95'									
OW1	<5	<10	<10	16	<0.1	0.93	<20	3.6	0.38
OW2	<5	<10	<10	17	<0.1	0.9	<20	3.5	0.4
0-0.5	<5	<10	<10	610	<0.1	1.4	<20	4.5	0.44
0.5-1	<5	<10	<10	480	<0.1	1.4	<20	4.8	0.44
1-1.5	<5	<10	<10	330	<0.1	1.6	<20	5	0.5
1.5-2	<5	20	10	230	<0.1	1.7	<20	5.4	0.67
2-2.5	<5	26	<10	240	<0.1	1.7	<20	5.6	0.77
5T1A2									
OW1	5.6	<10	<10	13	<0.1	0.9	<20	3.3	0.4
OW2	<5	<10	<10	12	<0.1	0.92	<20	3.3	0.39
0-0.5	<5	10	<10	410	<0.1	1.5	<20	4.5	0.46
0.5-1	<5	<10	<10	250	<0.1	1.7	<20	5.4	0.59
1-1.5	10	23	<10	200	<0.1	1.9	<20	5.8	0.94
1.5-2	<5	34	<10	34	3.6	2.1	<20	7.3	1.3
2-3	67	37	<10	<10	14	2.4	<20	8	1.8
3-4	<5	33	<10	<10	18	2.3	<20	6.9	2
4-6	<5	28	<10	<10	22	2.4	<20	6.9	2.5
5T5 Blk 1	<5	<10	<10	<10	<0.1	<0.2	<20	<0.1	<0.01
5T2B Blk 1	<5	<10	<10	<10	<0.1	<0.2	<20	<0.1	<0.01
5T2B Blk 2	<5	<10	<10	<10	<0.1	<0.2	<20	<0.1	<0.01
5T1A Blk 1	<5	<10	<10	<10	<0.1	<0.2	<20	<0.1	<0.01
5T1A Blk 2	<5	<10	<10	<10	<0.1	<0.2	<20	<0.1	<0.01

Table 6 (continued). Data for bottom water (BW), water overlying the core (OW), and porewater at sites T5, T2B, and T1A in Terrace Reservoir and blanks (Blk) during June 1995. Depth intervals in cores are in units of centimeters. Analyses for BW are not yet completed (2/96).

	diss Mo	diss Na	diss Ni	diss Pb	diss Si	diss Sr	diss V	diss Zn
5T51	ppb	ppm	ppb	ppb	ppm	ppb	ppb	ppb
BW at 37'								
OW1	<20	4.5	<10	<30	4.5	120	<10	94
OW2	<20	4.5	<10	<30	4.6	120	<10	96
0-0.5	<20	12	10	<30	6.8	430	<10	240
0.5-1	<20	14	11	<30	7.5	450	<10	220
1-1.5	<20	16	15	<30	9.1	490	<10	180
1.5-2	<20	16	18	<30	8.7	470	<10	170
2-2.5	<20	18	<10	<30	8.3	510	<10	160
5T52								
OW1	<20	4.4	<10	<30	4.7	120	<10	98
0-0.5	<20	10	19	<30	11	450	<10	380
0.5-1	<20	13	19	<30	9.9	470	<10	280
1-1.5	<20	15	19	<30	9.6	480	<10	200
1.5-2	<20	16	<10	<30	9.4	530	<10	230
2-3	<20	17	16	<30	8.8	530	<10	140
3-4	<20	17	14	<30	8.3	570	<10	150
4-6	<20	17	16	<30	8.6	590	<10	180
5T2B1								
BW at 66'								
OW1	<20	6.2	<10	<30	4.9	140	<10	67
OW2	<20	6.1	<10	<30	4.8	140	<10	67
0-0.5	<20	9.2	15	<30	11	230	<10	440
0.5-1	<20	13	<10	<30	9	260	<10	160
1-1.5	<20	14	<10	<30	7.9	310	<10	110
1.5-2	<20	15	<10	<30	7.8	320	<10	100
2-2.5	<20	15	<10	<30	7.1	320	<10	83
5T2B2								
OW1	<20	6.1	<10	<30	4.8	140	<10	79
OW2	<20	6	<10	<30	4.9	130	<10	74
0-0.5	<20	10	17	<30	10	260	<10	520
0.5-1	<20	13	21	<30	9.3	290	<10	380
1-1.5	<20	14	16	<30	8.3	310	<10	290
1.5-2	<20	15	14	<30	7.4	330	<10	240
2-3	<20	15	16	<30	7.1	330	<10	210
3-4	<20	14	12	<30	5.2	320	<10	130
4-6	<20	13	<10	<30	5.1	350	<10	110
5T1A1								
BW at 95'								
OW1	<20	7.4	<10	<30	4.9	170	<10	58
OW2	<20	7.3	<10	<30	5.1	170	<10	59
0-0.5	<20	8.7	<10	<30	7.6	230	<10	170
0.5-1	<20	9.2	<10	<30	7.8	230	<10	180
1-1.5	<20	10	11	<30	7.7	240	<10	220
1.5-2	<20	11	15	<30	8.2	260	<10	310
2-2.5	<20	12	13	<30	8.6	280	<10	350
5T1A2								
OW1	<20	6.6	<10	<30	5.2	160	<10	63
OW2	<20	6.6	10	<30	5.3	160	<10	84
0-0.5	<20	9.2	10	<30	8.1	220	<10	200
0.5-1	<20	11	15	<30	8.5	260	<10	260
1-1.5	<20	12	14	<30	9.8	280	<10	320
1.5-2	<20	15	11	<30	7.9	350	<10	290
2-3	<20	17	<10	<30	8.2	390	<10	130
3-4	<20	19	<10	<30	9	340	<10	36
4-6	<20	24	<10	<30	9.9	340	<10	<10
5T5 Blk 1	<20	<0.2	<10	<30	<0.1	<4	<10	<10
5T2B Blk 1	<20	<0.2	<10	<30	<0.1	<4	<10	<10
5T2B Blk 2	<20	<0.2	<10	<30	<0.1	<4	<10	<10
5T1A Blk 1	<20	<0.2	<10	<30	<0.1	<4	<10	<10
5T1A Blk 2	<20	<0.2	<10	<30	<0.1	<4	<10	<10

Table 7. Composition of benthic flux chamber (or lander) samples collected in Terrace Reservoir in 1994 and 1995.

July 1994	hrs	pH	diss Al	diss B	diss Ba	diss Be	diss Ca	diss Cd	diss Co	diss Cr
2T5			ppm	ppb	ppb	ppb	ppm	ppb	ppb	ppb
L1	0	5.566	0.3	21	27	<10	23	<10	12	<10
L2	5	5.423	0.4	24	32	<10	24	<10	14	<10
L3	10	5.370	0.4	20	39	<10	23	<10	15	<10
L4	15	5.320	0.4	<20	37	<10	25	<10	19	<10
Blank			<0.1	<20	<7	<10	<1	<10	<10	<10
Volume (L)	2.65									
2T1A										
L1	0	4.995	0.5	22	27	<10	24	<10	16	<10
L2	5	5.011	0.4	<20	31	<10	24	<10	15	<10
L3	10	5.144	0.4	<20	33	<10	24	<10	15	<10
L4	15	5.240	0.4	22	34	<10	25	<10	16	<10
Volume (L)	2.49									
August 1994										
3T2B										
L1	0	5.291	0.7	36	31	<10	28	<10	22	<10
L2	5	5.163	0.55	24	30	<10	27	<10	23	<10
L3	10	5.167	0.52	24	34	<10	28	<10	21	<10
L4	15	5.168	0.81	51	36	<10	29	<10	28	<10
Blank			0.16	<20	<7	<10	<0.2	<10	<10	<10
Volume (L)	2.76									
3T1A										
L1	0	5.736	0.82	<20	34	<10	30	<10	25	<10
L2	5	5.514	0.71	29	33	<10	30	<10	22	<10
L3	10	5.490	0.65	35	35	<10	31	<10	24	<10
L4	15	5.472	0.65	<20	35	<10	31	<10	21	<10
Volume (L)	3.23									
June 1995										
5T5a										
L1	0	7.036	<0.1	<20	46	<10	17	<5	<10	<10
L2	5	6.793	<0.1	<20	43	<10	20	<5	<10	<10
L3	10	no samples								
L4	15	no samples								
Volume (L)	2.14									
5T5b										
L1	0	6.619	<0.1	<20	28	<10	15	<5	<10	<10
L2	5	6.343	<0.1	<20	30	<10	18	<5	<10	<10
L3	10	no samples								
L4	15	no samples								
Volume (L)	1.94									

Table 7 (continued). Composition of benthic flux chamber (or lander) samples collected in Terrace Reservoir in 1994 and 1995.

July 1994	hrs	diss Cu	diss Fe	diss K	diss Li	diss Mg	diss Mn	diss Mo	diss Na	diss Ni
2T5		ppb	ppm	ppm	ppb	ppm	ppm	ppb	ppm	ppb
L1	0	730	2.1	<1	<20	3.7	0.76	<20	7.5	<30
L2	5	690	2.3	4.6	<20	3.8	1	<20	7.6	<30
L3	10	640	1.7	3.9	<20	3.7	1.1	<20	7.2	<30
L4	15	670	1.7	4.1	<20	4.1	1.3	<20	8.1	<30
Blank		<30	0.3	<1	<20	<1	0.037	<20	<1	<30
Volume (L)	2.65									
2T1A										
L1	0	910	1.7	1.4	<20	3.9	0.72	<20	8.7	<30
L2	5	850	0.4	6.6	<20	4	0.74	<20	8.7	<30
L3	10	770	0.4	5.8	<20	4	0.77	<20	8.8	<30
L4	15	720	0.2	5.6	<20	4.1	0.81	<20	8.9	<30
Volume (L)	2.49									
August 1994										
3T2B										
L1	0	870	3.1	1.2	<20	4.5	0.96	<20	9.5	<30
L2	5	790	1.7	5.4	<20	4.4	1.1	<20	8.9	<30
L3	10	800	1.4	5.1	<20	4.5	1.2	<20	9.4	<30
L4	15	780	1.3	5	<20	4.6	1.4	<20	9.3	<30
Blank		<30	0.26	<0.2	<20	<0.04	0.009	<20	<0.2	<30
Volume (L)	2.76									
3T1A										
L1	0	880	2.3	0.88	<20	4.9	1	<20	9.2	<30
L2	5	830	3	4.8	<20	4.8	1	<20	9.3	<30
L3	10	800	2.6	4.9	<20	4.9	1.1	<20	9.6	<30
L4	15	770	2	4.6	<20	5	1.1	<20	9.7	<30
Volume (L)	3.23									
June 1995										
5T5a										
L1	0	19	0.1	0.77	<20	3	0.42	<20	4.6	<10
L2	5	57	0.26	6.1	<20	3.4	0.49	<20	5.2	<10
L3	10	no samples								
L4	15	no samples								
Volume (L)	2.14									
5T5b										
L1	0	21	0.36	0.93	<20	2.4	0.41	<20	3.9	<10
L2	5	72	1.5	7.2	<20	2.9	0.59	<20	4.5	<10
L3	10	no samples								
L4	15	no samples								
Volume (L)	1.94									

Table 7 (continued). Composition of benthic flux chamber (or lander) samples collected in Terrace Reservoir in 1994 and 1995.

July 1994	hrs	diss Pb	diss Si	diss Sr	diss V	diss Zn	diss Cl	diss SO4	diss NO3-NO2	diss NH4 (N)
2T5		ppb	ppm	ppb	ppb	ppb	ppm	ppm	ppm	ppm
L1	0	<30	5.8	170	<10	300	1.5	96	0.14	0.19
L2	5	<30	6	180	<10	290	5	104	0.17	0.29
L3	10	<30	5.6	180	<10	300	4.6	102	0.14	0.27
L4	15	<30	6.1	200	<10	290	4.6	109	0.13	0.28
Blank		<30	0.06	<4	<10	<20	0.22	<0.2	<0.05	<0.1
Volume (L)	2.65									
2T1A										
L1	0	<30	6.2	180	<10	350	2.4	109	0.17	0.27
L2	5	<30	6.3	160	<10	330	7	113	0.14	0.29
L3	10	<30	6.3	190	<10	360	6.6	108	0.16	0.33
L4	15	<30	6.4	190	<10	380	6.3	101	0.2	0.42
Volume (L)	2.49									
August 1994										
3T2B										
L1	0	<30	7	220	<10	370	1.4	101	0.23	0.16
L2	5	<30	6.8	220	<10	370	4.8	103	0.21	0.2
L3	10	<30	6.9	220	<10	330	4.2	100	0.2	0.23
L4	15	<30	7	230	12	370	4.5	102	0.19	0.25
Blank		<30	0.08	<4	<10	<20	<0.1	<0.2	no sample	no sample
Volume (L)	2.76									
3T1A										
L1	0	<30	7.3	240	<10	430	1.5	110	0.22	0.2
L2	5	<30	7.2	240	<10	340	4.7	114	0.2	0.29
L3	10	<30	7.3	240	<10	380	4.3	113	0.22	0.26
L4	15	<30	7.3	250	<10	370	4	111	0.21	0.21
Volume (L)	3.23									
June 1995										
5T5a										
L1	0	<30	5	130	<10	130	0.94	52	no sample	no sample
L2	5	<30	4.8	150	<10	150	7.5	59	no sample	no sample
L3	10		no samples							
L4	15		no samples							
Volume (L)	2.14									
5T5b										
L1	0	<30	4.2	110	<10	130	0.93	46	no sample	no sample
L2	5	<30	4.4	130	<10	120	9 8	57	no sample	no sample
L3	10		no samples							
L4	15		no samples							
Volume (L)	1.94									

Table 8. Composition and precision of control samples as a function of time for Terrace Reservoir project.

1SWB2FA	diss Al	diss B	diss Ba	diss Be	diss Ca	diss Cd	diss Co	diss Cr	diss Cu	diss Fe	diss K
	ppm	ppb	ppb	ppb	ppm	ppb	ppb	ppb	ppb	ppm	ppm
June 1993	12	110	29	<20	44	<40	92	<40	8600	17	<5
June 1994	11	120	22	<10	45	12	90	<10	7800	16	1.5
July 1994	12	110	22	<10	46	12	78	<10	7900	18	1.4
Aug 1994	13	130	23	<10	48	11	91	<10	8700	16	1.7
Sep 1994	11	120	19	<10	44	<10	88	<10	8000	13	1.2
June 1995	13	120	25	<10	48	11	87	<10	7900	18	1.8
Precision (%)	6.8	5.8	13		3.7	6.7	5.3		4.4	10	14

1SWG1FA	diss Al	diss B	diss Ba	diss Be	diss Ca	diss Cd	diss Co	diss Cr	diss Cu	diss Fe	diss K
	ppm	ppb	ppb	ppb	ppm	ppb	ppb	ppb	ppb	ppm	ppm
June 1993	<1	<50	<20	<20	13	<40	<40	<40	360	<1	<1
June 1994	0.1	<20	17	<10	14	<10	12	<10	360	0.4	<1
July 1994	0.1	<20	17	<10	14	<10	<10	<10	360	0.9	<1
Aug 1994	0.22	<20	19	<10	15	<10	10	<10	390	1	0.33
Sep 1994	0.27	<20	16	<10	14	<10	13	<10	400	0.85	<0.2
June 1995	<0.1	<20	18	<10	16	<5	<10	<10	340	0.77	0.73
Precision (%)	43		5.9		6.6		11		5.5	26	

1SWB2FA	diss Li	diss Mg	diss Mn	diss Mo	diss Na	diss Ni	diss Pb	diss Si	diss Sr	diss V	diss Zn
	ppb	ppm	ppm	ppb	ppm	ppb	ppb	ppm	ppb	ppb	ppb
June 1993	<40	6	2.4	<80	47	95	<80	6	170	<40	1700
June 1994	<20	5.9	2.4	<20	49	83	<30	6.6	180	<10	1700
July 1994	<20	6.1	2.4	<20	50	88	<30	6.7	160	<10	1700
Aug 1994	<20	6.3	2.6	<20	54	97	<30	7.2	200	<10	1800
Sep 1994	<20	5.8	2.3	<20	49	91	<30	6.5	180	<10	1700
June 1995	<20	6.1	2.6	<20	52	81	<30	6.5	170	<10	1500
Precision (%)		2.6	4.6		4.5	6.6		5.4	5.6		5.3

1SWG1FA	diss Li	diss Mg	diss Mn	diss Mo	diss Na	diss Ni	diss Pb	diss Si	diss Sr	diss V	diss Zn
	ppb	ppm	ppm	ppb	ppm	ppb	ppb	ppm	ppb	ppb	ppb
June 1993	<40	2	0.31	<80	6	<40	<80	4	93	<40	180
June 1994	<20	2.2	0.31	<20	6	<30	<30	4.6	100	<10	190
July 1994	<20	2.2	0.32	<20	6.2	<30	<30	4.6	100	<10	190
Aug 1994	<20	2.3	0.34	<20	7	<30	<30	4.9	110	<10	190
Sep 1994	<20	2.3	0.34	<20	7	<30	<30	4.9	110	<10	190
June 1995	<20	2.2	0.34	<20	7.6	<10	<30	4.6	100	<10	170
Precision (%)		4.5	4.2		9.1			6.5	5.9		4.1

1SWB2FA (originally collected in June 1993 from the Wightman Fork at 0.5 km upstream of its confluence with the Alamosa River)
1SWG1FA (originally collected in June 1993 from the Alamosa River at 2 km upstream of Terrace Reservoir in June 1993)

Table 9. Porosity and composition of sediments in core 2 at sites T5, T2B, and T1A in Terrace Reservoir in June 1994. Depth intervals in cores are in units of centimeters.

1T52	porosity	sed Ag	sed Al	sed As	sed Cd	sed Co	sed Cr	sed Cu	sed Fe	sed Hg	sed Mn	sed Ni	sed Pb	sed Sb	sed Ti	sed Zn
		ppm	wt %	ppm	ppm	ppm	ppm	ppm	wt %	ppm	ppm	ppm	ppm	ppm	wt %	ppm
0-0.5	0.99	<0.5	10.1	83	0.2	23	20	4000	10.9	no data	390	5	62	1.6	0.25	157
0.5-1	0.97	<0.5	9.7	96	0.5	20	21	3400	8.2	no data	450	9	68	2.2	0.33	200
1-1.5	0.93	<0.5	9.6	65	0.5	18	21	2300	6.5	no data	490	11	66	1.9	0.37	190
1.5-2	0.87	<0.5	9.2	37	0.4	15	19	1100	5.5	no data	550	8	65	1.7	0.43	139
2-3	0.67	<0.5	8.7	25	0.6	15	18	710	5.2	no data	560	11	58	2.1	0.47	133
2-3 DUP		<0.5	8.1	23	0.5	14	16	670	4.9	no data	530	9	62	1.9	0.44	123
3-4	0.67	<0.5	7.7	23	0.6	15	17	610	4.8	no data	530	10	56	2.1	0.44	123
4-6	0.69	<0.5	7.4	24	0.8	16	14	820	4.6	no data	520	9	54	2	0.4	138

1T2B2	porosity	sed Ag	sed Al	sed As	sed Cd	sed Co	sed Cr	sed Cu	sed Fe	sed Hg	sed Mn	sed Ni	sed Pb	sed Sb	sed Ti	sed Zn
		ppm	wt %	ppm	ppm	ppm	ppm	ppm	wt %	ppm	ppm	ppm	ppm	ppm	wt %	ppm
0-0.5	0.96	<0.5	9.7	61	0.1	15	19	2300	8.1	0.42	490	8	71	2.7	0.31	314
0.5-1	0.91	0.8	9.7	64	<0.1	20	23	1800	8.5	0.73	380	9	90	3.4	0.34	164
1-1.5	0.92	0.9	10	65	0.6	25	24	1900	7.2	0.82	410	12	95	3.4	0.35	219
1.5-2	0.90	0.5	10.8	36	0.3	20	26	1000	6.4	0.4	470	14	69	1.9	0.36	142
2-3	0.92	<0.5	9.9	85	0.1	19	25	2200	8.2	0.24	430	11	48	1.8	0.33	139
3-4	0.93	<0.5	10.1	58	0.7	11	22	2000	10.1	0.32	360	10	73	1.8	0.28	153
4-6	0.87	0.6	9.8	56	0.2	10	20	840	7.5	0.25	380	6	77	2.1	0.34	116
4-6 DUP		0.5	9.6	53	0.1	10	19	760	7	0.27	370	7	75	2	0.36	118

1T1A2	porosity	sed Ag	sed Al	sed As	sed Cd	sed Co	sed Cr	sed Cu	sed Fe	sed Hg	sed Mn	sed Ni	sed Pb	sed Sb	sed Ti	sed Zn
		ppm	wt %	ppm	ppm	ppm	ppm	ppm	wt %	ppm	ppm	ppm	ppm	ppm	wt %	ppm
0-0.5	0.98	<0.5	9	76	1.1	13	22	2900	9.1	0.38	480	15	58	2.7	0.26	331
0.5-1	0.94	<0.5	10.3	74	0.6	16	23	2400	8.2	0.34	590	17	67	2.2	0.34	366
1-1.5	0.96	<0.5	9.6	53	0.7	18	22	2700	8.6	0.32	510	16	63	1.8	0.3	372
1.5-2	0.95	<0.5	9.9	33	0.3	16	26	1600	7.7	0.24	480	16	43	1.1	0.32	161
2-3	0.95	<0.5	10	69	0.1	12	24	2200	8.7	0.29	420	11	58	1.7	0.31	137
2-3 DUP		0.5	10.1	81	0.2	12	21	2200	8.6	0.26	420	10	55	1.6	0.31	135
3-4	0.94	0.7	10.2	53	0.1	11	22	2600	11.8	0.34	360	10	70	1.6	0.27	180
4-6	0.89	<0.5	9.8	56	<0.1	9	21	960	8.1	0.21	330	7	60	2.1	0.36	112

Table 10. Porosity and composition of sediments in core 2 at sites T5, T2B, and T1A in Terrace Reservoir in July 1994. Depth intervals in cores are in units of centimeters.

2T52	porosity	sed Ag ppm	sed Al wt %	sed As ppm	sed Cd ppm	sed Co ppm	sed Cr ppm	sed Cu ppm	sed Fe wt %	sed Mn ppm	sed Ni ppm	sed Pb ppm	sed Sb ppm	sed Ti wt %	sed Zn ppm
0-0.5	0.99	<0.5	10.5	163	<0.1	17	28	2010	8.9	310	3	87	1.6	0.27	110
0.5-1	0.97	<0.5	9.7	254	0.2	13	24	1730	6.9	440	8	64	2.8	0.33	120
1-1.5	0.91	<0.5	9.3	122	0.2	13	21	1590	6.5	530	11	69	2.5	0.39	150
1-1.5 DUP		<0.5	8.9	23	0.3	13	22	1520	6.2	500	11	62	2.5	0.37	140
1.5-2	0.92	<0.5	8.9	107	0.4	15	22	1940	6.6	510	11	70	2.8	0.38	200
2-3	0.89	<0.5	9.6	53	0.6	19	23	2270	8.8	510	14	60	2.1	0.39	270
3-4	0.96	<0.5	9.3	45	0.3	21	21	2590	6.8	450	12	62	1.8	0.35	200
4-6	0.82	<0.5	8.6	32	0.3	15	21	770	5.4	530	12	56	1.7	0.44	130

2T2B2	porosity	sed Ag ppm	sed Al wt %	sed As ppm	sed Cd ppm	sed Co ppm	sed Cr ppm	sed Cu ppm	sed Fe wt %	sed Mn ppm	sed Ni ppm	sed Pb ppm	sed Sb ppm	sed Ti wt %	sed Zn ppm
0-0.5	0.95	<0.5	10.4	73	0.2	12	22	1400	8.4	370	9	64	1.6	0.35	140
0.5-1	0.89	<0.5	10.5	65	0.1	10	23	770	7.4	350	6	75	1.5	0.36	110
1-1.5	0.86	<0.5	8.8	67	0.6	16	22	920	7	360	12	70	2.4	0.38	180
1-1.5 DUP		<0.5	8.4	33	0.6	16	22	870	6.6	340	12	70	2.5	0.36	170
1.5-2	0.74	<0.5	8.1	35	0.9	18	19	880	5.1	380	13	70	2.6	0.44	200
2-3	0.77	<0.5	7.9	44	0.7	16	15	870	5.2	370	9	72	2.6	0.4	190
3-4	0.81	<0.5	8.9	52	0.5	16	20	980	6	390	10	88	3	0.42	180
4-6	0.81	<0.5	8.5	44	0.3	16	22	950	6.6	420	12	83	2.5	0.42	180

2T1A2	porosity	sed Ag ppm	sed Al wt %	sed As ppm	sed Cd ppm	sed Co ppm	sed Cr ppm	sed Cu ppm	sed Fe wt %	sed Mn ppm	sed Ni ppm	sed Pb ppm	sed Sb ppm	sed Ti wt %	sed Zn ppm
0-0.5	0.92	<0.5	10.1	28	0.5	17	16	1100	9.2	430	12	64	1.7	0.3	220
0.5-1	0.87	<0.5	10.1	39	1.2	27	18	930	7.7	520	20	68	1.7	0.33	320
0.5-1 DUP		<0.5	9.8	40	1.1	26	19	880	7.3	490	20	66	1.9	0.32	300
1-1.5	0.87	<0.5	9.8	58	1.6	46	18	850	6.4	580	26	73	1.8	0.36	440
1.5-2	0.87	<0.5	10.2	38	1.5	51	22	860	6.9	620	27	95	2.1	0.36	470
2-3	0.84	<0.5	10.1	41	0.6	37	29	610	6.9	640	23	88	2.1	0.36	340
3-4	0.81	<0.5	10	28	0.6	29	19	530	6.4	680	17	67	1.8	0.41	270
4-6	0.82	<0.5	10.4	23	0.8	32	19	520	6.5	750	18	63	1.6	0.41	270

Table 11. Porosity and composition of sediments in core 2 at sites T5, T2B, and T1A in Terrace Reservoir in August 1994. Depth intervals in cores are in units of centimeters.

3T52	porosity	sed Ag	sed Al	sed As	sed Cd	sed Co	sed Cr	sed Cu	sed Fe	sed Mn	sed Ni	sed Pb	sed Sb	sed Ti	sed Zn
		ppm	wt %	ppm	ppm	ppm	ppm	ppm	wt %	ppm	ppm	ppm	ppm	wt %	ppm
0-0.5	0.93	<0.5	10.8	118	0.2	16	29	860	6.7	440	12	85	2.5	0.36	120
0.5-1	0.93	<0.5	10.2	194	0.2	14	24	1500	6.8	460	8	68	2.5	0.36	120
0.5-1 DUP		<0.5	10.2	195	0.3	14	25	1480	6.6	450	8	73	2.5	0.36	120
1-1.5	0.90	<0.5	9.2	118	0.4	15	23	1780	6.7	490	9	64	2.5	0.39	170
1.5-2	0.89	<0.5	9.4	75	0.5	17	23	1660	7.3	510	11	65	2.1	0.41	230
2-3	0.96	<0.5	10.2	89	0.4	51	21	4500	12.7	390	7	58	2.1	0.25	170
3-4	0.91	<0.5	10.2	83	0.3	19	21	3300	7.1	450	10	70	1.8	0.36	210
4-6	0.83	<0.5	9.2	35	0.4	17	21	1090	5.7	530	9	65	2	0.44	150

3T2B2	porosity	sed Ag	sed Al	sed As	sed Cd	sed Co	sed Cr	sed Cu	sed Fe	sed Mn	sed Ni	sed Pb	sed Sb	sed Ti	sed Zn
		ppm	wt %	ppm	ppm	ppm	ppm	ppm	wt %	ppm	ppm	ppm	ppm	wt %	ppm
0-0.5	0.94	<0.5	10.1	70	<0.1	10	21	1380	7.9	360	9	59	1.4	0.33	110
0.5-1	0.90	<0.5	10	68	<0.1	11	22	1080	7.8	350	8	54	1.5	0.36	120
1-1.5	0.90	<0.5	10.5	79	0.2	12	20	850	8.3	360	5	63	1.5	0.36	110
1-1.5 DUP		<0.5	10.6	76	<0.1	10	21	850	8.2	350	8	61	1.4	0.37	110
1.5-2	0.91	<0.5	10.3	79	<0.1	8	24	590	8.6	350	6	76	1.5	0.34	87
2-3	0.80	<0.5	8.2	43	0.8	17	20	910	5.7	380	11	70	2.7	0.43	180
3-4	0.72	<0.5	8.4	33	0.9	18	20	790	5.3	420	12	65	2.8	0.46	190
4-6	0.81	<0.5	8.1	45	0.6	17	21	990	6.1	400	204	76	2.7	0.42	170

3T1A2	porosity	sed Ag	sed Al	sed As	sed Cd	sed Co	sed Cr	sed Cu	sed Fe	sed Mn	sed Ni	sed Pb	sed Sb	sed Ti	sed Zn
		ppm	wt %	ppm	ppm	ppm	ppm	ppm	wt %	ppm	ppm	ppm	ppm	wt %	ppm
0-0.5	0.94	<0.5	10.8	60	0.1	13	22	1110	8.5	390	12	28	1.1	0.34	130
0.5-1	0.94	<0.5	9.9	78	0.1	12	24	930	10.7	380	12	53	1.5	0.29	130
1-1.5	0.91	<0.5	10.6	45	0.1	18	20	950	9.7	490	17	46	1.3	0.32	210
1-1.5 DUP		<0.5	11.1	47	0.3	19	20	990	9.8	500	16	58	1.5	0.34	220
1.5-2	0.88	<0.5	10.8	31	1.3	26	18	610	6.9	620	20	63	1.8	0.35	300
2-3	0.85	<0.5	10.5	27	1	47	20	740	6.8	700	27	61	1.7	0.39	400
3-4	0.86	<0.5	10.8	38	0.3	41	24	680	7.4	780	22	73	1.9	0.4	350
4-6	no sample														

Table 12. Porosity and composition of sediments in core 2 at sites T5, T2B, and T1A in Terrace Reservoir in September 1994. Depth intervals in cores are in units of centimeters.

4T52	porosity	sed Ag ppm	sed Al wt %	sed As ppm	sed Cd ppm	sed Co ppm	sed Cr ppm	sed Cu ppm	sed Fe wt %	sed Mn ppm	sed Ni ppm	sed Pb ppm	sed Sb ppm	sed Ti wt %	sed Zn ppm
0-0.5	0.99	<0.5	11.1	131	0.2	29	24	4400	9.3	370	3	72	3.5	0.24	127
0.5-1	0.94	<0.5	10.8	103	0.1	20	23	2300	7.3	320	5	83	2.8	0.34	133
8	0.87	<0.5	10.1	62	0.5	15	22	1100	6.4	510	10	79	2.5	0.44	147
1.5-2	0.83	<0.5	9.2	56	0.5	13	20	890	5.5	460	10	80	2.4	0.42	134
2-3	0.78	<0.5	9	50	0.6	15	19	1000	5.4	470	10	72	2.6	0.43	147
2-3 DUP		<0.5	8.6	50	0.7	14	17	940	5.2	450	9	76	2.5	0.41	140
3-4	0.76	<0.5	8.4	47	0.6	16	18	1000	5.2	450	10	66	2.3	0.41	141
4-6	0.75	<0.5	8.5	43	0.7	16	18	1100	5.3	460	9	63	2.7	0.42	149

4T2B2	porosity	sed Ag ppm	sed Al wt %	sed As ppm	sed Cd ppm	sed Co ppm	sed Cr ppm	sed Cu ppm	sed Fe wt %	sed Mn ppm	sed Ni ppm	sed Pb ppm	sed Sb ppm	sed Ti wt %	sed Zn ppm
0-0.5	0.92	<0.5	10.6	55	<0.1	14	21	1100	6.7	390	9	75	1.9	0.36	155
0.5-1	0.91	<0.5	10.9	55	0.2	16	25	1400	7.8	420	11	60	1.5	0.36	136
1-1.5	0.89	<0.5	10.6	44	0.1	12	18	800	7	380	6	50	1.2	0.37	116
1.5-2	0.94	<0.5	11	110	0.1	9	23	880	10.7	320	5	70	1.7	0.26	86
2-3	0.89	<0.5	11.8	56	<0.1	6	23	475	8	360	3	98	1.5	0.32	80
3-4	0.94	<0.5	9.4	81	<0.1	10	26	780	11.8	370	5	63	2	0.28	115
4-6	0.78	<0.5	8.7	29	0.9	17	19	1000	5.3	390	8	67	2.6	0.44	186

4T1A2	porosity	sed Ag ppm	sed Al wt %	sed As ppm	sed Cd ppm	sed Co ppm	sed Cr ppm	sed Cu ppm	sed Fe wt %	sed Mn ppm	sed Ni ppm	sed Pb ppm	sed Sb ppm	sed Ti wt %	sed Zn ppm
0-1	0.95	<0.5	10.3	80	0.2	10	21	1500	10.4	330	9	56	1.8	0.28	145
1-2	0.95	<0.5	10.6	75	0.2	13	25	1600	11.4	380	11	64	1.9	0.29	169
2-2.75	0.93	<0.5	10.3	59	0.2	13	24	1000	11.5	420	10	67	1.9	0.29	152
2.75-3.5	0.92	<0.5	10.8	45	0.2	21	23	1200	9.8	510	18	63	1.6	0.31	240
3.5-4	0.90	<0.5	10.5	38	0.5	30	22	1100	8.7	640	24	77	1.8	0.31	370
4-5	0.85	<0.5	11.4	22	1.7	32	35	560	6.5	670	24	71	1.8	0.38	320
4-5 DUP		<0.5	11.1	17	2.2	30	18	530	6.3	650	20	77	2	0.37	320
5-6	0.87	<0.5	11.1	26	1	53	22	1000	7	760	31	70	1.6	0.38	430

Table 13. Porosity and composition of sediments in core 2 at sites T5, T2B, and T1A in Terrace Reservoir in June 1995. Depth intervals in cores are in units of centimeters.

5T52	porosity	sed Ag ppm	sed Al wt %	sed As ppm	sed Cd ppm	sed Co ppm	sed Cr ppm	sed Cu ppm	sed Fe wt %	sed Hg ppm	sed Mn ppm	sed Ni ppm	sed Pb ppm	sed Sb ppm	sed Ti wt %	sed Zn ppm
0-0.5	0.87	0.6	9.4	48	0.2	16	19	1600	8.4	0.23	440	12	59	2.5	0.41	200
0.5-1	0.73	0.5	9.4	41	0.4	16	24	1300	6.6	0.28	480	12	61	2.4	0.44	150
1-1.5	0.70	<0.5	8.9	35	0.4	14	17	830	5.7	0.23	510	10	59	2.6	0.45	130
1-1.5 DUP		<0.5	8.7	35	0.3	14	17	840	5.7	0.28	500	10	59	2.4	0.45	130
1.5-2	0.69	<0.5	8.6	36	0.5	14	17	840	5.6	0.27	530	11	63	2.7	0.46	140
2-3	0.66	<0.5	8.5	34	0.4	13	16	760	5.6	0.2	510	9.7	61	2.7	0.46	120
3-4	0.69	0.5	8.9	44	0.5	15	17	990	6.3	0.3	530	11	65	2.8	0.45	140
4-6	0.70	0.5	9.3	56	0.4	16	20	1200	6.6	0.39	540	11	77	3.4	0.45	150

5T2B2	porosity	sed Ag ppm	sed Al wt %	sed As ppm	sed Cd ppm	sed Co ppm	sed Cr ppm	sed Cu ppm	sed Fe wt %	sed Hg ppm	sed Mn ppm	sed Ni ppm	sed Pb ppm	sed Sb ppm	sed Ti wt %	sed Zn ppm
0-0.5	0.93	0.5	12	66	0.3	13	20	1100	8.2	0.28	400	11	79	2.6	0.39	160
0.5-1	0.93	<0.5	11	78	0.2	12	19	1200	8.8	0.22	390	11	65	2.4	0.37	140
1-1.5	0.91	<0.5	12	48	0.2	15	23	1400	8.5	0.33	430	13	64	1.8	0.38	130
1.5-2	0.93	<0.5	10	89	0.2	16	22	2500	9.2	0.3	410	13	52	2.1	0.37	160
2-3	0.89	<0.5	10	58	0.1	11	19	990	8.9	0.25	370	9	74	2.2	0.39	120
3-4	0.69	<0.5	11	57	0.1	13	18	910	7.8	0.18	390	11	53	1.8	0.41	130
4-6	0.93	<0.5	10	97	0.1	8.1	25	670	11	0.33	360	5.9	82	2.2	0.32	87

5T1A2	porosity	sed Ag ppm	sed Al wt %	sed As ppm	sed Cd ppm	sed Co ppm	sed Cr ppm	sed Cu ppm	sed Fe wt %	sed Hg ppm	sed Mn ppm	sed Ni ppm	sed Pb ppm	sed Sb ppm	sed Ti wt %	sed Zn ppm
0-0.5	0.95	0.5	9.9	75	0.3	11	21	2200	13	0.3	380	12	61	2.6	0.3	170
0.5-1	0.93	0.7	10	62	0.4	14	19	1400	12	0.35	490	13	74	2.7	0.31	230
1-1.5	0.91	0.6	10	49	0.9	26	18	1400	9.6	0.31	540	24	76	2.6	0.34	360
1.5-2	0.89	0.6	11	46	2.2	44	19	1200	8.1	0.36	550	39	94	2.7	0.38	640
2-3	0.87	0.5	12	40	2.2	50	20	820	7.2	0.35	570	33	92	2.6	0.4	580
3-4	0.83	0.6	10	35	1	46	18	560	6.9	0.35	630	23	73	2.3	0.43	360
3-4 DUP		<0.5	10	32	0.9	46	18	560	6.9	0.34	630	24	74	2.3	0.41	360
4-6	0.82	0.5	10	29	0.7	41	18	660	7.3	0.26	720	22	64	2.1	0.42	320

Table 14. 1 M HCl leach data for surface (0-0.5 cm) sediment and equilibrium concentrations of free Cu(II), Zn(II), and Co(II) in bottom water or overlying water at sites T5, T2B, and T1A in Terrace Reservoir during 1994 and 1995.

Sample	Fe µmole/g	Mn µmole/g	Cu µmole/g	Zn µmole/g	Co µmole/g	[Cu(II)] µmole/L	[Zn(II)] µmole/L	[Co(II)] µmole/L
1T51	880	2.0	48	0.94	0.25	12	3.1	0.18
1T2B1	620	2.8	20	0.91	0.24	11	3.1	0.21
1T1A1	930	2.9	32	1.8	0.26	11	3.0	0.20
2T51	660	3.7	25	1.3	0.22	17	5.1	0.32
2T2B1	1060	2.8	34	2.3	0.27	16	4.5	0.29
2T1A1	1210	2.6	15	1.3	0.29	15	6.3	0.30
3T51	380	2.7	7.9	0.66	0.14	9.1	5.6	0.40
3T2B1	540	2.5	15	0.91	0.19	13	4.4	0.33
3T1A1	830	7.2	12	1.6	0.32	14	4.5	0.35
4T51	800	0.85	57	0.96	0.29	4.7	2.9	0.26
4T2B1	1370	1.3	28	1.1	0.28	12	3.9	0.28
4T1A1	1410	1.7	22	0.96	0.29	12	3.8	0.29
5T51	440	3.8	16	1.1	0.21	0.25	1.1	0.11
5T51						0.30	1.1	0.11
5T2B1	710	2.7	11	1.4	0.19	0.15	0.70	0.11
5T2B1						0.15	0.71	0.11
5T1A1	1390	2.1	30	1.2	0.28	0.22	0.57	0.11
5T1A1						0.23	0.60	0.11

Equilibrium concentrations of free Cu, Zn, and Co calculated using HYDRAQL (see text) and total composition of bottom water (6/94, 7/94, 8/94, 9/94) and overlying water in cores (6/95).

Table 15. Summary of dissolved Cu, Zn, Co, and Mn fluxes at sites T5, T2B, and T1A in Terrace Reservoir during 1994 and 1995.
Negative flux = flux from water column to sediment porewater
Positive flux = flux from sediment porewater to water column

Site	Time	diss Cu core 1 µg/cm^2/y	diss Cu core 2 µg/cm^2/y	diss Cu lander µg/cm^2/y	diss Zn core 1 µg/cm^2/y	diss Zn core 2 µg/cm^2/y	diss Zn lander µg/cm^2/y
T5	6/94	380	-340				
T5	7/94	-600	-240	-260	-210	-100	-22
T5	8/94	1500	210		300	23	
T5	9/94	380	510		90	130	
T5	6/95 a	190	130	350	72	140	180
T5	6/95 b			420			-82
T2B	6/94	-480	100				
T2B	7/94	1100	-340		450	-4.4	
T2B	8/94	-270	370	-300	-26	61	0
T2B	9/94	-160	-370		17	17	
T2B	6/95	310	450		230	280	
T1A	6/94	-350	-270				
T1A	7/94	-640	-680	-690	-180	-240	130
T1A	8/94	-540	-670	-490	-160	-280	-280
T1A	9/94	-600	-290		-150	-73	
T1A	6/95	390	260		73	83	

Site	Time	diss Co core 1 µg/cm^2/y	diss Co core 2 µg/cm^2/y	diss Co lander µg/cm^2/y	diss Mn core 1 mg/cm^2/y	diss Mn core 2 mg/cm^2/y	diss Mn lander mg/cm^2/y
T5	6/94	27	20		4.7	4.8	
T5	7/94	17	11	25	6.8	3.7	1.9
T5	8/94	30	22		1.4	3.4	
T5	9/94	22	25		1.9	2.7	
T5	6/95 a				2.8	1.5	0.64
T5	6/95 b						1.5
T2B	6/94	8.5	18		1.7	1.1	
T2B	7/94	12	8.8		0.82	1.2	
T2B	8/94	19	16	19	2.1	1.3	1.7
T2B	9/94	6.7	18		0.91	1.6	
T2B	6/95				0.34	0.72	
T1A	6/94	0.90	7.7		0.15	0.12	
T1A	7/94	1.1	-2.2	0	0.41	0.36	0.32
T1A	8/94	-1.8	-2.4	-14	-0.05	0.18	0.55
T1A	9/94	1.1	0.85		0.71	0.27	
T1A	6/95				0.022	0.029	

Zn fluxes for 6/94 not calculated due to blank contamination.

Co fluxes for 6/95 not calculated due to concentrations below the detection limits in the overlying water and benthic flux chamber samples.

Table 16. Comparison of dissolved Cu and Zn fluxes across the sediment-water interface in aquatic systems impacted by mining activities. Negative fluxes indicate fluxes from the water column to the sediment porewater. Positive fluxes indicate fluxes from the sediment porewater to the water column.

Lake	pH overlying water column	Cu flux $\mu g\ cm^{-2}\ y^{-1}$	Zn flux $\mu g\ cm^{-2}\ y^{-1}$	Reference
-Buttle Lake B.C., Canada	7.5	-0.8	-16	Pedersen, 1983
-Clearwater Lake Ontario, Canada	4.5-5.5	------	-1.71	Carignan & Tessier, 1985
-Tantare Lake Quebec, Canada	5.3-5.5	------	-0.96	"
-Clearwater Lake Ontario, Canada				Carignan & Nriagu, 1985
15 m	4.6	-5.1	------	
20 m	6.1	-3.5	------	
-McFarlane Lake Ontario, Canada	7.5-8.0	-0.5	------	"
-40 Canadian lakes	4-6.1	------	-0.5 to -2.4*	Tessier & others, 1989
	6.1-8.4	------	-0.09 to 0.28*	
-Anderson Lake Manitoba, Canada	~7.5	negative (no value)	negative (no value)	Pedersen & others, 1993
-Pacheta Lake Arizona, USA	7.5	13	22	Williamson & Parnell, 1994
-Terrace Reservoir Colorado, USA	4.2-5.5	-690 to -160 (n = 20)	-280 to -4 (n = 20)	This study
	5.5-7.2	100 to 510 (n = 10)	17 to 300 (n = 10)	

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* assumes $D_0 = 4.5 \times 10^{-6}\ cm^2\ s^{-1}$ and porosity effects negligible (Carignan and Tessier, 1985).

Table A1. Temperature of the deepest samples in the water column as a function of site in Terrace Reservoir and time. Temperature in ^{0}C.

Date	T5	T2B	T1A
June 1994	7.6	8.1	8.4
July 1994	13.3	14.1	13.4
Aug 1994	11.4	15.2	15.3
Sept 1994	13	11.9	11.8
June 1995	4.8	5.5	5.7

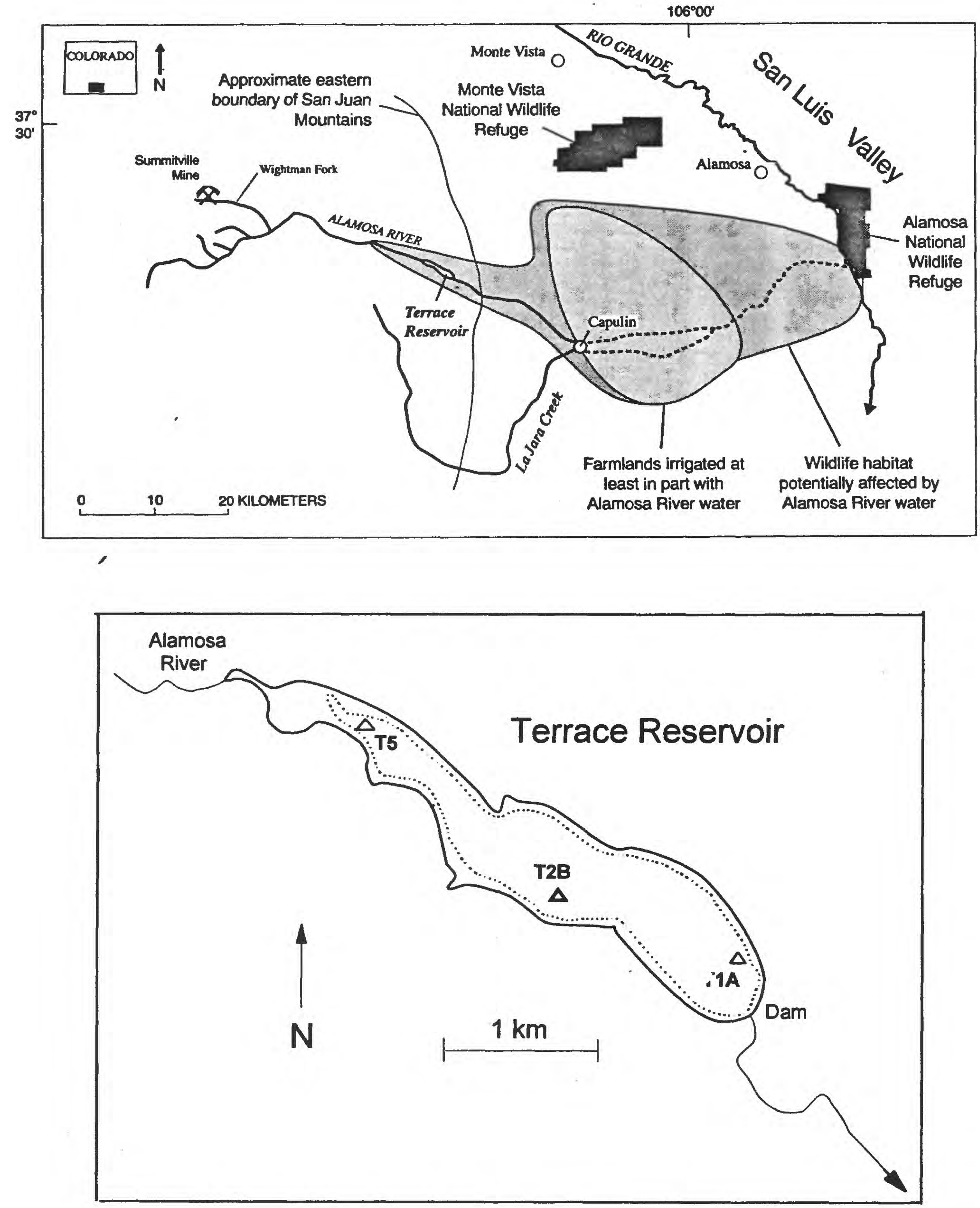

Fig. 1. Maps of the area from Summitville Mine to the San Luis Valley and location of study sites T5, T2B, and T1A in Terrace Reservoir, Conejos County, Colorado.

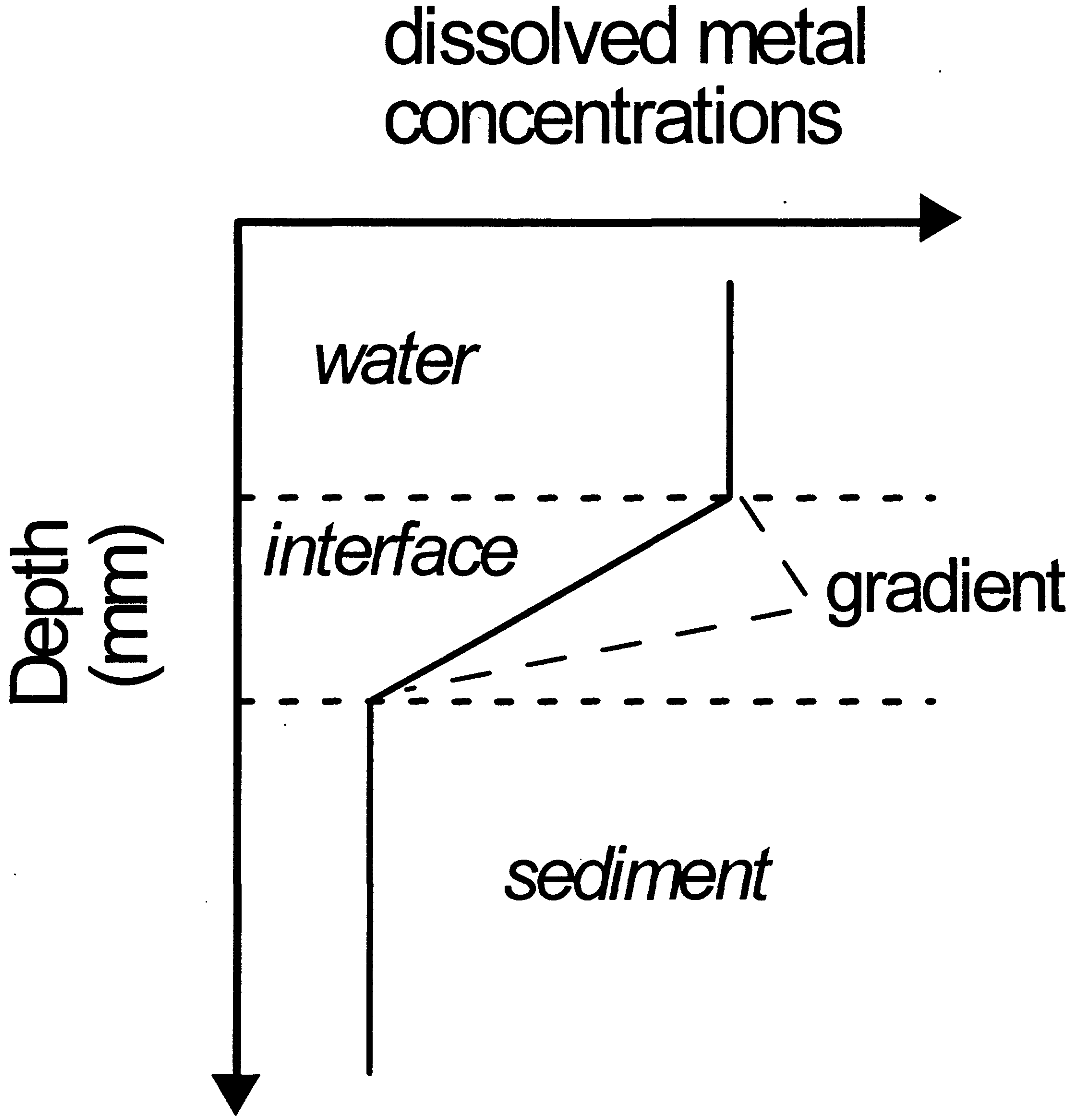

Fig. 2. Diagram of the gradient or change in dissolved metal concentration as a function of depth across the sediment-water interface.

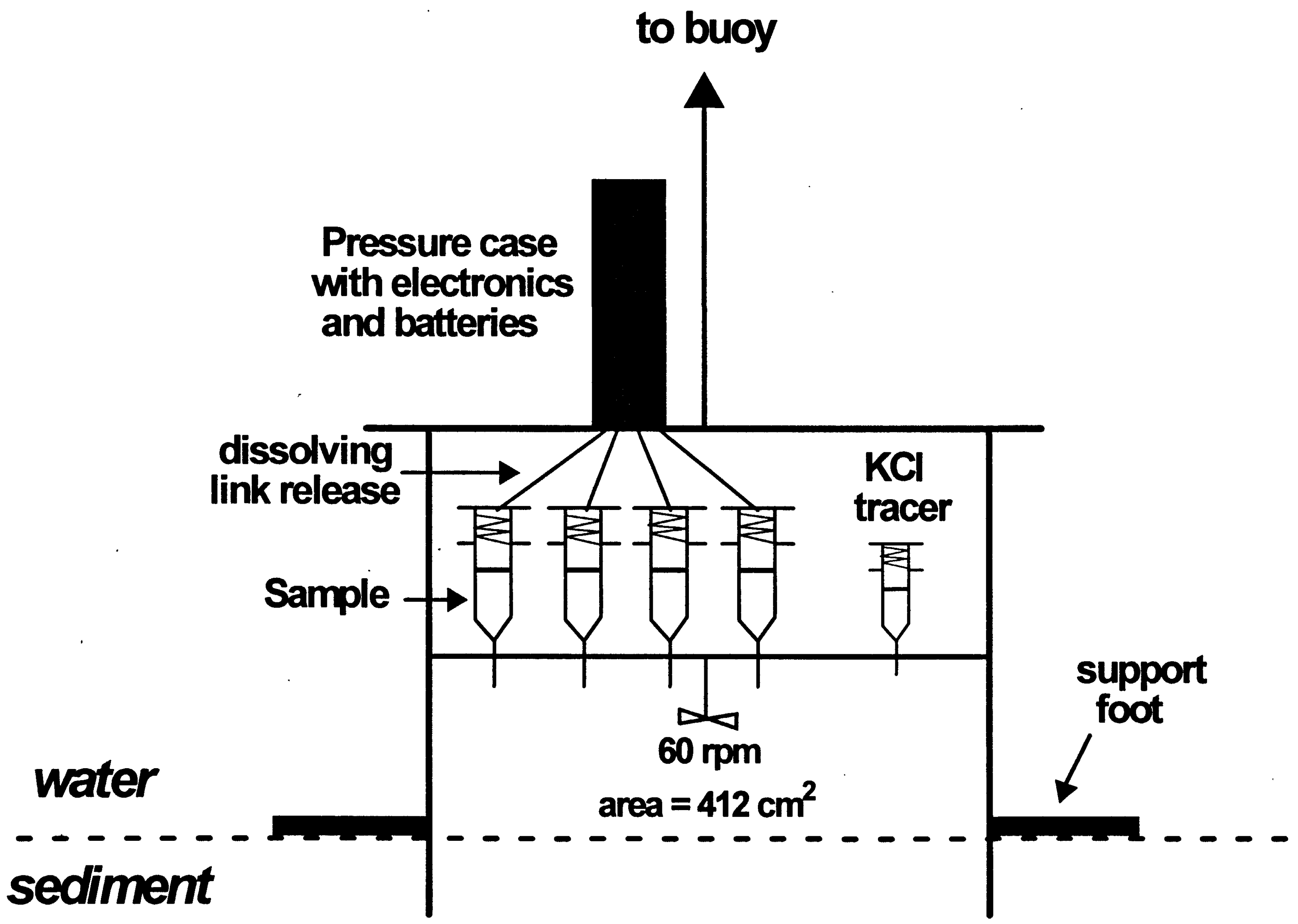

Fig. 3. Schematic diagram of benthic flux chamber or lander.

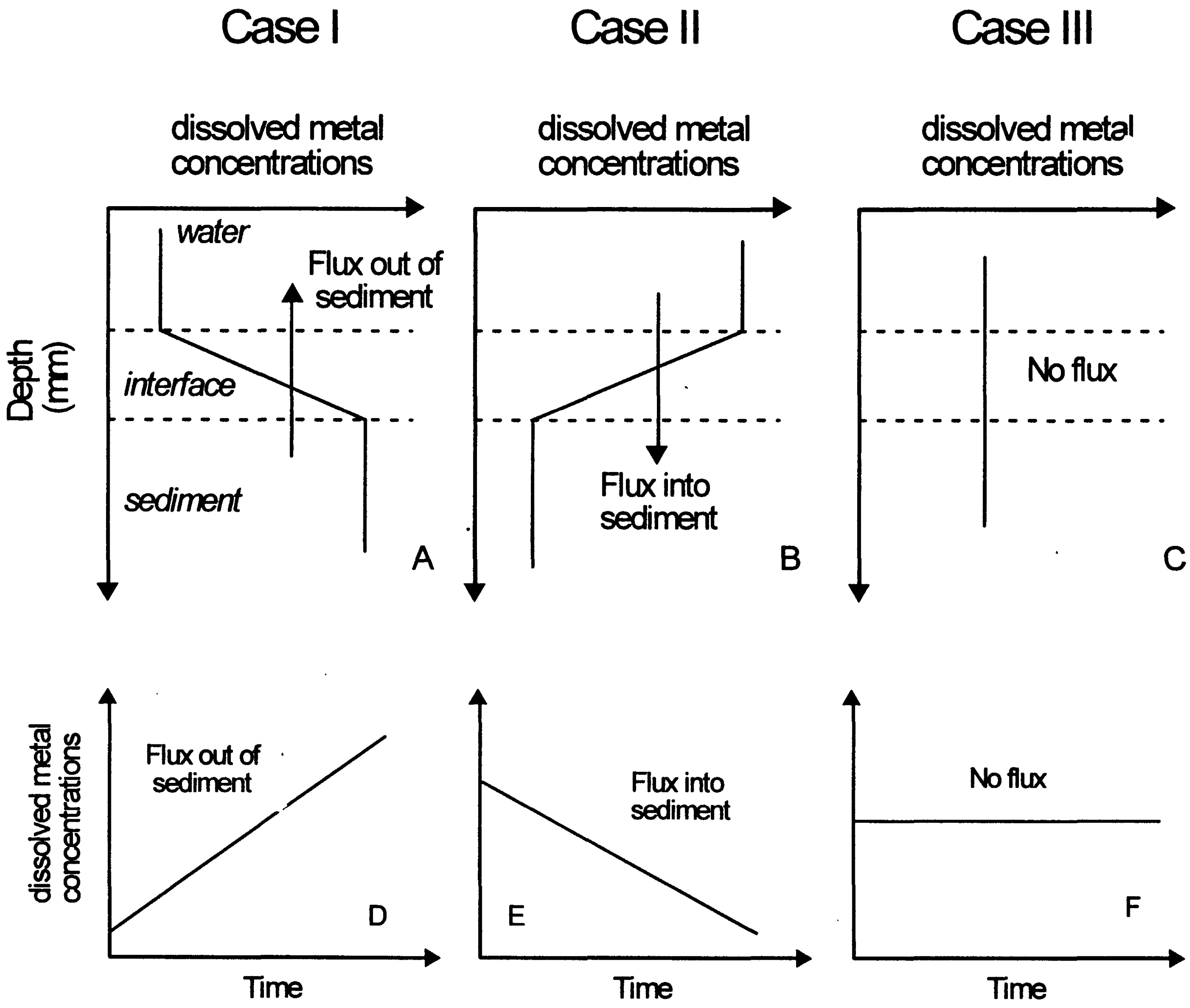

Fig. 4. Schematic diagrams of core (a, b, c) and benthic flux chamber (d, e, f) data for three flux cases. Case I: Flux from sediment porewater to water column. Case II: Flux from water column to sediment porewater. Case III: No flux.

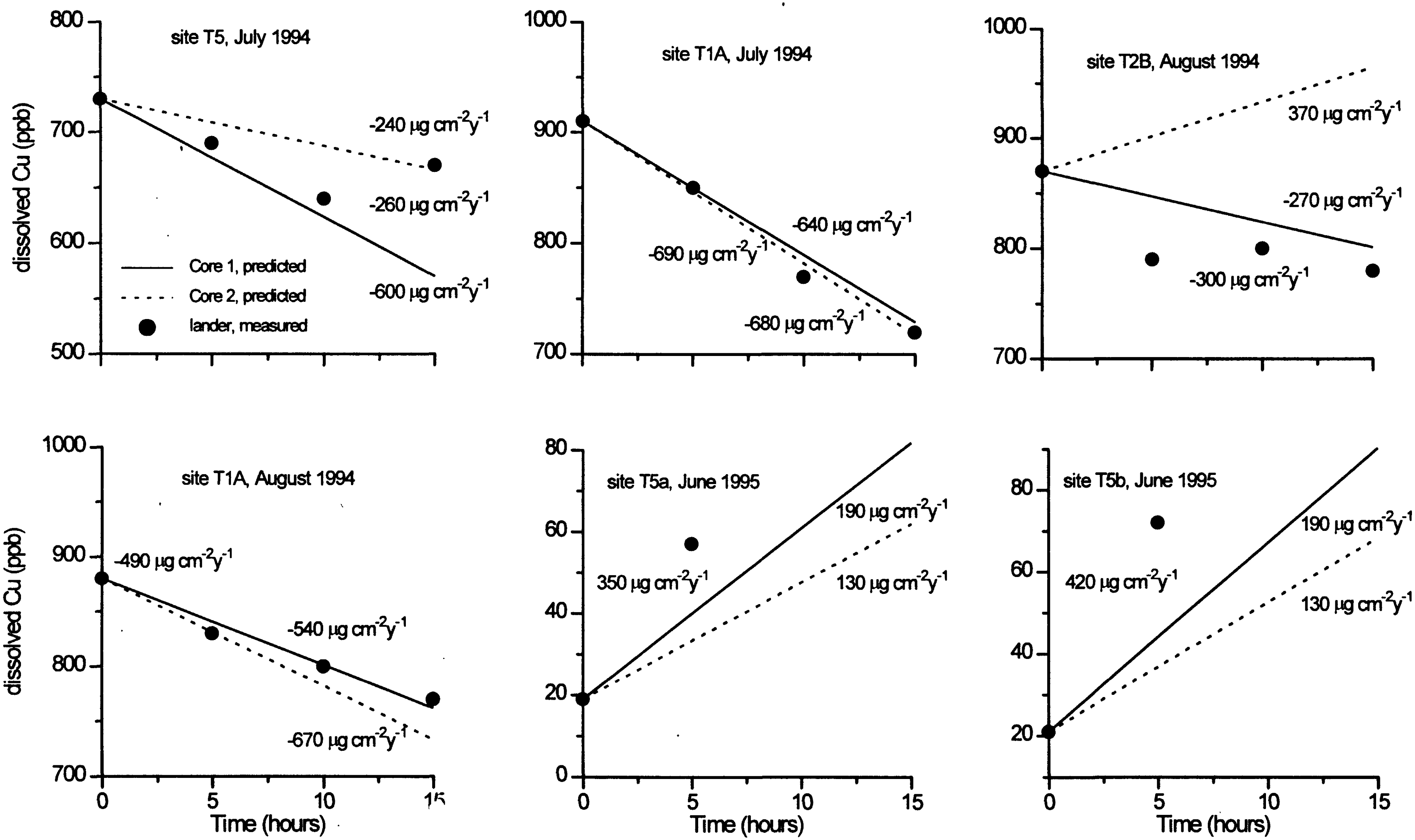

Fig. 5. Comparisons of observed dissolved Cu data from lander samples and predictions of changes in dissolved Cu concentrations as a function of time based on measured core fluxes. Values of measured Cu fluxes are also given.

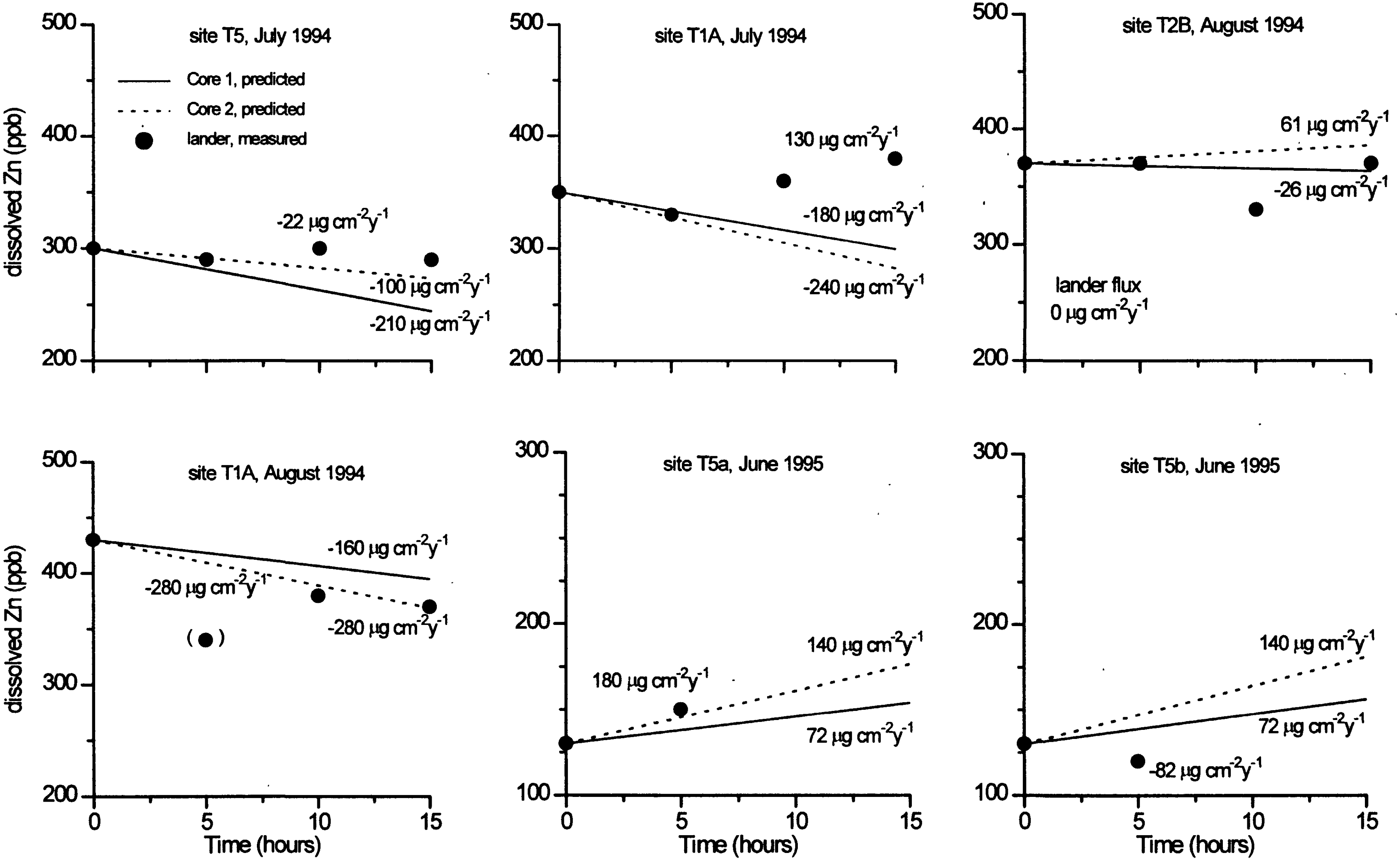

Fig. 6. Comparisons of observed dissolved Zn data from lander samples and predictions of changes in dissolved 7n concentrations as a function of time based on measured core fluxes. Values of measured Zn fluxes are also given.

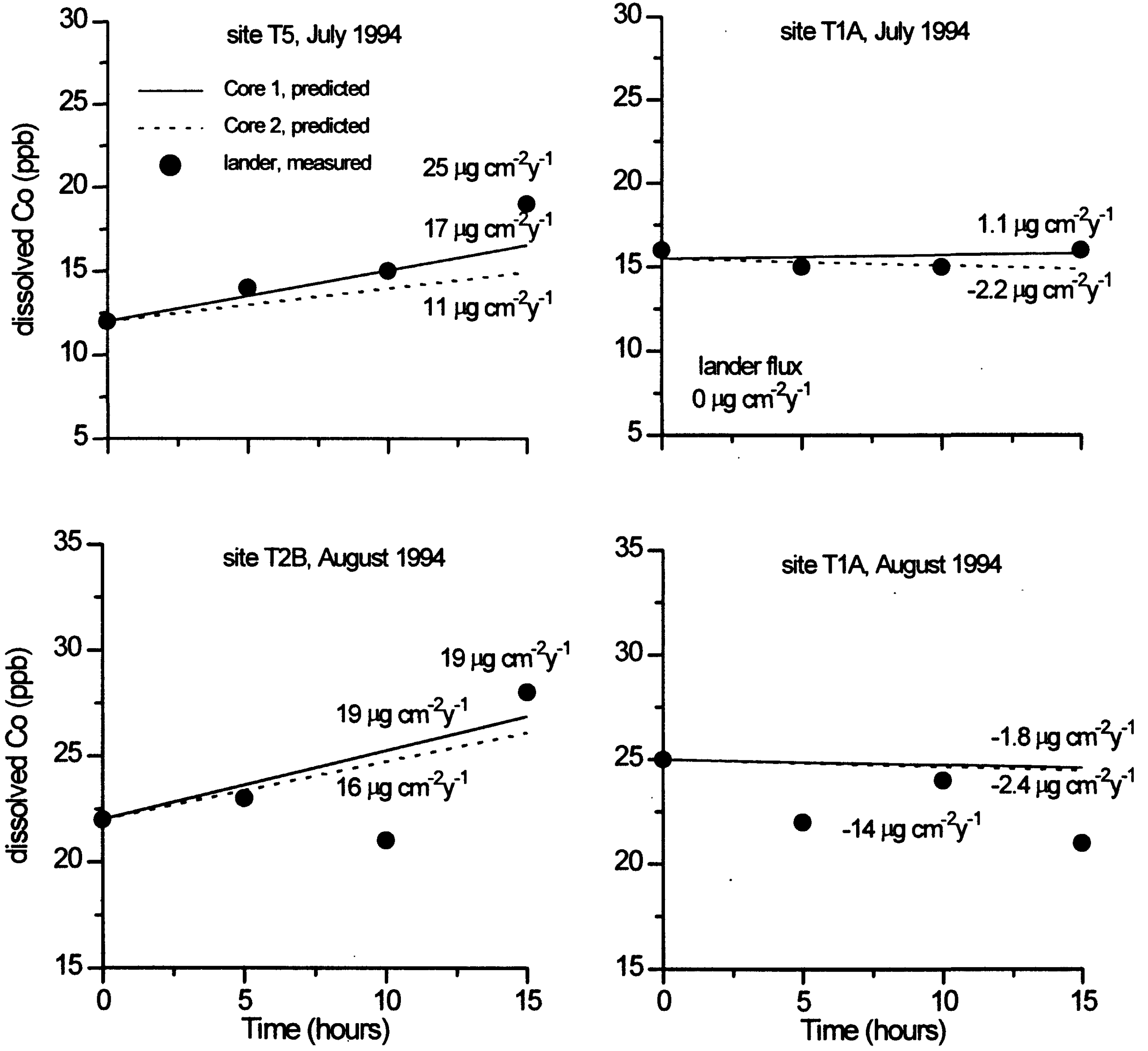

Fig. 7. Comparisons of observed dissolved Co data from lander samples and predictions of changes in dissolved Co concentrations as a function of time based on measured core fluxes. Values of measured Co fluxes are also given. Dissolved Co in lander samples for June 1995 were below the detection limits for the ICP-AES.

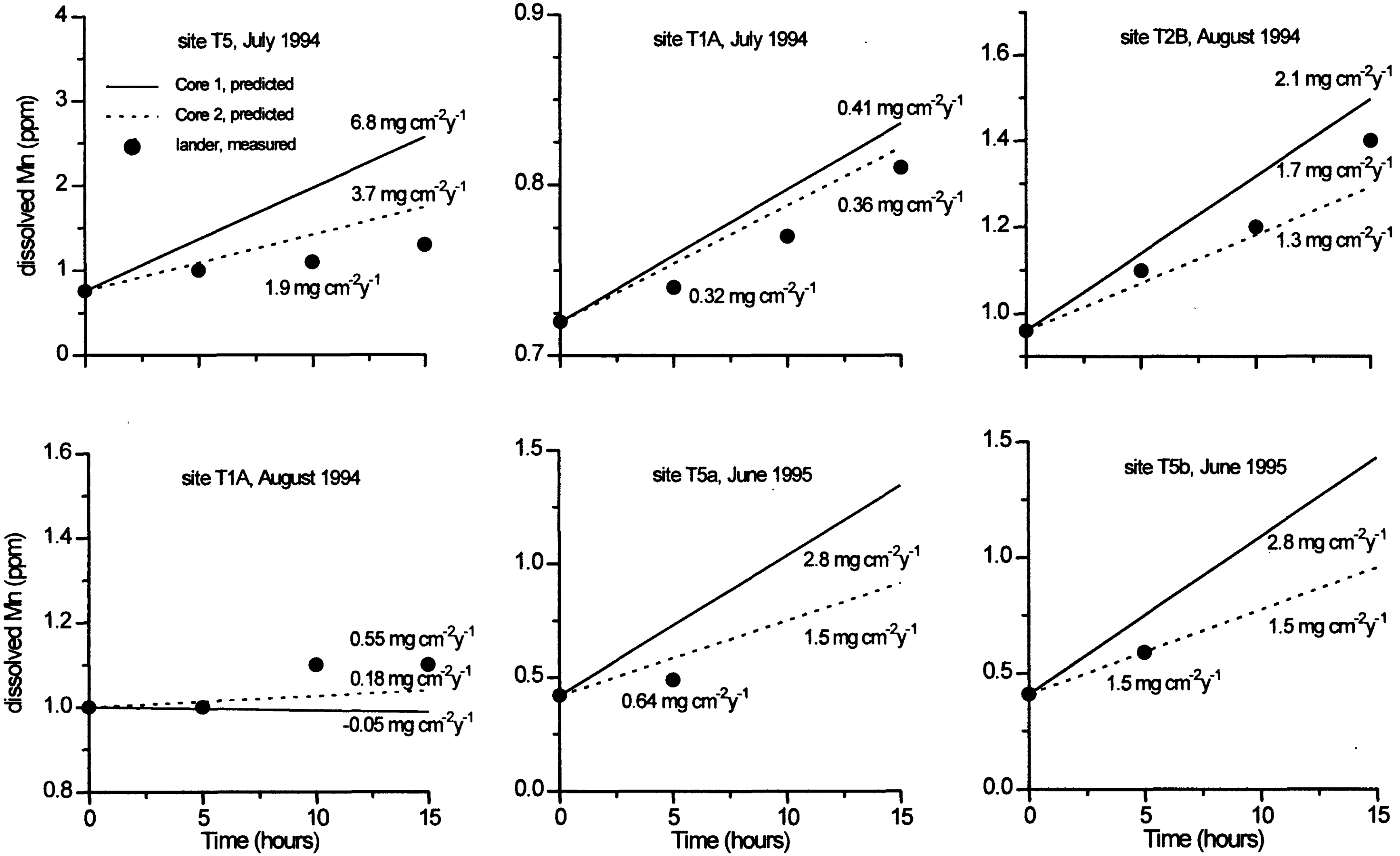

Fig. 8. Comparisons of observed dissolved Mn data from lander samples and predictions of changes in dissolved Mn concentrations as a function of time based on measured core fluxes. Values of measured Mn fluxes are also given.

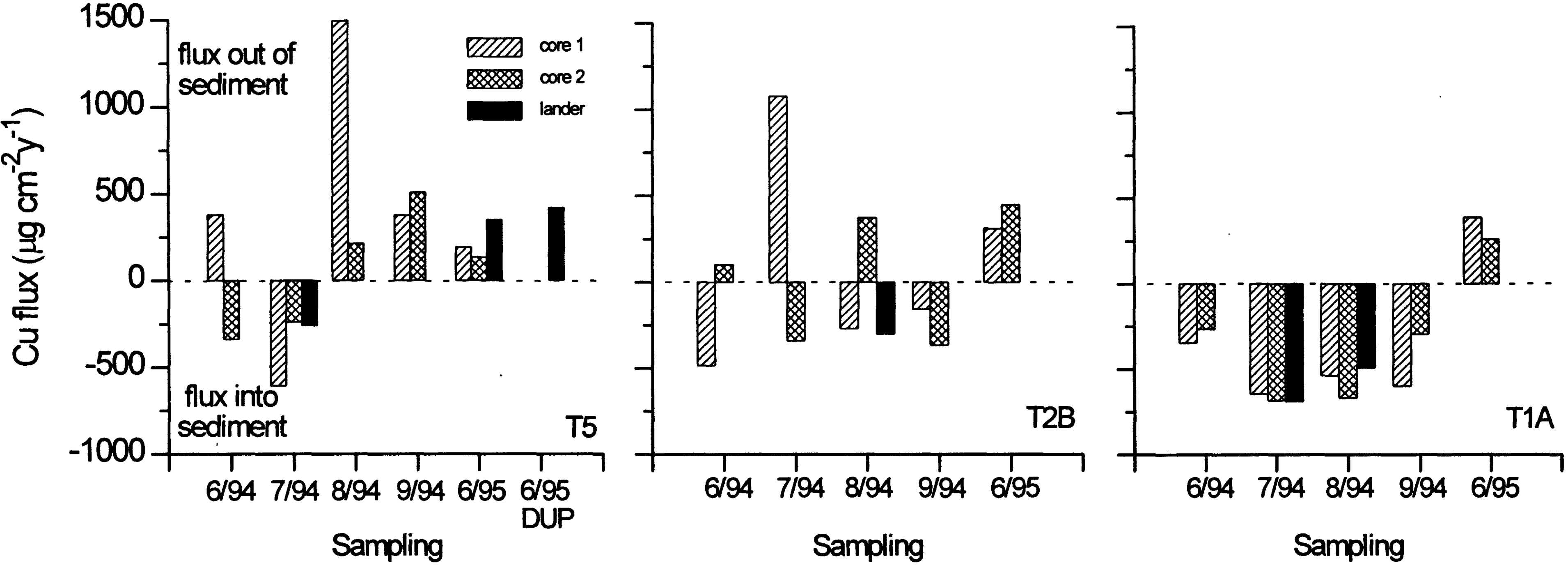

Fig. 9. Direction and magnitude of dissolved Cu fluxes at sites T5, T2B, and T1A in Terrace Reservoir during June, July, August, and September 1994 and June 1995.

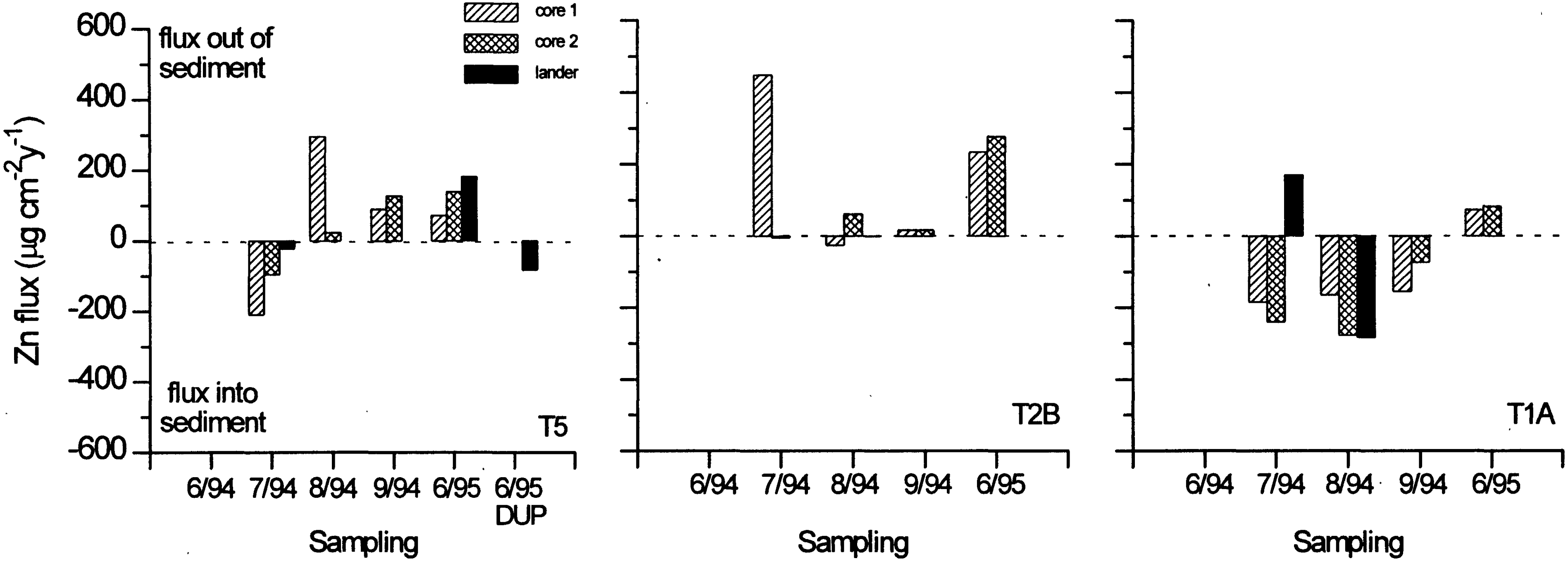

Fig. 10. Direction and magnitude of dissolved Zn fluxes at sites T5, T2B, and T1A in Terrace Reservoir during June, July, August, and September 1994 and June 1995. Fluxes for June 1994 were not calculated due to sample contamination.

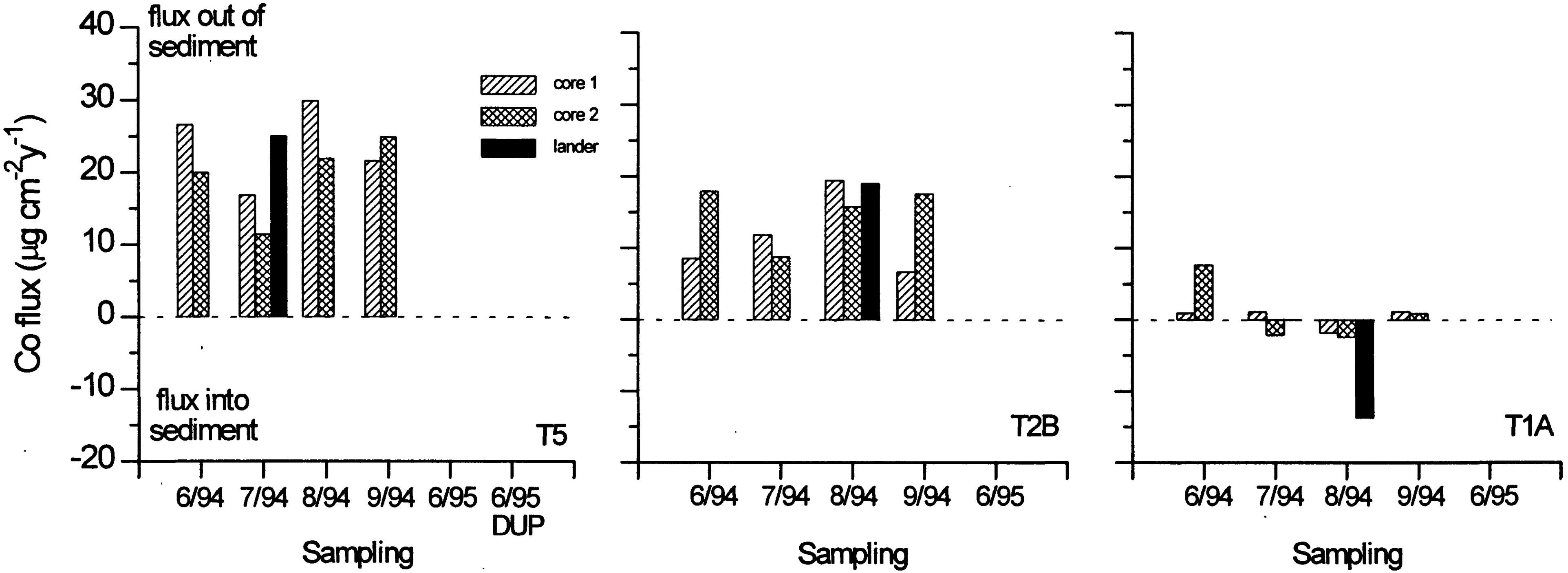

Fig. 11. Direction and magnitude of dissolved Co fluxes at sites T5, T2B, and T1A in Terrace Reservoir during June, July, August, and September 1994 and June 1995. Fluxes for June 1995 were not calculated because dissolved Co concentrations in the samples were below detection limits for the ICP-AES.

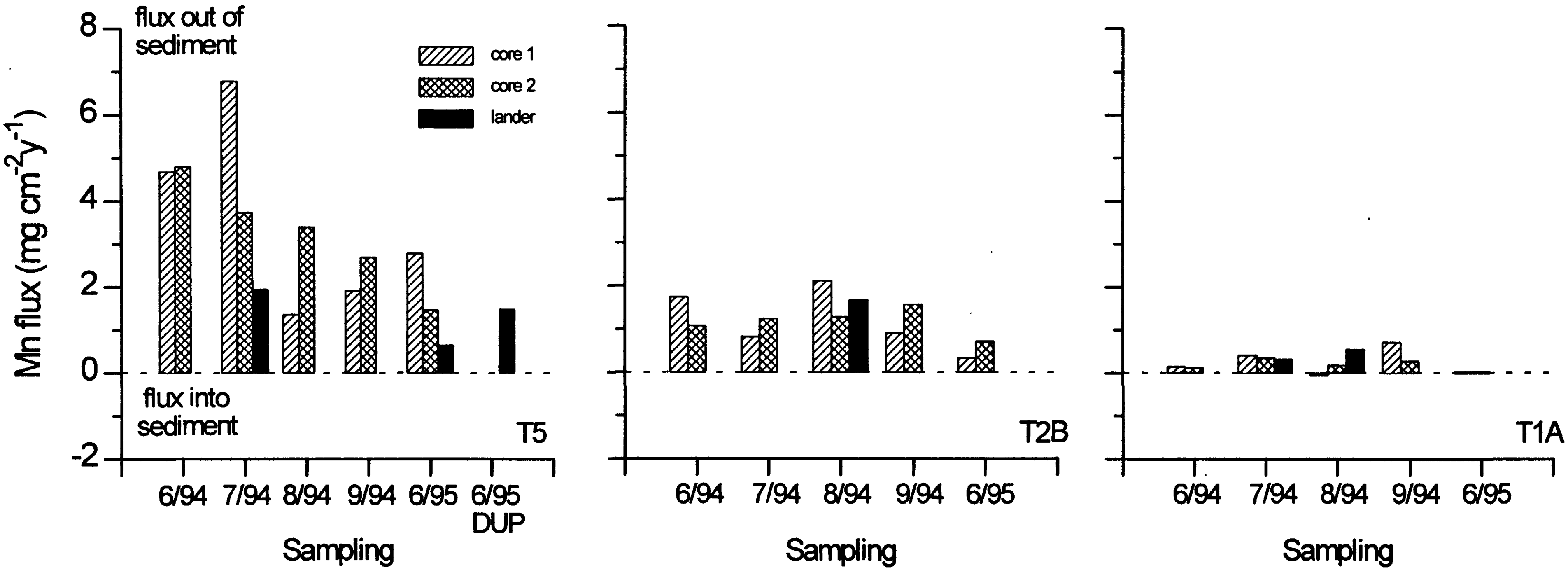

Fig. 12. Direction and magnitude of dissolved Mn fluxes at sites T5, T2B, and T1A in Terrace Reservoir during June, July, August, and September 1994 and June 1995.

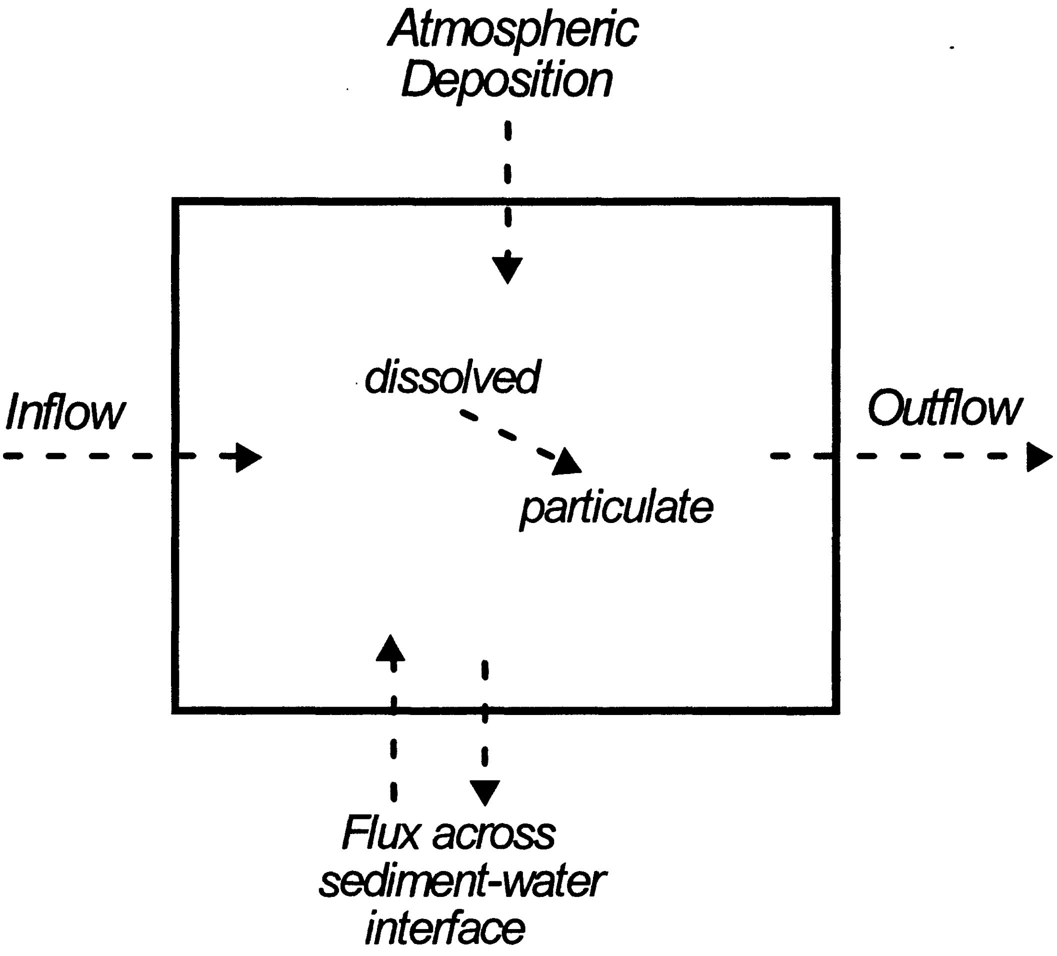

Fig. 13. Box model depicting the processes influencing dissolved metal concentrations in the water column of Terrace Reservoir.

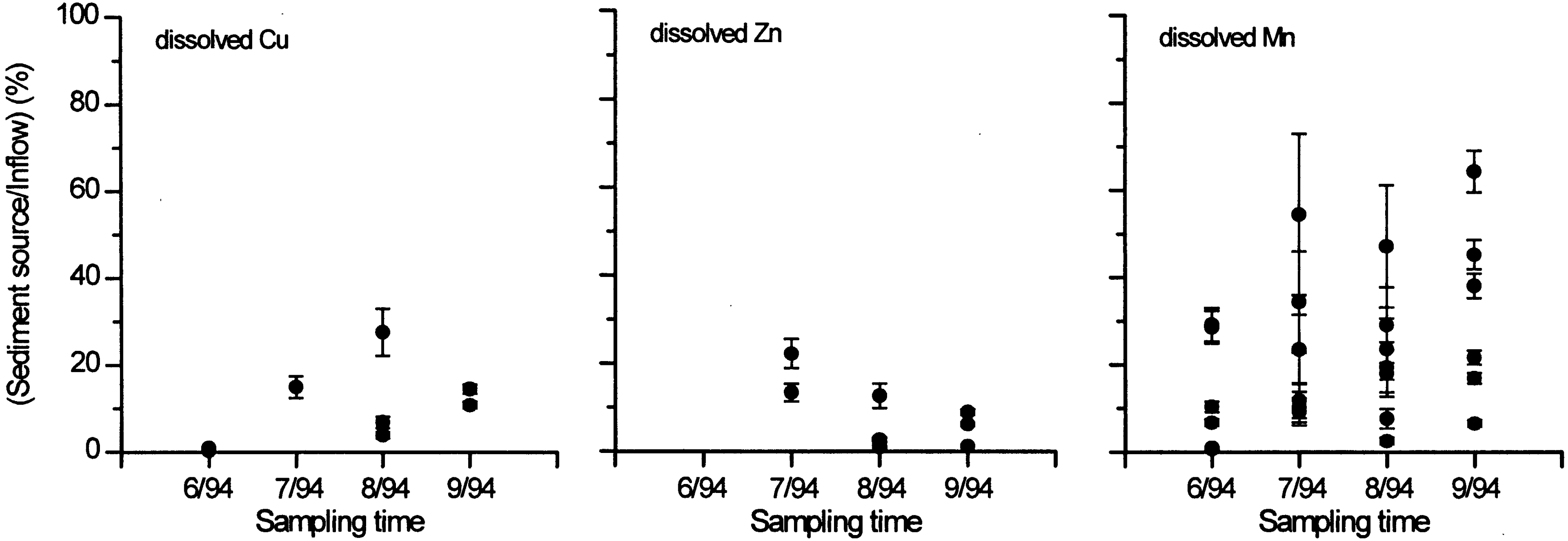

Fig. 14. The importance of the supply of dissolved Cu, Zn, and Mn to the water column of Terrace Reservoir during June, July, August, and September 1994 due to the flux of dissolved metal from the sediment porewater relative to inflow of dissolved metal from the Alamosa River.

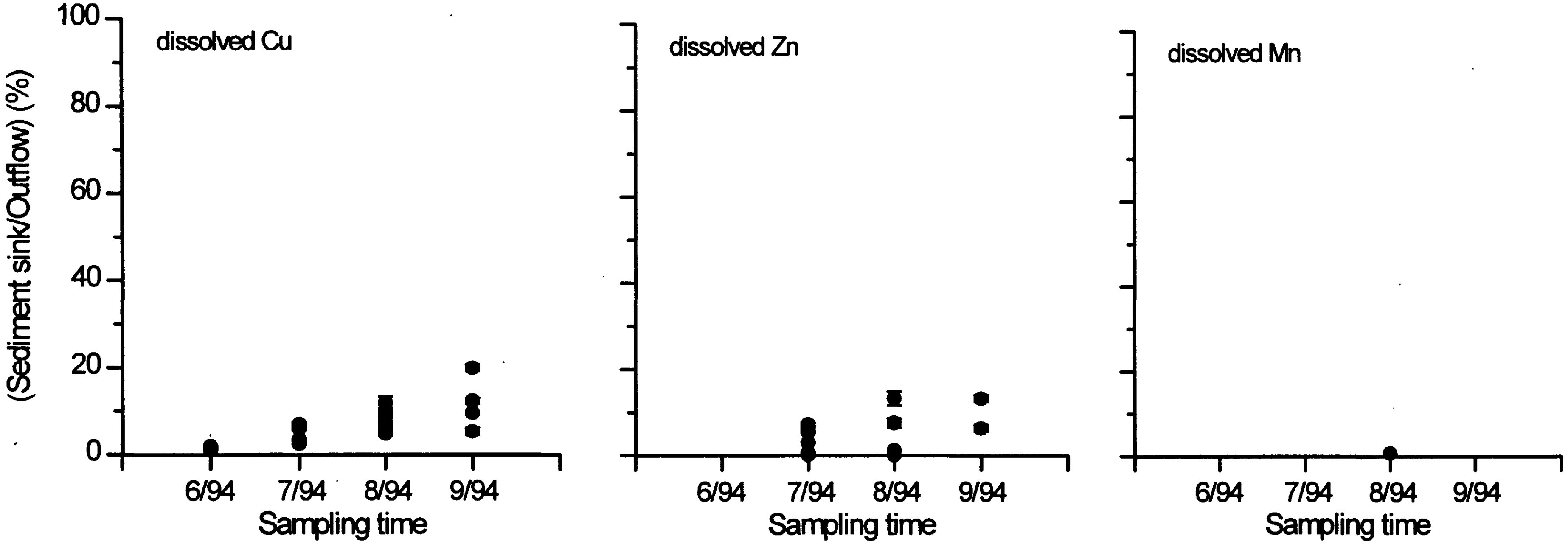

Fig. 15. The importance of the loss of dissolved Cu, Zn, and Mn from the water column of Terrace Reservoir during June, July, August, and September 1994 due to the flux of dissolved metal to the sediment porewater relative to outflow of dissolved metal by release of water through the dam.

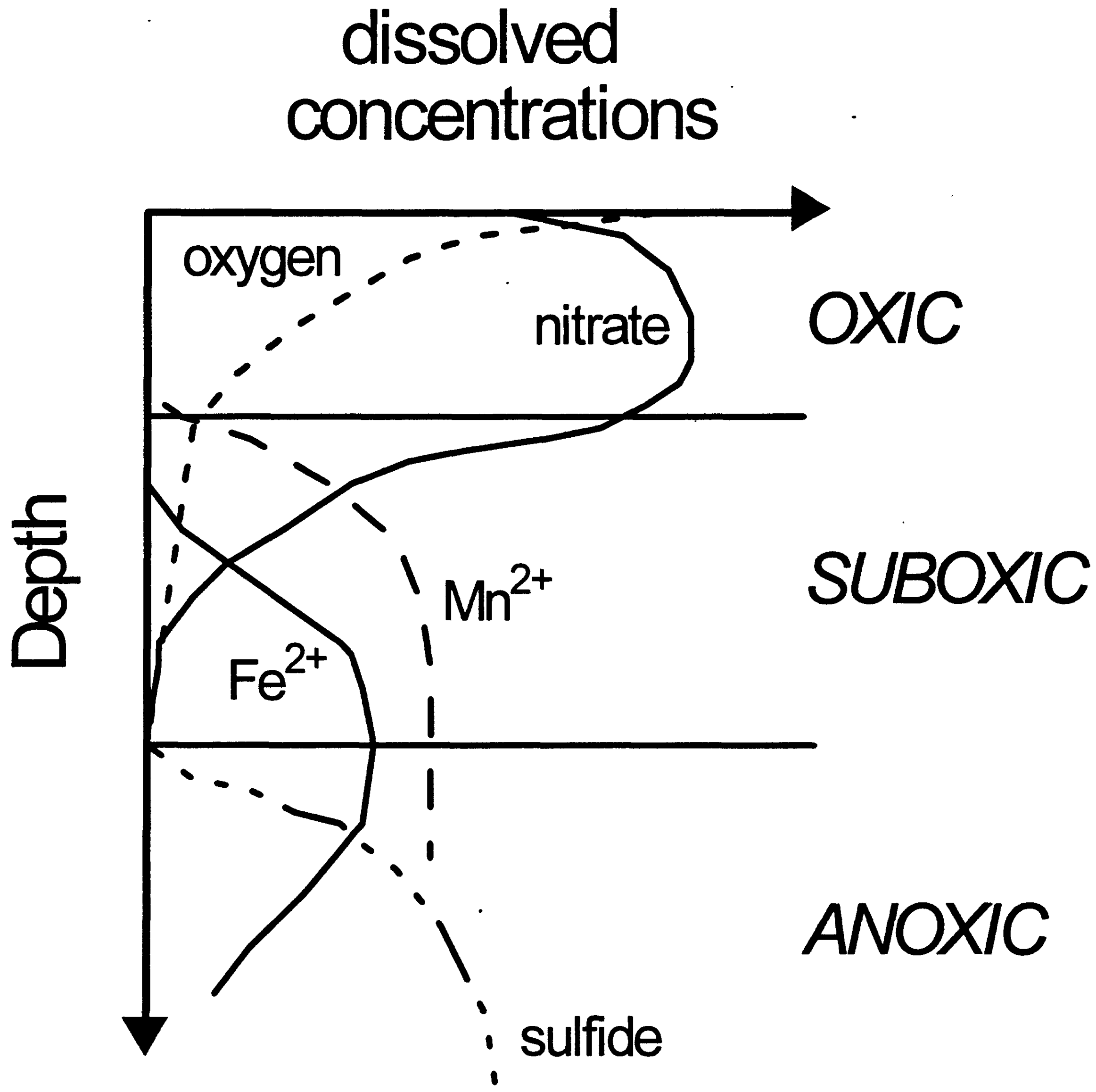

Fig. 16. Diagram of the changes in oxygen, nitrate, dissolved Mn (Mn^{2+}), dissolved Fe (Fe^{2+}), and sulfide concentrations as a function of depth in porewater resulting from the diagenesis of organic matter. (after Froehlich and others, 1979).

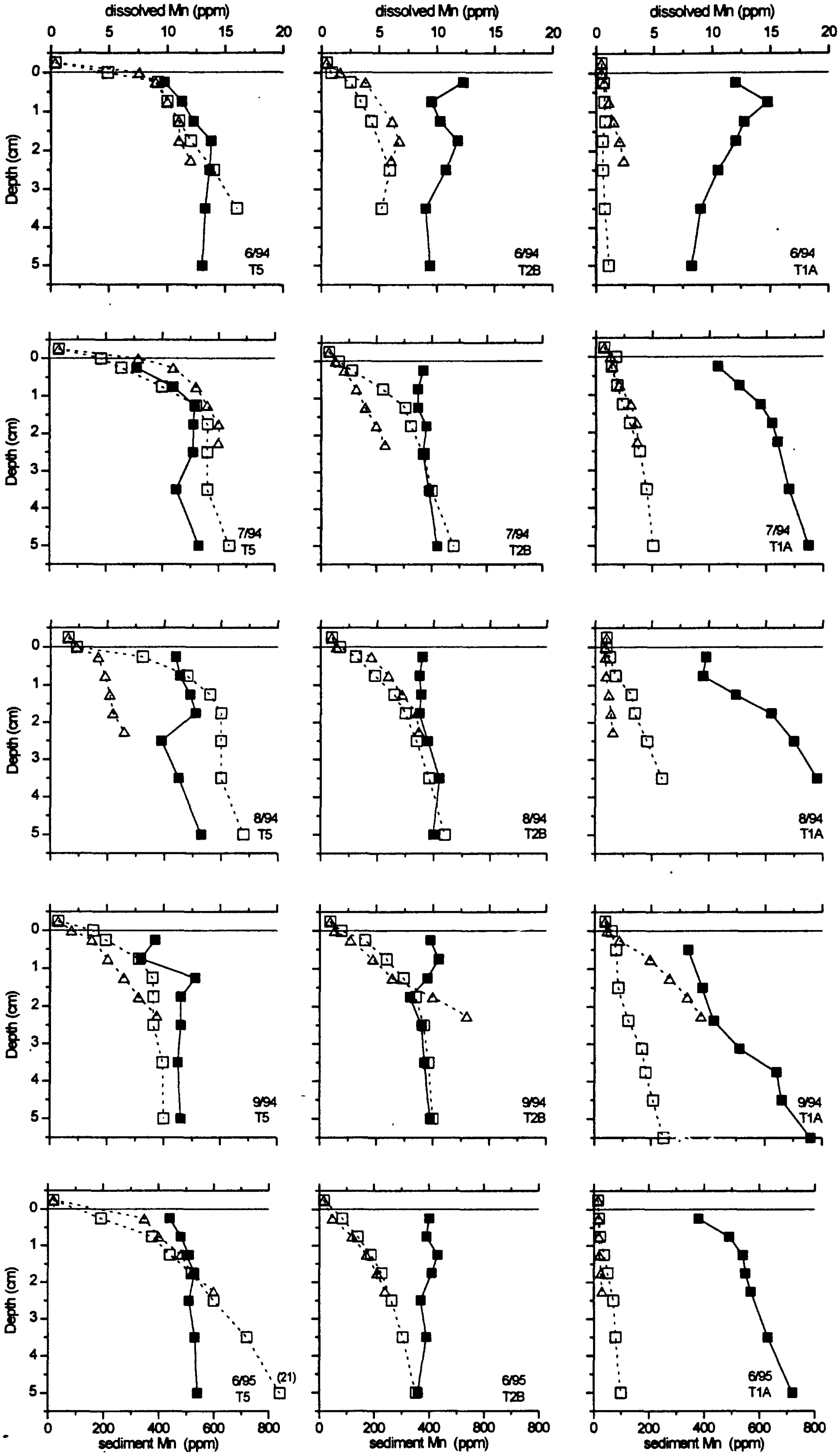

Fig. 17. Concentrations of dissolved Mn in bottom water and porewater and solid phase Mn at sites T5, T2B, and T1A in Terrace Reservoir during June, July, August, and September 1994 and June 1995. Triangles denote dissolved data from core 1, open squares denote dissolved data from core 2, and solid squares denote solid phase data from core 2.

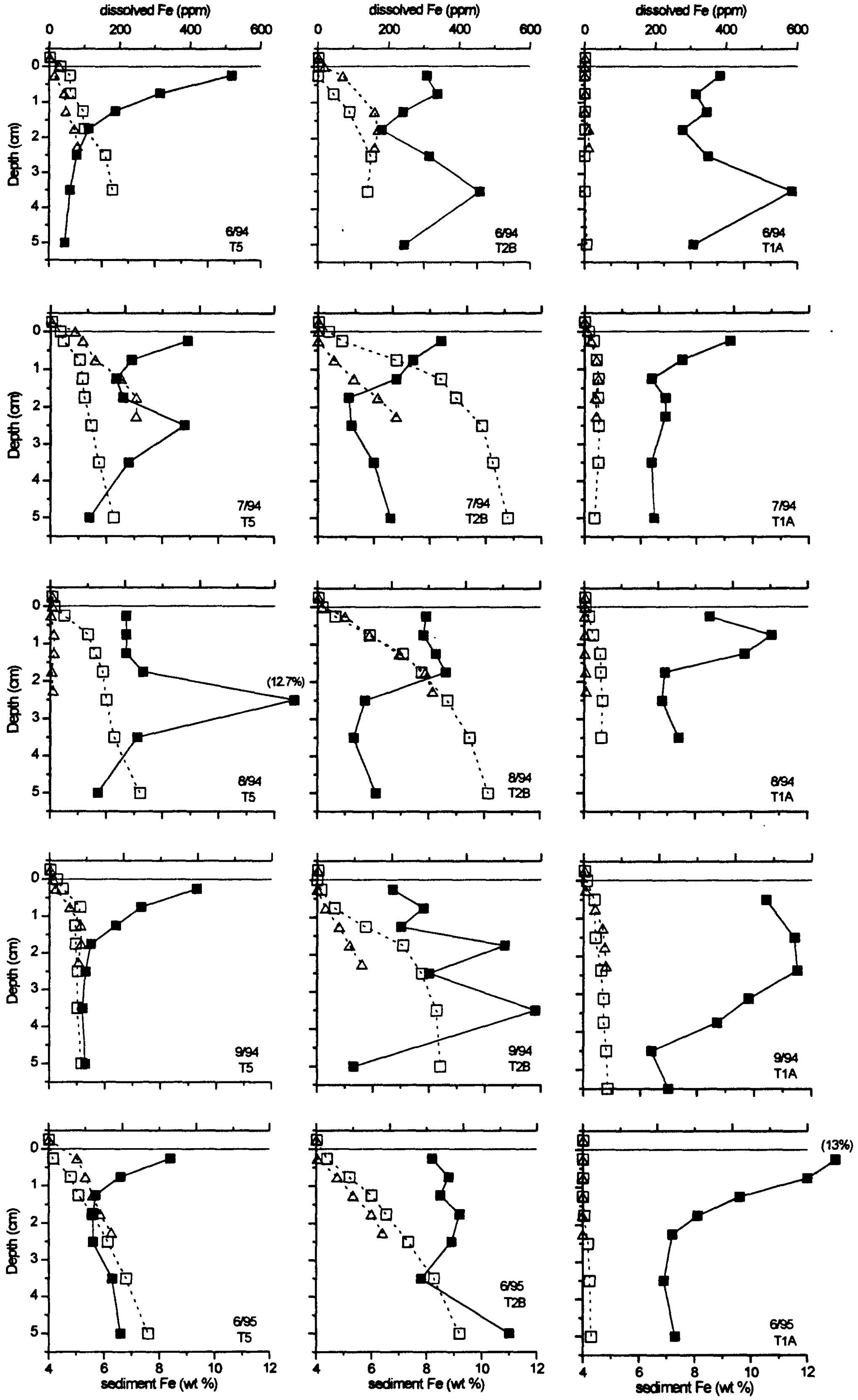

Fig. 18. Concentrations of dissolved Fe in bottom water and porewater and solid phase Fe at sites T5, T2B, and T1A in Terrace Reservoir during June, July, August, September 1994 and June 1995. Triangles denote dissolved Fe from core 1, open squares denote dissolved Fe from core 2, and closed squares denote solid phase Fe from core 2.

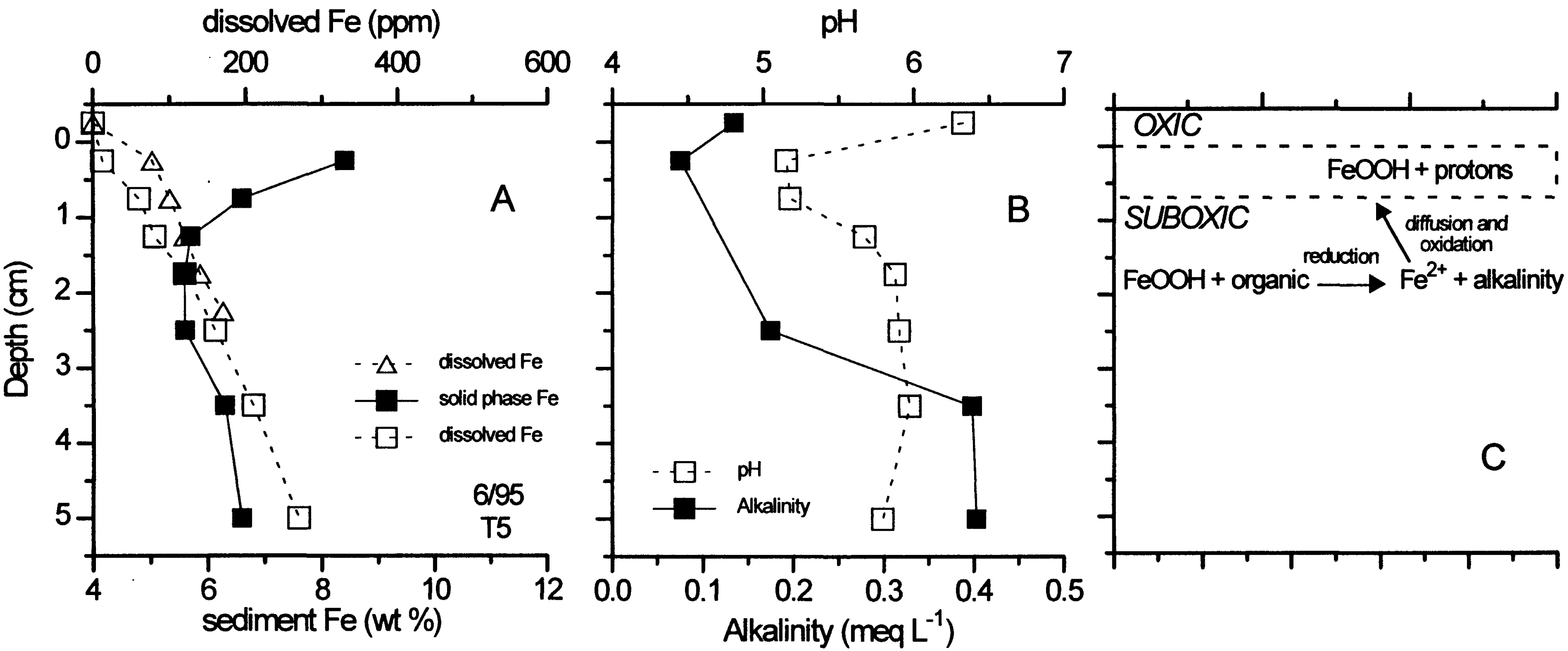

Fig. 19. a) Dissolved and solid phase Fe and b) pH and alkalinity from site T5 during June 1995. c) Schematic diagram of Fe cycling across the oxic-suboxic interface.

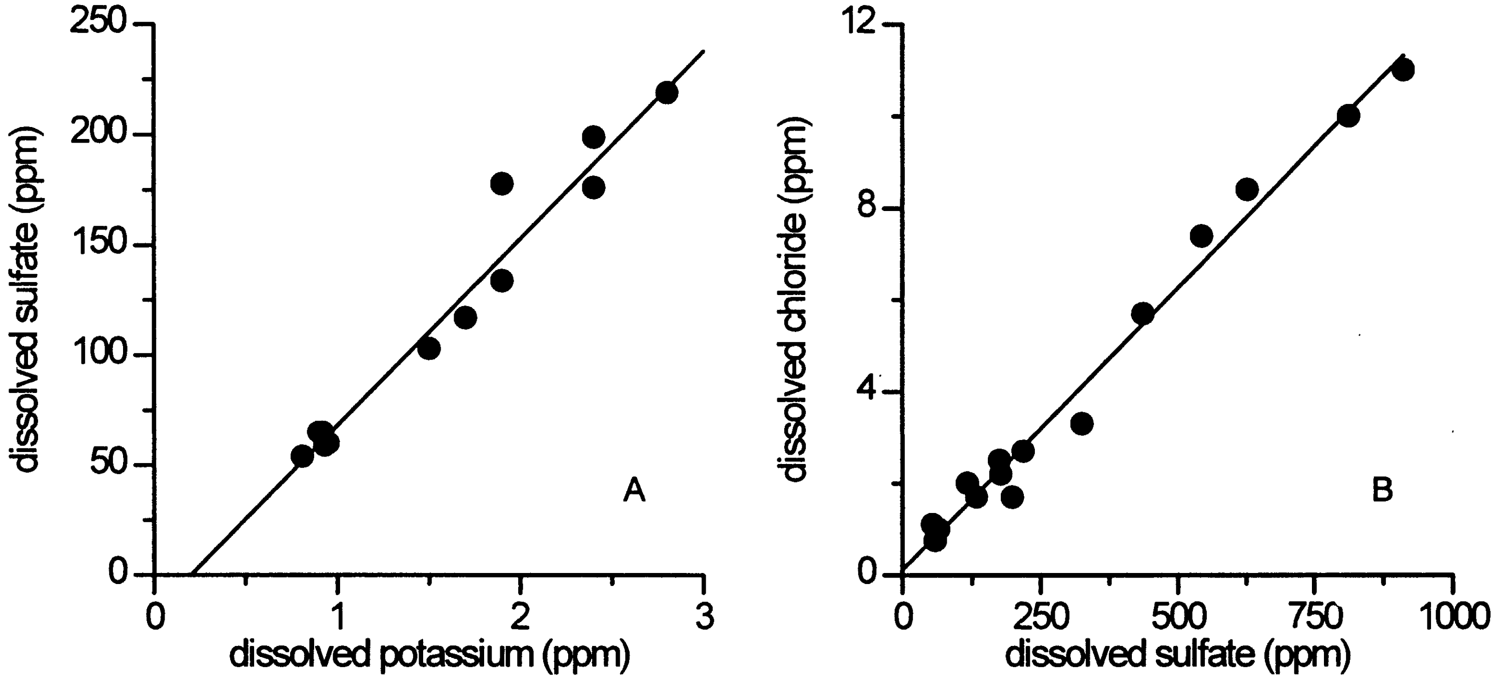

Fig. 20. Relationships between dissolved sulfate and a) dissolved potassium or b) dissolved chloride in porewater from all sites during June 1995.

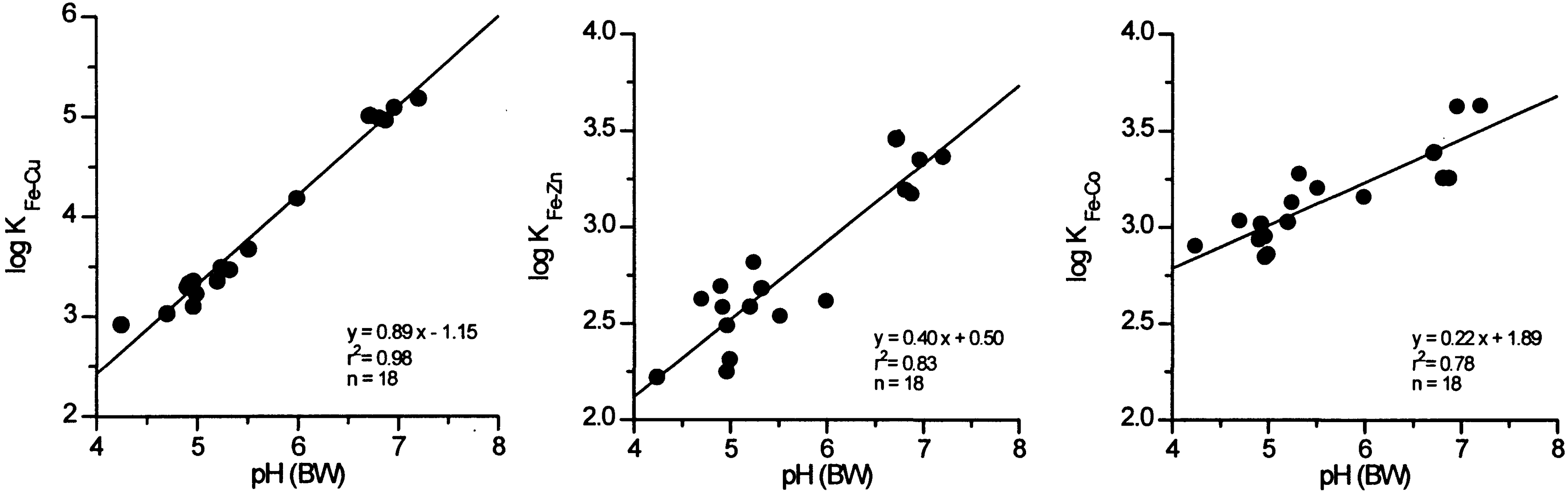

Fig. 21. The value of the apparent constant (log $K_{Fe\text{-}Me}$) defining the interaction between Fe oxyhydroxides in the surface sediment and free Cu, Zn, and Co concentrations in the bottom water versus pH of bottom water (BW) in Terrace Reservoir.

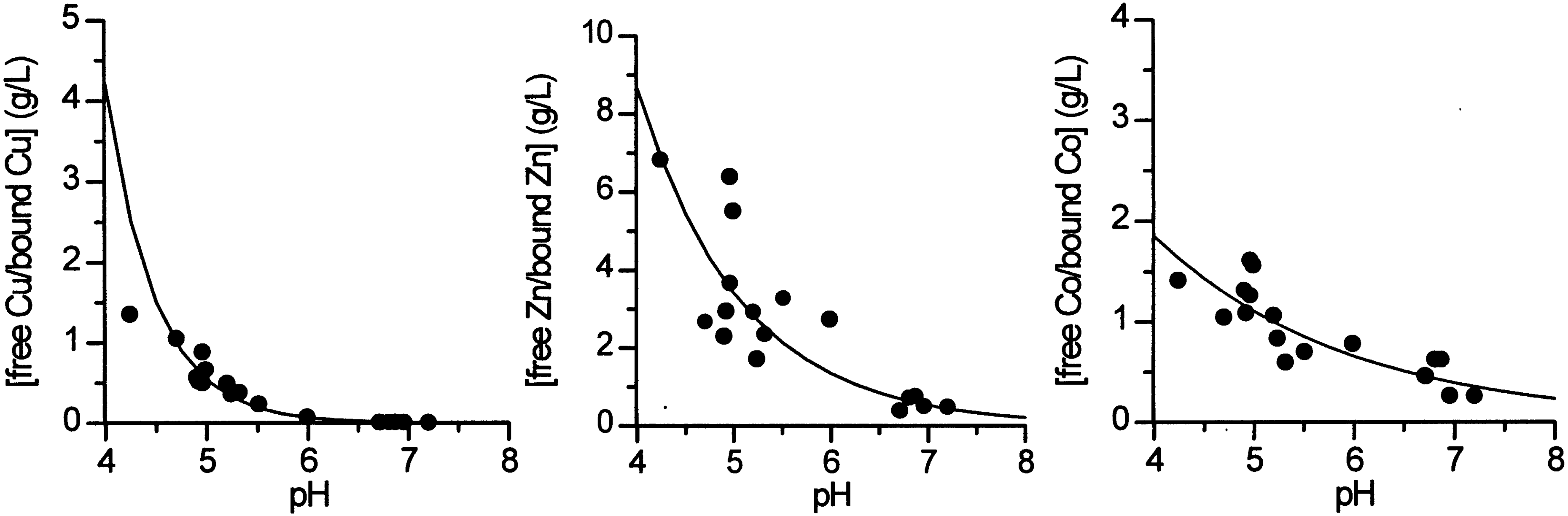

Fig. 22 Ratio of dissolved free metal to metal bound to Fe oxyhydroxides in surface sediments of Terrace Reservoir for Cu, Zn, and Co as a function of pH. The concentration of Fe oxyhydroxides is assumed to be 880 μmoles/g. The solid lines denote best fit values of $K_{Fe\text{-}Me}$ based on linear regressions in Fig. 21. The symbols denote values of $K_{Fe\text{-}Me}$ determined from leach data in Table 14.

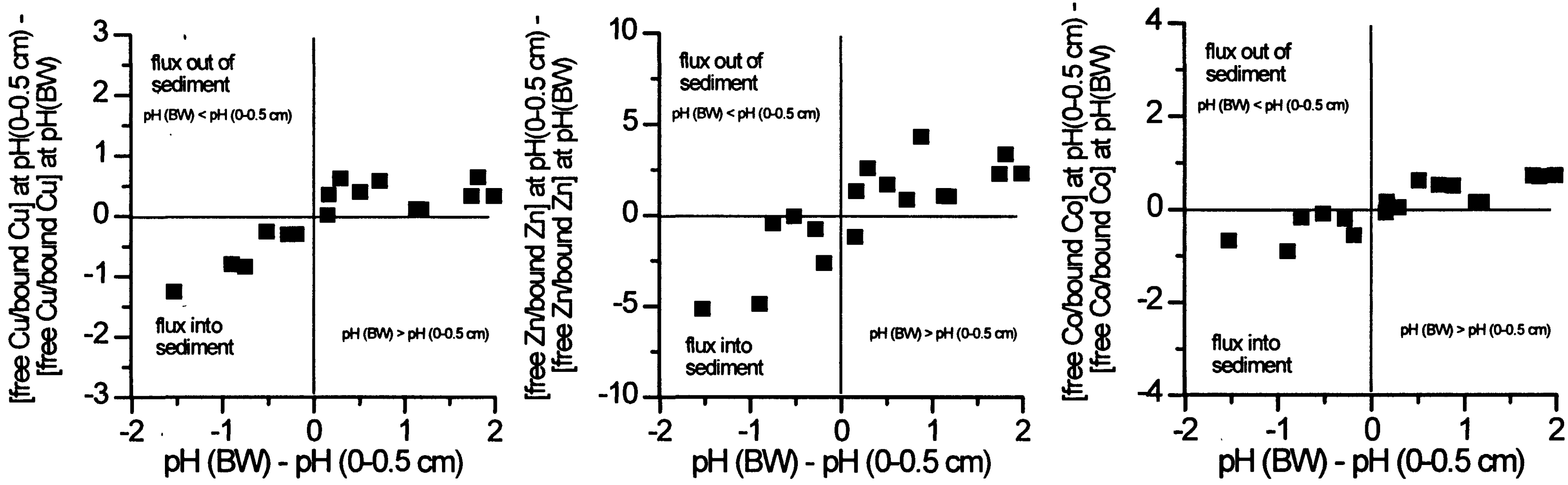

Fig. 23. The difference in the ratios of dissolved free metal to metal bound by Fe oxyhydroxides in the sediments of Terrace Reservoir for Cu, Zn, and Co for pH of porewater at 0-0.5 cm and pH of bottom water (BW) as a function of the difference in pH of the bottom water and porewater. The concentration of Fe oxyhydroxides is assumed to be 880 μmoles/g. The ratios were calculated using $K_{Fe\text{-}Me}$ values derived from leach data in Table 14.

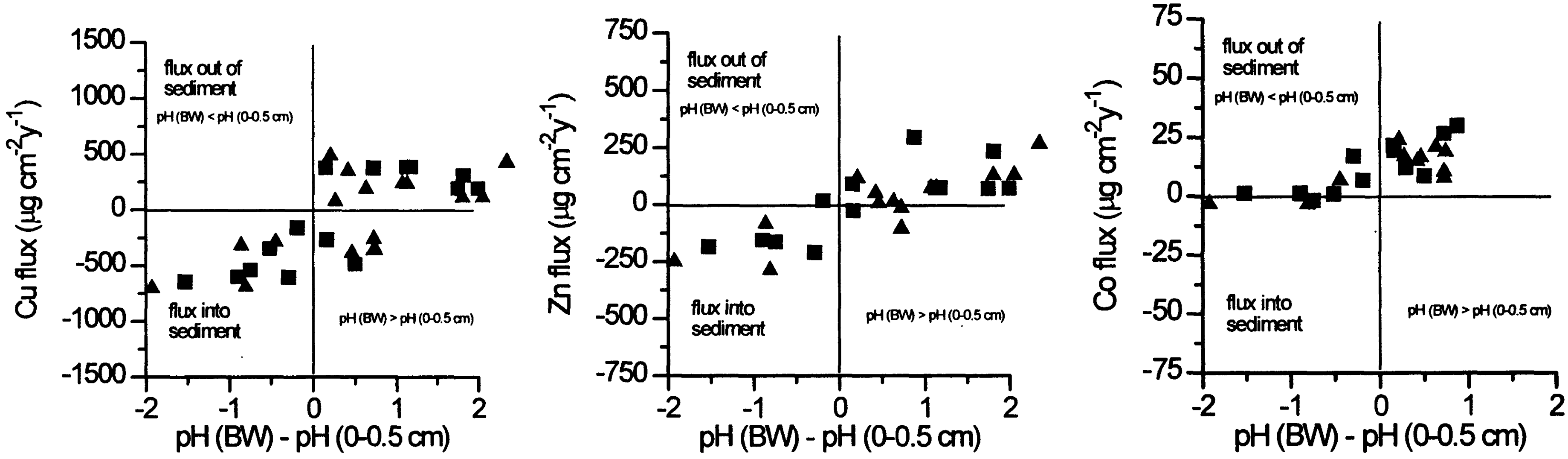

Fig. 24. Direction and magnitude of measured dissolved Cu, Zn, and Co fluxes as a function of the difference between the pH of bottom water (BW) and pH of porewater at 0-0.5 cm in Terrace Reservoir. Square symbols denote core 1, triangle symbols denote core 2.

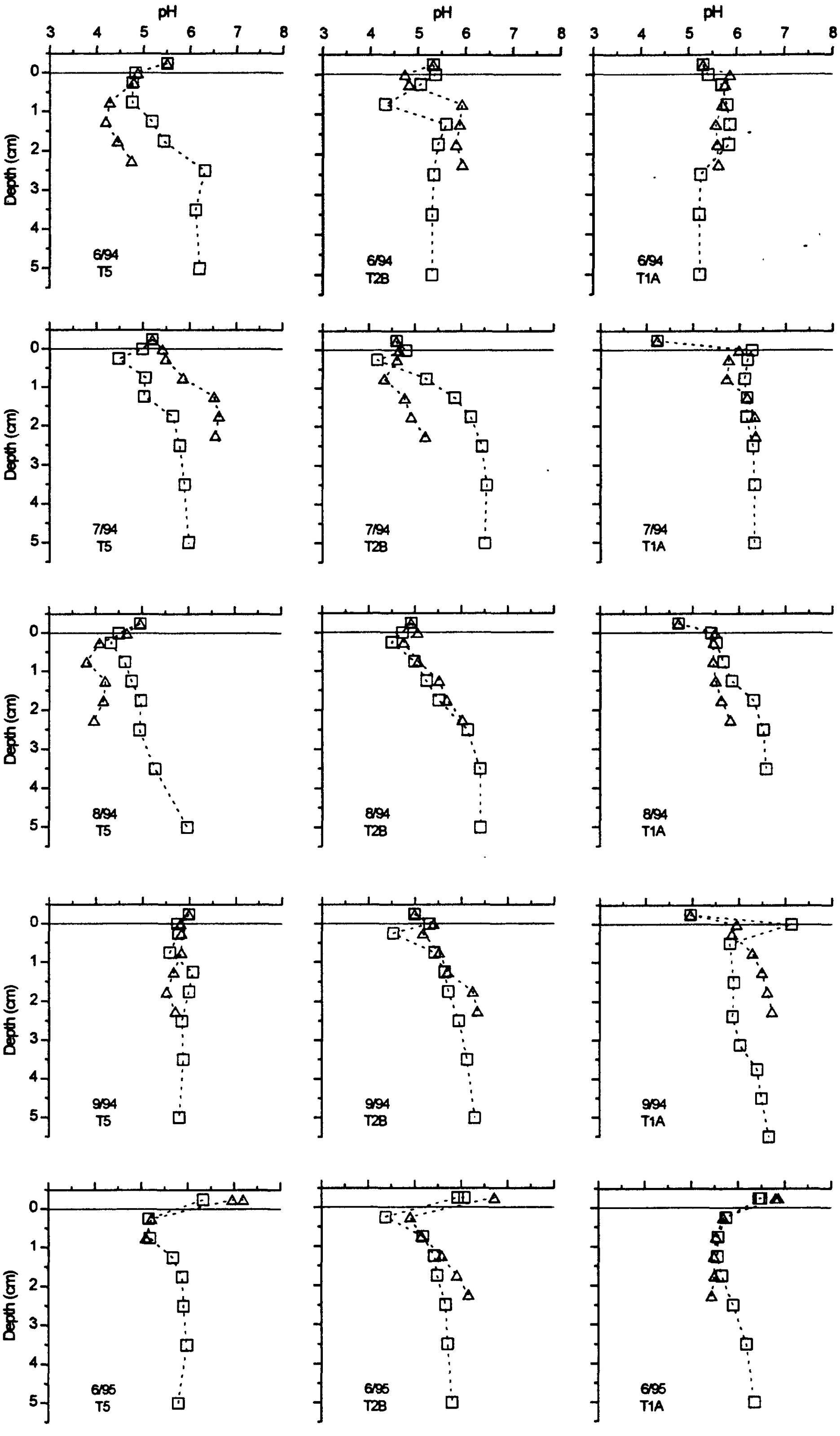

Fig. 25. Values of pH in bottom water and porewater at sites T5, T2B, and T1A in Terrace Reservoir during June, July, August, and September 1994 and June 1995. Triangle symbols denote core 1, square symbols denote core 2.

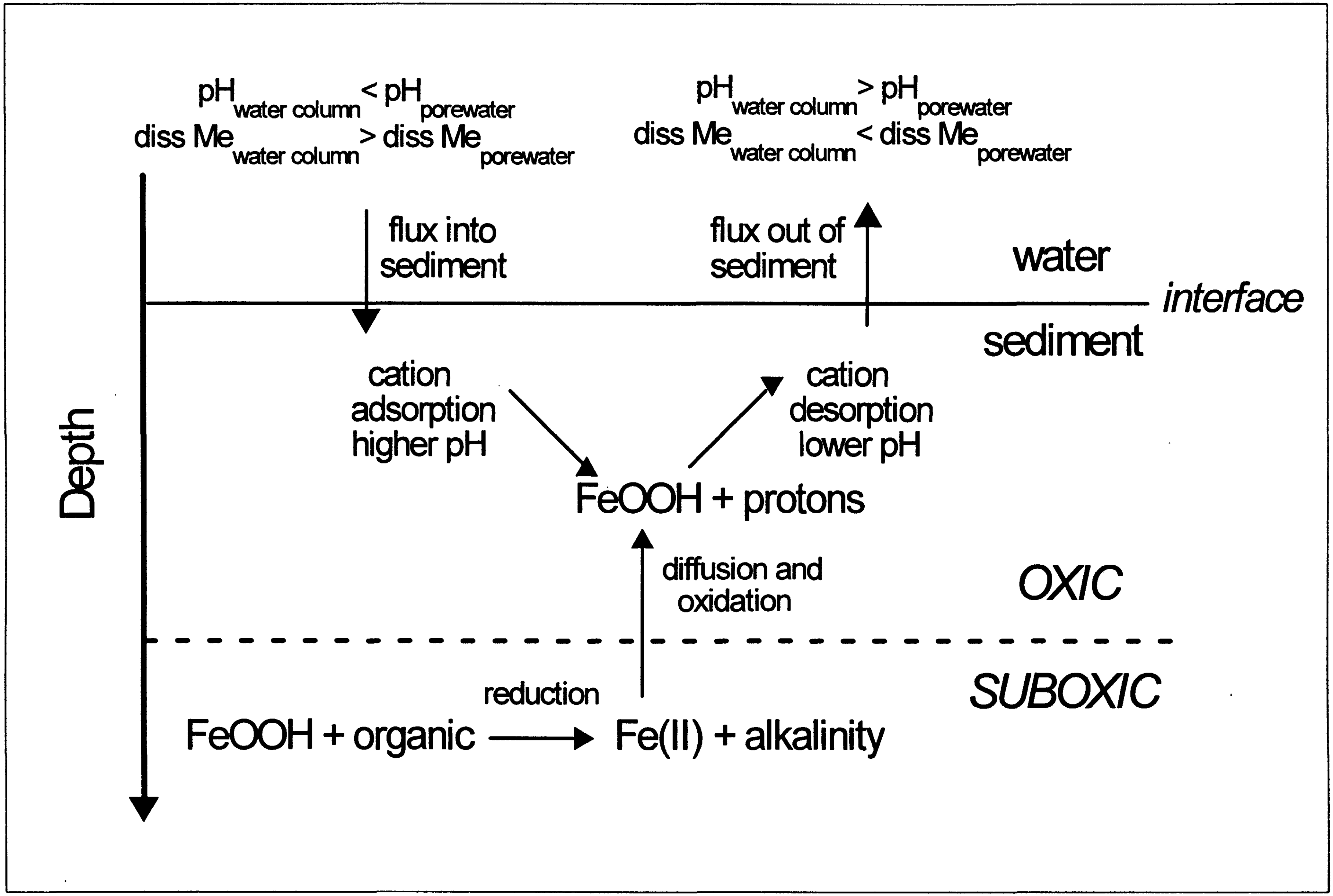

Fig. 26. Schematic diagram of processes occurring in the interfacial region in Terrace Reservoir.

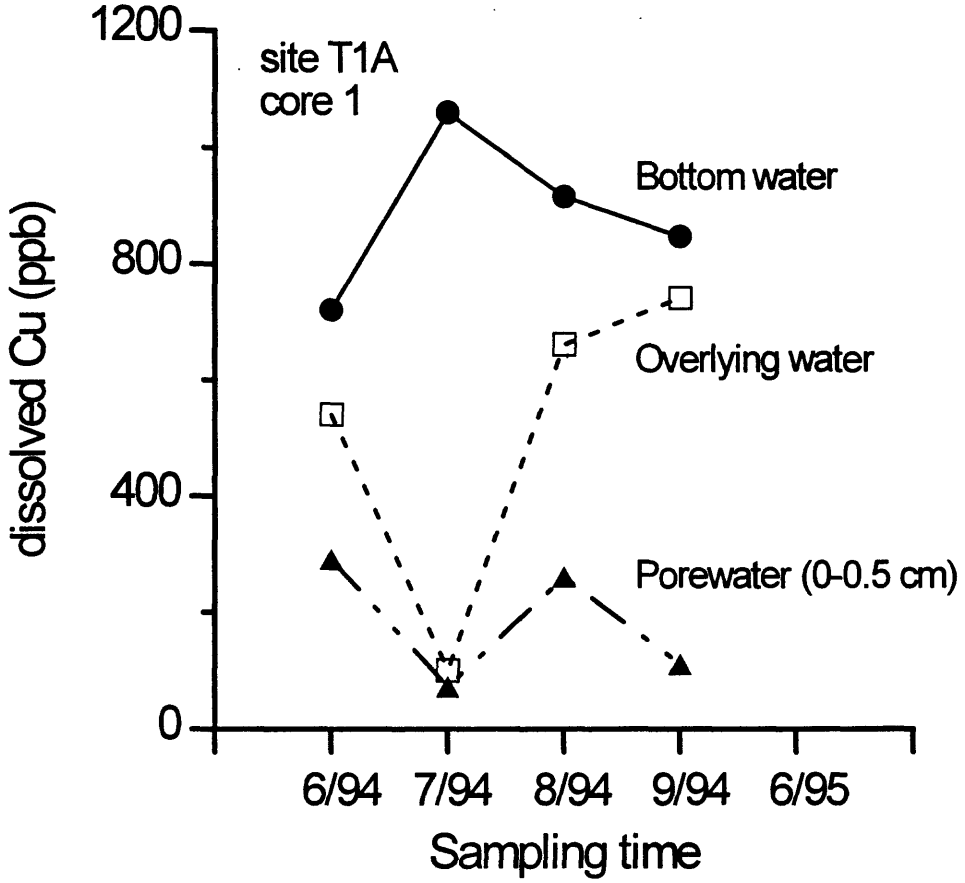

Fig. A1. Dissolved Cu concentrations in bottom water and overlying water and porewater (0-0.5 cm) from core 1 at site T1A as a function of time.

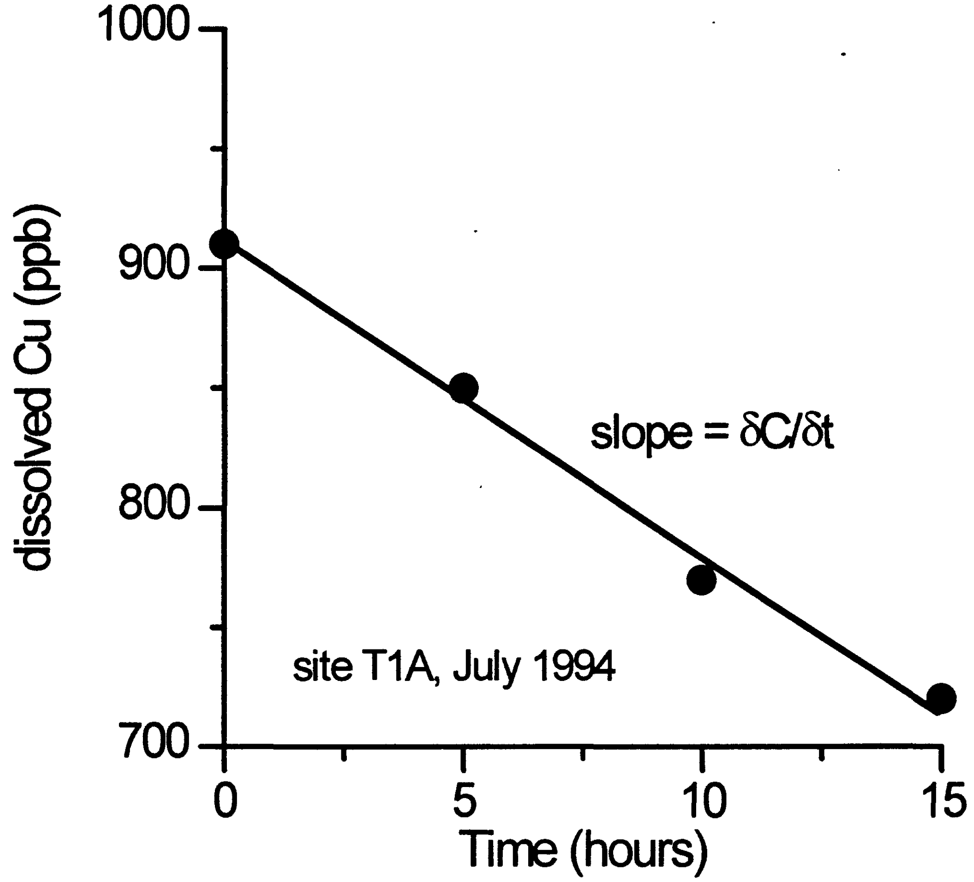

Fig. A2. Dissolved Cu concentrations as a function of time in the benthic flux chamber at site T1A during July 1994.