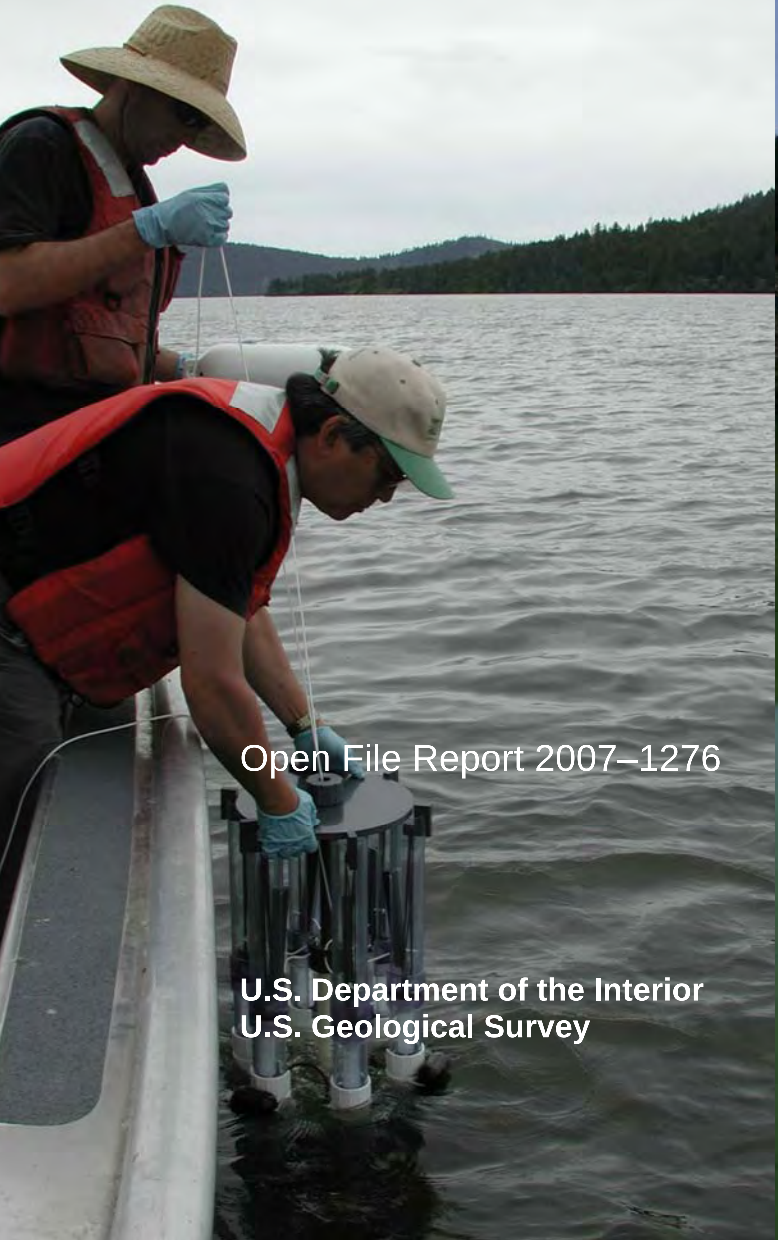
Prepared in cooperation with the U.S. Bureau of Reclamation

Quantifying the Benthic Source of Nutrients to the Water Column of Upper Klamath Lake, Oregon



Open File Report 2007–1276

U.S. Department of the Interior
U.S. Geological Survey

Prepared in cooperation with the U.S. Bureau of Reclamation

Quantifying the Benthic Source of Nutrients to the Water Column of Upper Klamath Lake, Oregon

By James S. Kuwabara[1], Dennis D. Lynch[2], Brent R. Topping[3], Fred Murphy[4], James L. Carter[5], Nancy S. Simon[6], Francis Parchaso[7], Tamara M. Wood[8], Mary K. Lindenberg[9], Katryn Wiese[10], Ronald J. Avanzino[11]

Open File Report 2007–1276

U.S. Department of the Interior
U.S. Geological Survey

[1] *kuwabara@usgs.gov*, U.S. Geological Survey, Menlo Park, CA
[2] *ddlynch@usgs.gov*, U.S. Geological Survey, Portland, OR
[3] *btopping@usgs.gov*, U.S. Geological Survey, Menlo Park, CA
[4] *fmurphy@usgs.gov*, U.S. Geological Survey, Menlo Park, CA
[5] *jlcarter@usgs.gov*, U.S. Geological Survey, Menlo Park, CA
[6] *nssimon@usgs.gov*, U.S. Geological Survey, Menlo Park, CA
[7] *parchaso@usgs.gov*, U.S. Geological Survey, Menlo Park, CA
[8] *tmwood@usgs.gov*, U.S. Geological Survey, Menlo Park, CA
[9] *mlinden@usgs.gov*, U.S. Geological Survey, Klamath Falls, OR
[10] *kwiese@ccsf.edu*, City College of San Francisco, San Francisco, CA
[11] *avanzino@usgs.gov*, U.S. Geological Survey, Menlo Park, CA

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia 2007
Revised and reprinted: 2007

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Kuwabara, J.S., Lynch, D.D., Topping, B.R. Murphy, Fred, Carter, J.L., Simon, N.S., Parchaso, Francis, Wood, T.M., Lindenberg, M.K., Wiese, Katryn, Avanzino, R.J., 2007, Quantifying the Benthic Source of Nutrients to the Water Column of Upper Klamath Lake, Oregon

Contents

Executive Summary 7
  Benthic flux of nutrients to the water column 7
  Dissolved nutrients in the water column 8
  Geochemistry of lakebed sediments 8
    Potential Management Implications 8
Background 10
Objectives 11
Results and Discussion 12
  Benthic flux of nutrients 12
  Dissolved nutrients in the water column 13
  Dissolved organic carbon (DOC) in the water column 13
  Dissolved trace metals in the water column 14
  Benthic macroinvertebrates 15
  Benthic chlorophyll 15
  Geochemistry of lakebed sediments 16
Study Design and Methods 18
  Biological Parameters 18
  Chemical Parameters 19
References Cited 21
Acknowledgments 24

Figures

Fig. 1 Sampling Locations for this study of Upper Klamath Lake, OR 25
Fig. 2 Preparation of pore-water profilers for deployment in Upper Klamath Lake, OR 26
Fig. 3 Water-column sampling with Teflon-coated Niskin bottle 27

Tables

Table 1 Sampling locations and location acronyms used in this report 28
Table 2 Summary of dissolved-nutrient benthic fluxes in Upper Klamath Lake, OR 29
Table 3 Dissolved-nutrient concentrations (micrograms per liter) in the water-column of Upper Klamath Lake, OR 30
Table 4 Dissolved organic carbon (DOC) in the water column of Upper Klamath Lake, OR 31
Table 5 Dissolved trace metals in the water column of Upper Klamath Lake, OR 32
Table 6 Variability of macro- and micronutrient compositions for tributary inputs to Upper Klamath Lake, OR 33
Table 7 Diffusive flux of dissolved iron in Upper Klamath Lake, OR 34
Table 8 Macroinvertebrate taxonomy of benthic assemblages within Upper Klamath Lake, OR 35
Table 9 Benthic chlorophyll and phaeophytin concentrations (in micrograms per square centimeter; n=3) at Upper Klamath Lake, OR 36

Table 10 Macronutrients (milligrams per gram, mg-g^{-1}) and major elements associated with lakebed sediments in pre-bloom conditions (April 2005) in Upper Klamath Lake, OR 37
Table 11 Macronutrients (milligrams per gram, mg-g^{-1}) and major elements associated with lakebed sediments during the AFA bloom (July 2005) in Upper Klamath Lake, OR 38
Table 12 Precision and recovery for sediment Standard Reference Material NIST SRM 2710 Montana Soil (n=5 analytical replicates) 39

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter (m)
Area		
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
gallon (gal)	3.785	liter (L)
cubic inch (in^3)	0.01639	liter (L)
Mass		
ounce, avoirdupois (oz)	28.35	gram (g)
micromolar (µM)	molecular weight	micrograms per liter ($\mu g\text{-}L^{-1}$)
micrograms per liter ($\mu g\text{-}L^{-1}$)	0.001	milligrams per liter ($mg\text{-}L^{-1}$)
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32
Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8
Vertical coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Vertical Datum of 1988 (NAVD 88).”
Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Datum of 1983 (NAD 83).”
Altitude, as used in this report, refers to distance above the vertical datum.
Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).
Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations and Acronyms

Abbreviations and Acronyms	Meaning
AFA	*Aphanizomenon flos–aquae*
DOC	Dissolved organic carbon
SRP	Dissolved reactive phosphate
UKL	Upper Klamath Lake
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey

Quantifying the Benthic Source of Dissolved Nutrients to the Water Column of Upper Klamath Lake, Oregon

By James S. Kuwabara, Dennis D. Lynch, Brent R. Topping, Fred Murphy, James L. Carter, Nancy S. Simon, Francis Parchaso, Tamara M. Wood, Mary K. Lindenberg, Katryn Wiese, Ronald J. Avanzino

Executive Summary

Five sampling trips were coordinated in April, May and August 2006, and May and July 2007 to sample the water column and benthos of Upper Klamath Lake, OR (Fig. 1; Table 1), before, during and after the annual cyanophyte bloom of *Aphanizomenon flos–aquae* (AFA). A pore-water profiler was designed and fabricated to obtain the first high-resolution (centimeter-scale) estimates of the vertical concentration gradients for diffusive-flux determinations. Estimates based on molecular diffusion may underestimate benthic flux because solute transport across the sediment-water interface can be enhanced by processes including bioturbation, bioirrigation and ground-water advection. Water-column and benthic samples were also collected to help interpret spatial and temporal trends in diffusive-flux estimates. Data from these samples complement geochemical analyses of bottom-sediments taken from Upper Klamath Lake (UKL) in 2005.

This ongoing study provides information necessary for developing process-interdependent solute-transport models for the watershed (that is, models integrating physical, geochemical and biological processes), and supports efforts to evaluate remediation or load-allocation strategies. To augment studies funded by the U.S. Bureau of Reclamation (USBR), the Department of Interior supported an additional full deployment of pore-water profilers in July 2007, during the summer AFA bloom. Results from this recent field trip are not fully completed. Data not presented herein will be included in a subsequent publication, scheduled for March 2009.

Benthic flux of nutrients to the water column

A prototype pore-water profiler was successfully deployed in Howard Bay on 18 April 2006 during pre-bloom conditions. Refinements in design from that test were incorporated into 15 profilers deployed on 31 May 2006 (bloom), 2 August 2006 (post-bloom), 1 May 2007(pre-bloom), and 9 July 2007 (bloom) (Fig. 2). The profilers provided a high-resolution (centimeter-scale) vertical profile of pore-water chemistry near (within 10 centimeters) the sediment-water interface. Based on Fick's Law, these profiles were used to determine benthic flux of solutes based on diffusion.

Benthic flux of soluble (0.2-micron filtered) reactive phosphorus (that is, biologically available phosphorus, primarily as orthophosphate; SRP) was consistently positive (that is, out of the sediment into the overlying water column) and ranged between 0.5 and 6.1 milligrams per square meter per day. Assuming a lake area of 200 square kilometers, this converts to a mass flux

to the entire lake of 8,000 to 100,000 kilograms over a 3-month AFA bloom season; comparable in magnitude to riverine inputs (Nutrient-flux discussion). An additional concern related to fish toxicity was identified. Dissolved ammonium also displayed consistently positive benthic fluxes of 4 to 100 milligrams per square meter per day; also comparable to riverine inputs. In contrast, dissolved nitrate exhibited a consistently negative flux (consumed by the sediment) with values ranging between -20 to -0.1 milligrams per square meter per day. Although taxonomic analyses are ongoing, macroinvertebrate densities at least of the order of 10^5 individuals per square meter (Macroinvertebrate discussion), suggest that the diffusive-flux estimates mentioned above may be significantly enhanced by bioturbation.

Although phosphorus is a logical choice for the limiting nutrient when nitrogen-fixing cyanophytes dominate, initial trace-metal results (coordinated benthic flux, water-column and tributary-inlet data) suggest that the role of iron availability to primary producers in the lake should not be overlooked.

Dissolved nutrients in the water column

Soluble reactive phosphorus (SRP) increased in August 2006, relative to April and May, by as much as an order of magnitude (107.8 $\pm$ 31.2 up from 7.6 $\pm$ 7.3 micrograms per liter ($\mu g\text{-}L^{-1}$), averaged over all sampling sites; (Nutrients discussion). Though the 2007 data do not include a post-bloom sampling data, SRP concentrations did increase substantially between May 2007 and July 2007. Dissolved-nitrogen species (ammonium and the sum of nitrate plus nitrite) gradually increased between April and May 2006 samplings, but as observed with SRP, an even greater increase (at least three-fold and up to order-of-magnitude) was observed between May and August 2006. Samples from the Williamson River plume site (WMR) displayed the highest SRP concentrations in both April and May 2006 relative to the other sampling sites, but exhibited the lowest concentration in August 2006. However, this spatial trend did not recur in 2007 for SRP, and no spatial trends were observed for dissolved nitrogen species in either year.

Geochemistry of lakebed sediments

The concentrations of total phosphorus (P) in bottom sediments of UKL were variable. Analyses of bottom sediments indicated that the accumulation or loss of P was patchy during the period between the onset and development of an AFA bloom in UKL in 2005. Data for concentrations of total P and geochemical species of P at one site south of Bare Island (SBI) indicated a loss of P from surface sediment between the onset and development of the AFA bloom. In contrast, data for concentrations of total P and geochemical species of P at another Mid-Lake site (MDL) indicated a gain of P in surface sediment between the onset and development of the AFA bloom. The embayment sites (EBB and HDB) indicated no net loss or gain of P between the onset and development of an AFA bloom in 2005.

Potential Management Implications

Evaluation of proposed remediation efforts and load allocations in the Klamath River Basin may be linked to a variety of water-quality objectives in Upper Klamath Lake such as: decreasing concentrations of bioavailable forms of macronutrients that regulate phytoplankton community structure and abundance, decreasing solute loads to down-gradient systems, and reducing the impacts of nutrient cycling on biological resources (for example, endangered and commercial fish populations as well as consumers of those resources). Because phosphorus is currently considered the limiting nutrient for the annual blooms of the nitrogen-fixing, cyanophyte *Aphanizomenon flos–*

aquae (AFA), this work provides initial measurements of benthic sources of dissolved macronutrients and examines the significance of this source in relation to riverine sources and changes in water-column chemistry associated with the summer AFA bloom. In addition to phosphorus, initial results presented herein indicate significant ammonia flux from the sediments that may have toxicological consequences for fish resources in the lake. This study also provides initial distributions of dissolved trace-metal and dissolved organic carbon (DOC) concentrations in the lake. Some of these trace solutes (for example, iron) also may play a role in regulating phytoplankton dynamics in the lake. The information herein is provided as a contribution and will assist in future evaluations of proposed management or remediation strategies. Application of the pore-water profilers, designed and fabricated for this study, can help locate areas ("hot spots") of particular concern and subsequent emphasis for restoration activities in the lake and other peripheral areas in the basin.

Background

Annual cyanophyte blooms in Upper Klamath Lake generate a source of organic carbon to the lakebed and hence increase oxygen demand by the sediment. That demand can induce an environmental stress for endangered fish populations (Wood and others, 2006). As phosphorus (P) is typically the limiting nutrient for those nitrogen-fixing cyanophytes, this project provides initial determinations of the internal loading of dissolved macronutrients (phosphorus and nitrogen species) not only to help meet the adaptive-management goals of the 5-year plan for Lake Restoration (U.S. Fish and Wildlife Service, Hatfield Restoration Program; http://www.fws.gov/klamathfallsfwo/ero/2007rfp/2007rfp.pdf), but also to provide comparative data critical for source management as described in the Program's plan for river restoration. These data will provide valuable information about the timing, spatial variability, and cause of the benthic flux of P to the lake.

For the past 50 to 100 years large blooms of a near monoculture of *Aphanizomenon flos–aquae* (AFA) developed each summer in Upper Klamath Lake (UKL). Because AFA has an active buoyancy system that allows surface "scums" to be wind-concentrated, low dissolved oxygen concentrations develop in large parts of UKL when these blooms senesce. The resulting hypoxia stresses two endangered sucker populations of the shortnose sucker (*Chasmistes brevirostris*) and Lost River sucker (*Deltistes luxatus*), and can lead to mass mortality of adults, suboptimal year-to-year survival, and poor recruitment. Improving sustainability for sucker populations depends on finding ways to improve UKL water quality by decreasing the severity of blooms and shifting the algal assemblage away from AFA monocultures.

Problematic algal blooms are fueled by large external and internal loads of P. It is the internal loading from bottom sediments (benthic flux, including diffusion controlled flux and bioturbation), however, that appears to cause lake P concentrations to rise from 80 to 250 micrograms per liter in late spring, typically in June. Developing an understanding of the mechanisms controlling this benthic flux, and how long it would persist if external loads could be reduced, is necessary for developing sound remediation strategies and for setting realistic expectations for water-quality improvements. This sentiment is not new. Forty years prior to this report, Miller and Tash (1967) concluded about UKL that, "It is imperative to know the extent to which nutrients in the sediments can interchange with the overlying water." This study provides the first benthic-flux determinations for nutrients in UKL, and is part of an interdependent set of investigations that responds to the challenge posed by Miller and Tash to examine sediment-water interactions in the lake.

Early hypotheses for internal P loading included: (1) wind-induced resuspension of bottom sediments, (2) desorption of P from surface sediments by high pH waters induced by algal production, and (3) release of P from ferric oxyhydroxide coatings on sediments exposed to reducing conditions during episodic thermal stratifications. These hypotheses have been discounted by subsequent studies leaving the question unanswered as to the actual process controlling benthic flux (Fisher and Wood, 2001). This issue can best be resolved by directly measuring gradients of dissolved ortho-P (and other constituents) across the sediment-water interface, determining diffusive benthic-flux rates, and testing additional hypotheses as to the possible biological, chemical, and physical interactions that influence those rates.

Dissolved ortho-P is a particle-reactive solute, which means that it can form surface complexes on a variety of mineral and biotic surfaces (Sigg and Stumm, 1981; Goldberg, 1985; Kuwabara and others, 1986). As particulate P settles in the lake, it accumulates in the bottom sediments. Various biogeochemical processes related to changes in acid-base and redox (oxidation-reduction) chemistry near the sediment-water interface can recycle this P and generate a benthic flux of bioavailable P that may far exceed external sources (Kuwabara and others, 2003a).

Objectives

In an effort to develop tools to facilitate science-based management decisions related to water and ecosystem quality in UKL and the associated watershed, this study provided the first *in-situ* measurements of the benthic fluxes of dissolved nutrients and trace metals between the bed sediment and water column of UKL both before and during the period of internal loading associated with the annual AFA bloom. These benthic-flux measurements provide initial source information for various regions of the lake against which the goals of the 5-year Plan for Lake Restoration can be measured. Biological measurements also test whether diffusion-controlled benthic flux can quantitatively account for internal P loading based on previous mass-balance studies, or whether benthic-community composition suggests an enhancement of diffusive flux due to bioturbation. Because of current considerations stated in the 5-year Plan to "increase humics released into the lake", the study also provides initial measurements of the benthic flux of dissolved organic carbon (DOC) to the lake because many trace metals are biologically reactive and complex strongly with dissolved organic ligands represented by DOC measurements. Furthermore, elevated concentrations of dissolved iron in pore-waters are an indication of reducing conditions favorable for phosphorus remobilization. Where the magnitude of internal loading in the lake is significant in magnitude relative to other solute sources, solute-transport data from previous studies, primary and ancillary data from this study, and results from other ongoing studies in the lake is synthesized to help identify potentially important biogeochemical mechanisms that regulate internal loading.

This study complements another done in 2005 to examine the role of sediments in the internal loading of P to UKL by comparing characteristics of sediment cores collected before the onset of an AFA bloom, including the concentrations of total P and P associated with geochemical phases, with the characteristics of sediment cores collected after the development of an AFA bloom. The hypothesis tested in the 2005 sediment study was that**,** as a source of P to the overlying water column, sediments have quantifiable losses in the concentrations of P in the time period between the onset and development of an AFA bloom.

Results and Discussion

Benthic flux of nutrients

A prototype pore-water profiler was successfully deployed in Howard Bay on 18 April 2006 (Fig. 1). That test allowed us to refine the profiler design to provide 50 – 60 milliliters of water from each of six pore-water depths. After refinements were made, profilers were fully deployed in triplicate, except where indicated in Table 2, at each of five sampling sites in the lake.

The flux of SRP as determined from pore-water concentration gradients was consistently positive (that is, out of the sediment into the overlying water column) and ranged between 0.5 and 6.1 milligrams per square meter per day (Table 2). Large-scale (between site) spatial variability was observed, sometimes at order-of-magnitude levels. Meanwhile, small-scale (within site) variability was seen at certain sites to a lesser degree (>30% of mean values). Assuming a lake area of 200 square kilometers, estimated diffusive flux can be areally averaged to represent a range of 100 to 1200 kilograms per day of phosphorus as SRP. Our diffusive-flux measurements are also comparable in magnitude to the highest pumping load (or discharge) of dissolved and particulate phosphorus from the Williamson River reported by Synder and Morace (1997; 77 kilograms per day).

Extrapolated over a 3-month AFA bloom season, our observed range is 8,000 to 100,000 kilograms phosphorus as SRP. For comparison, riverine inputs (Kann and Walker, 1999; data from years 1991 throught 1998) averaged 21,000 $\pm$ 5,000 kilograms phosphorus as SRP during the 3-month AFA bloom season. Miller and Tash (1967) estimated that the Wood and Williamson Rivers contributed about 43 percent of the total phosphorus to the lake with a daily load, averaged over 14 months, of 460 kilograms per day (approximately 41,000 kilograms of total phosphorus during the 3-month algal growth season).

Because the negative logarithm of the equilibrium constant (pK) for the ammonia (NH_3) to ammonium (NH_4^+) reaction is 9.5 (Hogfeldt, 1982), lakes with extended periods where the pH is >9.5 like UKL (Wood and others, 2006) are locations where elevated ammonia or ammonium concentrations are of concern due to potential fish toxicity (Arillo and others, 1981; Randall and Tsui, 2002). As with SRP, dissolved ammonium also displayed consistently positive benthic fluxes of 4 to 100 milligrams per square meter per day. Extrapolated over a 3-month AFA bloom season, this range is approximately 70,000 to 2,500,000 kilograms of nitrogen as dissolved ammonium. The higher fluxes for ammonium relative to SRP reflect higher concentration gradients across the sediment water interface despite increasing water-column concentrations for dissolved ammonium as the AFA bloom progressed (Table 2). Using Kann and Walker (1999) again for comparison, the riverine inputs for total dissolved inorganic nitrogen (that is the sum of ammonium, nitrate and nitrite concentrations) during the 3-month AFA bloom season are 13,000 $\pm$ 3,000 kilograms. In contrast to both dissolved ammonium and SRP, dissolved nitrate exhibited negative fluxes (consumed by the sediment) with values ranging between -20 to -0.1 milligrams per square meter per day, with the exception of the unreplicated test of 18 April 2006, that generated a slightly positive nitrate flux (3 milligrams per square meter per day).

The growth and subsequent settling of phytoplankton provide a carbon source to microbial and macroinvertebrate assemblages near the lakebed. It has been demonstrated that feeding and foraging mechanisms by certain macroinvertebrates may significantly enhance the benthic flux of solutes (Kuwabara and others, 1999; Boudreau and Jorgensen, 2001). In addition to collecting samples for chemical constituents in the lake water column and interstitial waters, replicate samples were also taken during each sampling event to provide initial information on macroinvertebrate and benthic-chlorophyll distributions. Our data thus far indicate benthic macroinvertebrate densities varied substantially both temporally and spatially with densities at least of the order of 10^5 individuals per square meter, an order of magnitude similar to those reported previously (Strayer, 1994; Crane and others, 1997). The magnitude of these macroinvertebrate densities, suggest that the diffusive-flux estimates reported herein represent lower bounds for solute benthic fluxes that may be physically enhanced by bioturbation.

Dissolved nutrients in the water column

Dissolved-nitrogen species (ammonium and nitrate plus nitrite) gradually increased between April and May 2006 samplings, but experienced at least three-fold and up to order-of-magnitude increases in August 2006 relative to previous dates (Table 3). However, these temporal trends were not maintained at all stations for the 2007 sampling. Consistent with previous monitoring in the lake (Wood and others, 2006), concentrations > 0.5 (but < 1.0) milligrams per liter for dissolved ammonium were observed at the end of the bloom period in August 2006. Although the upper bound of 1 milligram per liter is lower than published acute toxicity values (LC50) for fish and other freshwater species (Randall and Tsui, 2002), concentrations of the order of tenths of milligrams per liter, as reported herein, have been shown to induce sublethal effects in fish (Daoust and Ferguson, 1984; LeMarie and others, 2004). Concentrations of dissolved nitrogen species at WMR were the lowest on average relative to all other sampling sites, particularly in May 2007.

SRP also increased in August 2006 relative to April 2006 and May 2006 concentrations (overall averages for the April and May versus August 2006 samplings were 7.6 $\pm$ 7.3 versus 107.8 $\pm$ 31.2 micrograms per liter, respectively). In terms of inter-annual differences, only a minor (that is, statistically insignificant) increase was observed for SRP between pre-bloom (April 2006) and bloom (May 2006) conditions. In contrast, pre-bloom and bloom conditions in 2007 exhibited much greater SRP differences (overall averages of 10.1 $\pm$ 3.6 and 103 $\pm$ 15.4 micrograms per liter for pre-bloom (May 2007) and bloom conditions (July 2007), respectively; Table 3). The samples from the Williamson River plume site (WMR) displayed the highest SRP concentrations in both April 2006 and May 2006 (that is, pre-bloom and bloom conditions, respectively) relative to the other sampling sites, but the lowest SRP among sites in August 2006 (post-bloom conditions). In contrast, similar SRP concentrations relative to other sites were observed in 2007 pre-bloom and bloom samplings.

Dissolved silica serves as an essential macronutrient for diatoms but also a ligand that may compete in complexation and sorption reactions. Because annual summer blooms are not dominated by diatoms, silica was not examined in 2006 field work, but samples for dissolved silica were collected in 2007 to provide initial information that might affect our understanding of the speciation or partitioning of other ligands like phosphate. Only three sites were sampled for silica due to budgetary constraints (SBI, EBB and MRM). Water-column concentrations were spatially consistent in May 2007 (10.8 to 10.9 milligrams Si per liter with a standard error of 0.1 milligrams Si per liter) and July 2007 (14.6 to 14.9 milligrams Si per liter with a standard error of 0.1 milligrams Si per liter). Note that silica and organic carbon are the only solutes to be expressed in these units (all others in micrograms per liter).

Dissolved organic carbon (DOC) in the water column

Dissolved organic matter, measured as DOC, is a ligand that can compete for trace-metal complexation in the water, and hence affect the remobilization and bioavailability of biologically reactive trace metals (Kuwabara and others, 1986). For example, Kuwabara and others (1989 and 2002) noted that spatial trends for certain dissolved trace metals (copper and zinc) in South San Francisco Bay and Lahontan Reservoir (mercury) were coincident with DOC. Although DOC concentrations in the water column of UKL were spatially consistent on a given sampling date, concentrations taken before and during the AFA bloom (5.8 $\pm$ 0.1 milligrams carbon per liter or 484 $\pm$ 12 micromolar carbon; n=26 for April and May 2006 samples) were consistently lower than observed in August 2006 (8.2 $\pm$ 0.3 or 687 $\pm$ 28 micromolar carbon; n= 12), at the conclusion of the bloom (Table 4). Similarly in 2007, DOC concentrations increased at all sites as the AFA bloom progressed.

Dissolved trace metals in the water column

Trace elements can represent both essential micronutrients as well as highly effective algal toxins. In the dissolved phase, trace elements (for example, copper, manganese and zinc) are more bioavailable than if particle-bound, and can compete for ligands in both dissolved and particulate phases, and hence affect trace-metal speciation and partitioning. During all sampling trips to UKL, dissolved cadmium, zinc, and sometimes lead were below the method detection limits of our ICP-MS analyses (Table 5). In terms of spatial trends, dissolved trace-metal concentrations did not vary significantly between sites on any of the three dates. Dissolved-nickel concentrations were both spatial and temporally consistent (0.346 $\pm$ 0.051 micrograms per liter for the mean concentration over all trips; n=61). Dissolved manganese and cobalt increased in August 2006 relative to our April 2006 and May 2006 samplings, and again between May 2007 and July 2007. In contrast, dissolved iron became depleted (less than 5 micrograms per liter) at all five sampling sites by the end of the algal-bloom period in August 2006. The fact that SRP increased at the end of the AFA bloom (Table 3) while dissolved iron was depleted, suggests that iron availability may play an important role in regulating primary productivity in the lake. Dissolved iron associated with organic ligands varied considerably (by orders of magnitude) in tributary inputs to UKL (Table 6). In May 2007, 83 percent of the variation in dissolved iron was explained by spatial trends in the DOC data (that is, the correlation coefficient, r = 0.91). However, in July 2007, the Williamson tributary, having the highest DOC and dissolved iron in May, was no longer flowing. With no Williamson tributary data in July, the coefficient of determination for dissolved iron on DOC decreased to 0.14. In both May and July tributary samples, the correlation between SRP, silica and DOC remain consistently significant (coefficients of determination between 0.73 and 1.00; Table 6).

Diffusive flux of iron from the lakebed averages 2.9 $\pm$ 2.3 milligrams of iron per square meter of lakebed per day (Table 7). Using the afore mentioned 200 square-kilometer surface area estimate, this mean extrapolates to 53,800 kilograms of dissolved iron diffusing into the water column over the 3-month AFA bloom. Alternately, using an average lake depth of 2.8 meters (Wood and others, 2006), iron flux would be estimated to increase the lake-wide water-column concentration of dissolved iron by approximately 1 microgram per liter per day, or approximately 90 micrograms per liter over the 3-month AFA bloom. The possibility of dissolved iron as a limiting nutrient in the AFA bloom cannot be discounted, even before considering that these fluxes are likely to be underestimates due to the possibility of advective flux by bioturbation.

It should be noted that trace-metal concentrations for the lake and proximal rivers have been previously reported (Miller and Tash, 1967). However, seminal studies by Patterson and Settle (1976) and later by Fitzwater and others (1982) revealed that the utility of data from all prior trace-metal studies (that is, at least before the mid 1970s) was constrained by problems with sampling (i.e., the lack of ultra-clean sampling and processing techniques) and analytical methods. The analysis of dissolved Zn is particularly susceptible to sample contamination during collection, handling and processing (Bruland and others, 1978; Fitzwater and others, 1982). As noted above, dissolved-Zn concentrations reported here were consistently below a conservative ICP-MS detection limit of 1 microgram per liter. In contrast, the lowest lake Zn concentration reported by Miller and Tash (1967) was 7 micrograms per liter with the majority of measurements above 20 microgram per liters.

Benthic macroinvertebrates

This study includes some initial characterizations of the benthic macroinvertebrate assemblages associated with the 5 lake-sampling sites. Measurements thus far suggest that abundances of the order of tens of thousands of individuals per square meter are typical in the lake, so it is reasonable to assume that bioturbation by the macroinvertebrate assemblage will to some extent enhance the diffusive-flux measurements determined by the profiler (Table 8). Flux measurements presented herein do not quantify the percentage of the total benthic flux attributable to bioturbation. As a point of reference, benthic flux of trace elements and nutrients in Coeur d'Alene Lake, ID, a transitional oligotrophic-mesotrophic system impacted by a century of mining activities, is diffusion dominated (that is, neglible biological enhancement of benthic flux) because the abundance of macroinvertebrates is sparse (98 + 125 macroinvertebrates per square meter; n= 12; Kuwabara and others, 2003b) at sampling sites that were examined. In a hypothetical example, if one assumes that a water column source of phosphorus around 300 micrograms per liter per month stimulates the annual summer AFA bloom (Fisher and Wood, 2001), one can estimate that a bioturbation-enhancement factor of approximately 15 would account for a predominantly benthic source (i.e., 300/20; using the average dissolved ortho-P benthic flux from Table 2 and assuming an average water-column depth of 3 meters). The magnitude of this enhancement factor is within reason because; (1) in certain aquatic environments, bioturbation and bioirrigation by benthic macroinvertebrates can enhance the benthic flux of solutes by orders of magnitude (that is, a bioturbation/bioirrigation enhancement factor of tens to hundreds; Charbonneau and Hare, 1997; Kuwabara and others, 1999), and (2) the benthic flux of dissolved ortho-P is one of many dissolved forms of phosphorus, albeit the most bioavailable form, that may be transported into the water column from the underlying sediment.

Benthic chlorophyll

Benthic-chlorophyll measurements provide an indication of the settled carbon load to the lake bed as phytoplanktonic bloom conditions wax and wane. This study includes some initial measurements of benthic chlorophyll for the lake associated with the 5 sampling/profiling sites (Table 9). As one might expect, measurements for benthic chlorophyll varied widely over the bloom season (0.4 to 5.0 micrograms chlorophyll per square centimeter) as did the associated phaeophytin (3.1 to 14.1 micrograms phaeophytin per square centimeter). In 2006, benthic-chlorophyll concentrations decreased at all sites as the bloom progressed, and because phaeopigments represent degradative products of chlorophyll, phaeophytin concentrations coincidently increased. However in 2007, benthic chlorophylls were significantly lower at the beginning of the bloom (that is, during our early May 2007 sampling) and phaeophytin higher than in 2006 (Table 9). Hence, the average ratio of benthic chlorophyll to phaeophytin (that is, the concentration ratio of chlorophyll to the sum of chlorophyll and phaeophytin is significantly lower in 2007 than in 2006. That ratio serves as a coarse indicator of the reproductive status of the benthic algal assemblage. When this ratio is high (near 1), pigments are dominated by active chlorophyll a, indicating a viable algal population that is growing and developing quickly (that is, near maximum growth rates). Conversely, a low ratio (< 0.5) indicates a predominance of phaeopigments, associated with: (1) the termination of blooms, (2) degradation or senescence of cells settled on the lakebed, or (3) an active benthic fauna that consumes benthic algae and generates phaeopigment-rich feces. Because of cell settling and light absorption, this ratio is typically higher in the water-column than in the bottom sediments (Carmen and others, 1997). Note that all tabulated ratios (all dates and locations) are < 0.5 with lowest values in 2007 of <0.1. In 2006, chlorophyll-a concentrations were monitored by the USGS Oregon Water Science Center at HDB and WMR (http://or.water.usgs.gov/projs_dir/klamath_ltmon/). The highest benthic-chlorophyll concentrations (and chlorophyll to phaeopigment ratios) at these sites were observed in April, prior to the AFA bloom in the water column. In 2007, those pre-bloom peaks in benthic-chlorophyll concentrations were not observed and phaeophytin concentrations were elevated prior to the AFA bloom, as they were after the bloom in August 2006. If the annual and seasonal components to the variability of parameters that characterize the benthic environment are of similar magnitudes, as suggested by this initial data set (Table 9), it maybe prudent in subsequent monitoring studies to quantify and isolate variability over multiple time scales.

Geochemistry of lakebed sediments

P Concentrations

Concentrations of total P in the April 2007 sediment samples (Table 10) ranged from 0.23 mg/g to 1.11 mg/g DW. Concentrations of total P in the July 2007 sediment samples (Table 11) ranged from 0.24 to 1.07.

P Speciation

Loosely bound P: Data for P concentrations in extractions using 1M $MgCl_2$ (pH=8) indicate that approximately 10 to 15 percent of the concentration of total P in the surface sediment from the cores collected for this study is loosely bound phosphate. In all cores the concentration of easily desorbed P is largest in sediment closest to the sediment-water interface (<5 cm depth).

P associated with poorly crystalline Fe oxides: The largest concentrations of phosphate associated with poorly crystalline Fe oxides are in surface sediments from EBB and SBI (Table 10; Table 11). As with the loosely bound P, the concentrations of P sorbed to poorly crystalline Fe oxides were largest near the sediment-water interface (<5 cm depth).

P associated with carbonates and low energy bonds in organic matter: One molar HCl extracted approximately 10 to 20 percent of total P in both the April and July cores (Tables 10 and 11, respectively) collected at the EBB, SBI, and HDB sites. One molar HCl extracted approximately 10 to 30 percent of the total P in the April and July cores collected at the MDL site.

Organic P: The residual sediment material remaining after treatment with the extraction sequence is considered free of inorganic matter and therefore is calculated to contain the organic fraction of P. Calculated average values for the percent of total P represented by organic P was 71 $\pm$ 10 percent for all samples collected in April 2005, and 82 $\pm$ 12 percent for all samples collected in July 2005.

Metals

Concentrations of total Fe, total Al and total Ca are similar in sediments from all cores at all depths with the following exceptions (Table 10; Table 11). Concentrations of total Fe in sediment cores from EBB are larger than the concentrations of total Fe in cores from the other three sites in this study. Concentrations of total Al and total Ca in the top 5 cm of sediment are larger in cores from MDL than in the cores from other study sites.

Organic C and N

The organic compound used as a primary standard (acetanilide) contains 71.05 percent carbon. Replicate samples provided concentrations of 71.28 $\pm$ 0.20 percent of C (n= 5). On average, concentration data for percent C could be approximately 0.01 percent larger than the true concentration. There were no differences between the concentrations of C in samples analyzed by flash oxidation of the sample and separation of the gaseous products before and after treatment with hydrochloric acid (HCl). The similarity in the concentrations of C in samples before and after treatment with HCl indicates that the C concentrations represent organic C with negligible contributions of inorganic C.

Study Design and Methods

The protocol described in this section focuses on method applications in this sampling of the water column and benthos in UKL. Details (for example, quality control specifications) for each analysis have been previously documented (Woods and others, 1999; Praskins and others, 2001; Kuwabara and others, 2003a).

Within UKL, sampling was performed on five trips beginning 18 April 2006, 31 May 2006, 2 August 2006, 2 May 2007 and 9 July 2007, to chemically characterize the water column and benthos (Fig. 1; Table 1). A non-metallic pore-water profiler was designed and fabricated for this study (Fig. 2). In addition to water just above (approximately 1 centimeter) the sediment-water interface, samplers collected interstitial water from five depths within the top 10 centimeters of the lakebed, with fritted polypropylene probes at 1, 2, 3.3, 5.5 and 10 cm, to characterize dissolved-solute vertical gradients (that is, six independent sampling circuits). Each sampling circuit collected filtered (0.2 micron) water into acid-washed 60-milliliter syringes. After being lowered onto the lakebed, the device was tripped mechanically to begin sample collection and retrieved approximately 24 hours later. Dye experiments indicated that this extended sampling period avoided short circuiting of samples between depths and along device surfaces. After retrieval, the sample syringes were valved closed, placed in argon-filled bags and refrigerated in darkness for chemical analyses. On 18 April 2006, a prototype of the pore-water profiler was tested at the long-term monitoring site in Howard Bay (HDB), providing the first set of nutrient data to estimate diffusive flux from the lake sediments. Based on that initial trip, the design of the profiler was refined and 15 units were fabricated. During four subsequent sampling events, pore-water profilers were deployed in triplicate at five locations in UKL corresponding to long-term USGS monitoring sites in the lake (Wood, unpublished). A patent application has been submitted for this pore-water profiler. Flux calculations, based on Fick's Law, assume that the process is diffusion controlled with solute-specific diffusion coefficients (Li and Gregrory, 1974; Applin 1987). Hence, the calculated benthic flux of dissolved solutes based on pore-water profiles can be enhanced by bioturbation, bioirrigation, wind resuspension, and potential ground-water inflows.

At each profiler-deployment site, water-column samples for dissolved (0.2-micron filtered) nutrients, trace elements and dissolved (0.7-micron filtered) organic carbon were collected with a fluoroethylene polymer-coated Niskin bottle (General Oceanics; Fig. 3) to minimize contamination and crossover of analytes. Benthic samples for macroinvertebrate taxonomy and benthic chlorophyll were also obtained by sub-coring replicate grab samples.

Sampling methods have been previously described (Kuwabara et al. 2003b), but details are provided below. At each site, the following samples were collected, unless otherwise noted:

Biological Parameters

1. **Benthic invertebrate sampling:** After water-column sampling was completed at each sampling site, three deployments of an Ekman grab sampler (15 x 15 centimeter cross section) were used to collect replicate samples for macroinvertebrate taxonomic analyses. The sieved samples (500-micrometer mesh) were fixed with 10-percent buffered formalin, later transferred to 70-percent ethanol, then sorted at 10× magnification and identified to the lowest practicable taxonomic level. Samples were stained with Rose Bengal to facilitate sorting. No subsampling was used.

2. **Benthic chlorophyll-a:** At each lake site, surficial sediment (that is, the top 0.5 centimeters of lakebed material) was collected from a fresh Ekman grab and stored refrigerated in a plastic Petri

dish within a sealed plastic bag. Each dish was sub-sampled in triplicate for benthic chlorophyll-*a*. The surficial sediment for each replicate was collected on a glass-fiber filter and buffered with 1 milliliter of magnesium carbonate. Water was removed from the buffered samples by vacuum at less than 5 pounds per square inch to avoid cell lysis. Samples were then frozen in darkness for preservation until spectrophotometrically analyzed by methods described in Thompson and others (1981) and Franson (1985).

Chemical Parameters

1. Dissolved trace elements: Water-column samples were collected in duplicate in 250-milliliter acid-washed high-density polyethylene bottles, filtered (0.2-micrometer polycarbonate membrane) and acidified (pH 2) to provide dissolved trace-metal information for the lake by flow-injection inductively coupled plasma mass spectrometry (ICP-MS; Topping and Kuwabara, 1999; Topping and Kuwabara, 2003a).

2. Dissolved organic carbon (DOC): Dissolved organic carbon samples were also collected in duplicate in baked 60-milliliter glass bottles with acid-washed fluoroethylene-polymer caps, filtered (0.7-micron baked glass-fiber filter) for analysis by high-temperature combustion (Qian and Mopper, 1996; Vandenbruwane and others, 2007). Potassium phthalate was used as the standard. Low-DOC water (blanks less than 40 micrograms organic C per liter) was generated from a double-deionization unit with additional ultraviolet treatment (Milli-Q Gradient, Millipore Corporation).

3. Dissolved nutrients: Nutrient samples were filtered (0.2-micron polycarbonate membranes) and immediately refrigerated in darkness. Unlike trace-metal samples, nutrient samples were not acidified. Concentrations for dissolved (0.2-micron filtered) nitrate, ammonia, orthophosphate (SRP) and silica were determined by automated spectrophotometry (Franson, 1985).

4. Geochemistry of lakebed sediments: In April, before the onset of an AFA bloom, and in July, after development of an AFA bloom, a long (27 cm) and a short (10 cm) sediment core were collected at the Ball Bay (EBB), Bare Island (SBI), Howard Bay (HDB) and Mid Lake (MDL) sites in UKL.

Cores were sampled at 1-cm intervals to a depth of 5 cm from the sediment water interface. Two-cm intervals were collected between depths of 5 and 15 cm; 3-cm intervals were collected between depths of 15 and 27 cm. Individual intervals of the cores were weighed, frozen and, subsequently, freeze-dried. Samples were ground to a 250 µm particle size. The weights of the wet and dry sediment were recorded and water content was calculated.

In preparation for determination of total P, major cations, and trace metals, approximately 0.1 g of each sample was digested with concentrated nitric and hydrofluoric acids using a microwave digestion system (CEM Corporation). Nitric and hydrofluoric acids were added in two steps. Diluted digests were analyzed for trace metals using inductively-coupled plasma mass spectroscopy (ICP-MS). Certified reference material, NIST SRM 2710, Montana soil, (National Institutes of Science and Technology, 2003) was analyzed to determine the accuracy and precision of the microwave technique (Table 12). This SRM was included in all sets of analyses and the results of the analyses of the standard sediment determined the acceptability of chemical data.

Total P was determined using diluted microwave digestion solutions and the molybdenum blue method. This colorimetric method for SRP (dissolved orthophosphate included) was used to determine P concentrations in all samples. The method detection limit for total P is 0.14 mg g^{-1} DW sediment. The microwave digestion procedure described above converts all forms of P in sediment samples to orthophosphate. Details of the method are given in Simon et al. (2005).

Phosphorus Speciation in sediments included determining concentrations of P in four geochemical phases. These forms of P are operationally defined by chemical extractions and include (1) loosely bound P, (2) P associated with poorly crystalline Fe oxides, (3) P associated with carbonates or bound in low-energy bonds to organic matter, and (4) residual P including organic P. The sequential extraction scheme used in this study was the method of Ruttenberg (1992) modified for a smaller sample size than is used in the published method. Loosely bound P was extracted with 1M MgCl2 (pH=8). A solution of bicarbonate-citrate (pH=7.7) plus dithionite was used to extract P from poorly crystalline Fe oxides. Extraction with 1M HCl was used to remove P sorbed to carbonates, hydrolysable organic P and P bound to metals in organic matter.

Organic P was determined by subtracting the sum of the concentrations of inorganic P extracted from sediment samples from the concentration of total P in each sediment sample.

Metals: Concentrations of aluminum (Al), calcium (Ca), copper (Cu), and iron (Fe) in sediment samples were determined using ICP-AES. Microwave digests of sediment samples were diluted with 0.05 percent nitric acid in preparation for ICP-AES analysis.

A laboratory study of methods used for analyses was run using the NIST SRM 2710 to determine the precision and recovery of concentrations of P and metals known to be related to P in sediments. Table 12 details the results of this quality assurance study.

Organic carbon (C) and nitrogen (N) were determined by using 20 mg of freeze-dried and ground sediment samples. Flash oxidation of each sample was followed by chromatographic separation of the gaseous products and infrared detection. A subset of sediment samples was treated with HCl to ensure removal of carbonates and analyzed for C and N concentrations. Samples from MDL, the site where Ca concentrations in sediment were the largest determined in this study, were included in the subset of sediment samples.

References Cited

Applin, K.R., 1987, The diffusion of dissolved silica in dilute aqueous solution: Geochimica et Cosmochimica Acta, v. 51, p. 2147-2151.

Boudreau, B.P. and Jorgensen, B.B., 2001, The Benthic Boundary Layer, Transport Processes and Biogeochemistry: Oxford University Press, New York, New York, 404 p.

Bruland, K.W., Knauer, G. A., and Martin, J. H., 1978, Zinc in northeast Pacific waters: Nature, v. 217, p. 741-743.

Carman, K.R., Fleeger, J.W., Pomarico, S.M., 1997, Response of a benthic food web to hydrocarbon contamination: Limnology and Oceanography, v. 42, p. 561-571.

Charbonneau, P., Hare, L., and Carignan, R., 1997, Use of X-ray images and a contrasting agent to study the behavior of animals in soft sediments: Limnology and Oceanography, v. 42, p. 1823–1828.

Crane, J.L., Schubauer-Berigan, Mary, and Schmude, Kurt, 1997, Sediment assessment of hotspot areas in the Duluth/Superior harbor: United States Environmental Protection Agency, EPA-905-R97-020.

Daoust, P.-Y., and Ferguson, H.W., 1984, The pathology of chronic ammonia toxicity in rainbow trout, Salmo gairdneri Richardson: Journal of Fish Diseases, v. 7, p. 199-205.

Fisher, L.H., and Wood, T.M., 2001, Effect of Water-column pH on Sediment-phosphorus Release Rates in Upper Klamath Lake, Oregon, U.S. Geological Survey, Water Resources Investigations Report 03-4271, 25 p.

Fitzwater, S. E., Knauer, G. A., and Martin, J. H., 1982, Metal contamination and its effect on primary production measurements: Limnology and Oceanography, v. 27, p, 544–551.

Franson, M.A.H., 1985, Standard Methods for the Examination of Water and Wastewater, Sixteenth Edition, Method 1003C.6: American Public Health Association, American Water Works Association, Water Pollution Control Federation, Washington, D.C., 1268 p.

Goldberg, S.A, 1985, Chemical modeling of anion competition on goethite using the constant capacitance model: Soil Science of America Journal, v. 49, p. 851-856.

Hogfeldt, E., 1982, Stability constants of metal ion complexes, Part A. Inorganic ligands: IUPAC Chemical Data Series 21. Pergammon Press, Oxford, 310 p.

Kann, Jacob, and W.W. Walker, 1999, Nutrient and hydrologic loading to Upper Klamath Lake: Klamath Tribes Natural Resource Department, U.S. Bureau of Reclamation Cooperative Studies, 48 p.

Kuwabara, J.S., Davis, J.A., and Chang, C.C.Y., 1986, Algal growth response to particle-bound orthophosphate and zinc: Limnology and Oceanography, v. 31, p. 503-511.

Kuwabara, J.S., Chang, C.C.Y., Cloern, J.E., Fries, T.L., Davis, J.A., and Luoma, S.N., 1989, Trace metal associations in the water column of South San Francisco Bay, California: Estuarine Coastal and Shelf Science, v. 26, p. 307-325.

Kuwabara, J.S., Topping, B.R. Coale, K.H., and Berelson, W.M., 1999, Processes affecting the benthic flux of trace metals into the water column of San Francisco Bay, In Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the Technical Meeting, Charleston, South Carolina, March 8-12, 1999--Volume 2--Contamination of Hydrologic Systems and Related Ecosystems: U.S. Geological Survey Water-Resources Investigations Report 99-4018B, p. 115-119.

Kuwabara, J.S., Marvin-Dipasquale, M., Praskins, Wayne, Byron, Earl, Topping, B.R., Carter, J.L., Fend, S.V., Parchaso, Francis, and Krabbenhoft, D.P., 2002, Flux of dissolved forms of mercury across the sediment-water interface in Lahontan Reservoir, Nevada: U.S. Geological Survey Water Resources Investigations Report 02-4138, 48 p. (Internet access at: http://water.usgs.gov/pubs/wri/wri024138)

Kuwabara, J.S., Alpers, C.N., Marvin-DiPasquale, M.C., Topping, B.R., Carter, J.L., Stewart, A.R., Fend, S.V., Parchaso, F., Moon, G.E., and Krabbenhoft, D.P., 2003a. Sediment-water Interactions Affecting Dissolved-mercury Distributions in Camp Far West Reservoir, California. U.S. Geological Survey Water Resources Investigations Report 03-0140, 64 p. (Internet access at: http://water.usgs.gov/pubs/wri/wri034140/)

Kuwabara, J.S., Woods, P.F., Berelson, W.M., Balistrieri, L.S., Carter, J.L., Topping, B.R., and Fend, S.V., 2003b, Importance of sediment-water interactions in Coeur d'Alene Lake, Idaho: Management Implications: Environmental Management, v. 32, p. 348-359.

Lemarié, Gilles, Dosdat, Antoine, Covès, Denis, Dutto, Gilbert, Gasset, Eric, and Person-Le Ruyet, Jeannine, 2004, Effect of chronic ammonia exposure on growth of European seabass (Dicentrarchus labrax) juveniles: Aquaculture, v. 229, p. 479-491.

Li, Y-H, Gregory, S., 1974, Diffusion of ions in sea water and in deep-sea sediments: Geochimica et Cosmochimica Acta, v. 38, p. 703-714.

Miller, W.E., and Tash, J.C., 1967, Interim report, Upper Klamath Lake studies, Oregon: Corvallis, Oregon, Federal Water Pollution Control Administration, Pacific Northwest Laboratory, Water Pollution Control Research Series, Paper WP-20-8, 37 p.

National Institutes of Science and Technology, 2003. Certificate of Analysis, Standard Reference Material 2710, Montana Soil, Standard Reference Materials Program, USDC, Gaithersburg, MS 20899 6 p.

Patterson, C. C., and Settle, D.M., 1976, The reduction of orders of magnitude errors in lead analyses of biological materials and natural waters by evaluating and controlling the extent and sources of industrial lead contamination introduced during sampling collection and analysis, p. 321. Zn Accuracy in tract analysis: Sampling, sample handling, analysis. U.S. NBS, Special Publication 322.

Praskins, Wayne, Byron, Earl, Marvin-Dipasquale, Mark, Kuwabara, J.S., Diamond, M.L., and Gustin, M.S., 2001, Sampling and Analysis Plan: Mercury Dynamics in Lahontan Reservoir: U.S. Environmental Protection Agency, March 22, 2001, 46 p.

Qian, J.-G., and Mopper, K., 1996, Automated high-performance, high-temperature combustion total organic carbon analyzer: Analytical Chemistry, v. 68, p. 3090–3097.

Ruttenberg, K.C., 1992. Development of a sequential extraction method for different forms of phosphorus in marine sediments: Limnology and Oceanography, v. 37, p. 1460-1482.

Sigg, Laura, and Stumm, Werner, 1981, The interaction of anions and weak acids with the hydrous goethite (α-FeOOH) surface: Colloids Surfaces, v. 2, p. 101-117.

Simon, N.S., O. P. Bricker, W. Newell, J. McCoy & R. Morawe, 2004. The distribution of phosphorus in Popes Creek, VA, and in the Pocomoke River, MD: Two watersheds with different land management practices in the Chesapeake Bay Basin: Water, Air and Soil Pollution, v. 164, p. 189-204.

Snyder D.T., and Morace J.L., 1997, Nitrogen and phosphorus loading from drained wetlands adjacent to Upper Klamath and Agency Lakes, Oregon. US Geological Survey Water-Resources Investigations Report 97-4059, 67 p. (Internet access at: http://or.water.usgs.gov/pubs_dir/Pdf/97-4059.pdf)

Strayer, D. L., 1994, Body size and abundance of benthic animals in Mirror Lake, New Hampshire: Freshwater Biology, v. 32, p. 83-90.

Thompson, J.K., Nichols, F.H., and Wienke, S.M., 1981, Distribution of benthic chlorophyll in San Francisco Bay, California, February 1980 – February 1981: U.S. Geological Survey Open File Report 81-1134, 55 p.

Topping, B.R. and Kuwabara, J.S., 1999, Flow-injection-ICP-MS method applied to benthic-flux studies of San Francisco Bay, In Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the Technical Meeting, Charleston, South Carolina, March 8–12, 1999--Volume 2--Contamination of Hydrologic Systems and Related Ecosystems: U.S. Geological Survey Water-Resources Investigations Report 99-4018B, p. 131-134 (Internet access at: http://toxics.usgs.gov/pubs/wri99-4018/Volume2/sectionA/2216_Topping/index.html)

Topping, B.R. and Kuwabara, J.S., 2003, Dissolved Nickel and Benthic Flux in South San Francisco Bay: A Potential for Natural Sources to Dominate: Bulletin of Environmental Contamination and Toxicology, v. 71, p. 46-51.

Vandenbruwane, J., De Neve, S., Qualls, R.G., Sleutel, S., and Hofman, G., 2007, Comparison of different isotherm models for dissolved organic carbon (DOC) and nitrogen (DON) sorption to mineral soil: Geoderma, v. 139, p. 144-153.

Wood, T.M., Hoilman, G.R., and Lindenberg, M.K., 2006, Water-Quality Conditions in Upper Klamath Lake, Oregon, 2002-04: U.S. Geological Survey Scientific Investigations Report 2006–5209, 54 p. (Internet access at: http://pubs.usgs.gov/sir/2006/5209/index.html)

Wood, T.M., A Plan for Long-Term Monitoring of Water Quality and Meteorological Variables in Upper Klamath Lake, Oregon", unpublished manuscript.

Woods, P.F., Nearman, M.J., and Barton, G.J., 1999, Quality assurance project plan for U.S. Geological Survey studies in support of Spokane River Basin RI/FS.: U.S. Environmental Protection Agency, Seattle, Washington, and U.S. Geological Survey, Boise, Idaho, 153 p.

Acknowledgments

The authors are grateful for critical logistical support from R. Shively, S. Vanderkooi and other personnel from the USGS Field Office in Klamath Falls, OR, and from the Oregon Water Science Center. Macroinvertebrate taxonomic analyses by S.V. Fend are appreciated. Participation in field studies by A. Engelstad, S. Foster, V. Greene and B. Swift was critical to its successful completion. The Klamath Falls Office of the USBR (Funding Agreement Number 06AA204159) and the USGS Toxic Substances Hydrology Program are also acknowledged for support of this ongoing work.

Fig. 1. Sampling Locations for this study of Upper Klamath Lake, OR

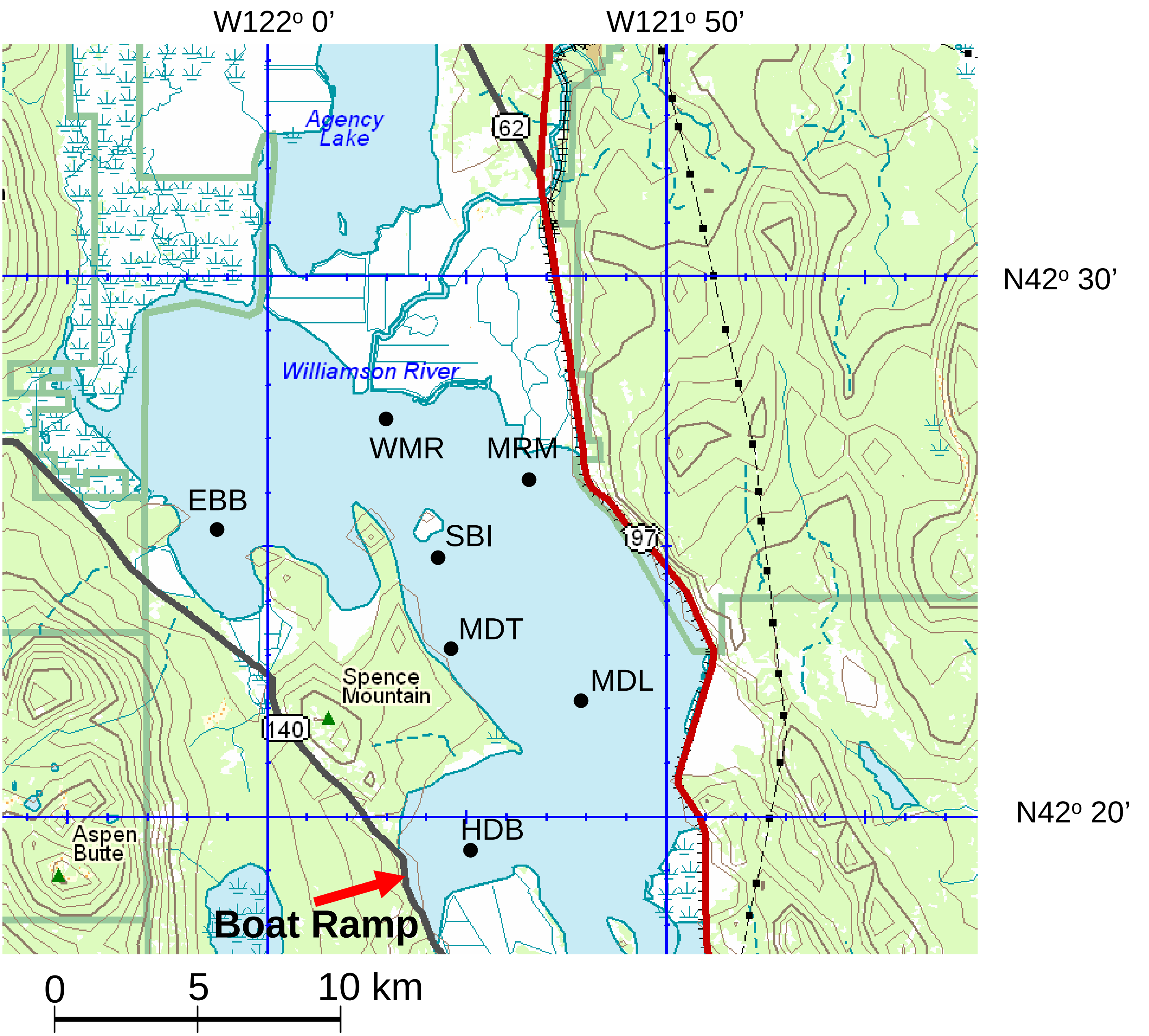


Fig. 2. Preparation of pore-water profilers for deployment in Upper Klamath Lake, OR

On-site profiler assembly
(May 31, 2006)

Profiler deployment and retrieval
(May 31 and June 1, 2006)

Fig. 3. Water-column sampling with Teflon-coated Niskin bottle

Table 1. Sampling locations and location acronyms used in this report (See map at Fig. 1).

Location	Site Acronym	Location Coordinates North Latitude	Location Coordinates West Longitude
Howard Bay	HDB	42^{o} 19.550'	121^{o} 55.000'
Modoc Rim	MRM	42^{o} 24.622'	121^{o} 51.874'
Entrance to Ball Bay[1]	EBB	42^{o} 25.313'	122^{o} 0.966'
Williamson River plume	WMR	42^{o} 27.334'	121^{o} 57.161'
South of Bare Island	SBI	42^{o} 24.572'	121^{o} 54.637'
Mid-Lake continuous monitoring site	MDL	42^{o} 23.200'	121^{o} 51.985'
Main Trench north of Howard Bay	MDT	42^{o} 23.085'	121^{o} 55.637'

[1] Ball Bay location sampled April 18, 2006 was approximately 1 kilometer south from EBB, and was too shallow for sampling at multiple depths.

Table 2. Summary of dissolved-nutrient fluxes for Upper Klamath Lake, OR.

18-Apr-06		Ortho-P		Nitrate		Ammonium	
Water-column temperature =	**7.0** °C						
Prototype test - only one sampler							
Site: Howard Bay	**Code:** HDB	**0.40** **mg-m^{-2}-day^{-1}**	**79** **kg-d^{-1}**	**0.01** **mg-m^{-2}-day^{-1}**	**3** **kg-d^{-1}**	**23.06** **mg-m^{-2}-day^{-1}**	**4613** **kg-d^{-1}**

31-May-06 — Water-column temperature = **14.0 to 15.8** °C

Site #	Site Location	Site Code	Ortho-P Site Average (mg-m^{-2}-day^{-1})	Ortho-P Site StDev (mg-m^{-2}-day^{-1})	Ortho-P Site Average (kg-d^{-1})	Ortho-P Site StDev (kg-d^{-1})	Nitrate Site Average (mg-m^{-2}-day^{-1})	Nitrate Site StDev (mg-m^{-2}-day^{-1})	Nitrate Site Average (kg-d^{-1})	Nitrate Site StDev (kg-d^{-1})	Ammonium Site Average (mg-m^{-2}-day^{-1})	Ammonium Site StDev (mg-m^{-2}-day^{-1})	Ammonium Site Average (kg-d^{-1})	Ammonium Site StDev (kg-d^{-1})	
1	Howard Bay	HDB	**0.99**	0.38	**198**	76	**-0.11**	0.07	**-23**	15	**4.46**	0.65	**891**	131	
2	Williamson River Plume	WMR	**2.50**	1.57	**500**	315	**-0.63**	0.30	**-127**	60	**3.55**	0.47	**709**	94	
3	Entrance to Ball Bay	EBB	**2.17**	2.33	**651**	388	**-0.22**	0.20	**-65**	21	**12.17**	0.67	**2433**	135	Only 2 replicates
4	Modoc Rim	MRM	**0.46**	0.18	**92**	36	**-0.06**	0.01	**-12**	2	**4.62**	4.52	**925**	904	Only 2 replicates
5	South of Bare Island	SBI	**1.69**	1.10	**338**	219	**-0.15**	0.02	**-31**	3	**4.30**	4.36	**860**	871	Within-site variability

2-Aug-06 — Water-column temperature = **19.2 to 20.3** °C

Site #	Site Location	Site Code	Ortho-P Site Average (mg-m^{-2}-day^{-1})	Ortho-P Site StDev (mg-m^{-2}-day^{-1})	Ortho-P Site Average (kg-d^{-1})	Ortho-P Site StDev (kg-d^{-1})	Nitrate Site Average (mg-m^{-2}-day^{-1})	Nitrate Site StDev (mg-m^{-2}-day^{-1})	Nitrate Site Average (kg-d^{-1})	Nitrate Site StDev (kg-d^{-1})	Ammonium Site Average (mg-m^{-2}-day^{-1})	Ammonium Site StDev (mg-m^{-2}-day^{-1})	Ammonium Site Average (kg-d^{-1})	Ammonium Site StDev (kg-d^{-1})	
1	Howard Bay	HDB	**6.09**	4.25	**1218**	851	**-2.87**	1.71	**-575**	341	**133.86**	59.34	**26773**	11868	
2	Williamson River Plume	WMR	**0.95**	0.70	**189**	140	**-5.84**	2.33	**-1168**	466	**40.89**	40.52	**8178**	8103	
3	Entrance to Ball Bay	EBB	**5.23**	2.02	**1045**	403	**-22.72**	14.76	**-3030**	3353	**106.58**	33.93	**21316**	6786	
4	Modoc Rim	MRM	**0.43**	0.06	**85**	11	**-1.27**	0.47	**-254**	94	**25.46**	29.50	**5092**	5901	Only 2 replicates
5	South of Bare Island	SBI	**1.28**	0.86	**256**	171	**-1.53**	0.03	**-305**	5	**11.03**	5.55	**2206**	1110	

2-May-07 — Water-column temperature = **12.4 to 12.8** °C

Site #	Site Location	Site Code	Ortho-P Site Average (mg-m^{-2}-day^{-1})	Ortho-P Site StDev (mg-m^{-2}-day^{-1})	Ortho-P Site Average (kg-d^{-1})	Ortho-P Site StDev (kg-d^{-1})	Nitrate Site Average (mg-m^{-2}-day^{-1})	Nitrate Site StDev (mg-m^{-2}-day^{-1})	Nitrate Site Average (kg-d^{-1})	Nitrate Site StDev (kg-d^{-1})	Ammonium Site Average (mg-m^{-2}-day^{-1})	Ammonium Site StDev (mg-m^{-2}-day^{-1})	Ammonium Site Average (kg-d^{-1})	Ammonium Site StDev (kg-d^{-1})	Silica Site Average (mg-m^{-2}-day^{-1})	Silica Site StDev (mg-m^{-2}-day^{-1})	Silica Site Average (kg-d^{-1})	Silica Site StDev (kg-d^{-1})	
1	Howard Bay	HDB	**1.06**	0.01	**211**	3	**-1.10**	0.96	**-331**	37	**6.30**	5.47	**1889**	85	No silica samples collected.				Only 2 replicates
2	Williamson River Plume	WMR	**0.49**	0.11	**98**	22	**-0.87**	0.86	**-260**	118	**7.01**	6.15	**2102**	272	No silica samples collected.				Only 2 replicates
3	Entrance to Ball Bay	EBB	**3.54**	4.39	**708**	877	**-3.16**	0.46	**-588**	101	**5.93**	5.46	**1186**	1091	**0.09**	0.02	**12**	11	
4	Modoc Rim	MRM	**0.76**	0.15	**153**	30	**-1.95**	0.22	**-389**	44	**6.85**	2.00	**1368**	399	**0.05**	0.04	**10**	7	
5	South of Bare Island	SBI	**1.83**	0.65	**365**	130	**-2.34**	0.41	**-467**	81	**9.20**	4.63	**1840**	925	**-0.05**	0.05	**-10**	11	

10-Jul-07 — Water-column temperature = **21.4 to 23.2** °C

Site #	Site Location	Site Code	Ortho-P Site Average (mg-m^{-2}-day^{-1})	Ortho-P Site StDev (mg-m^{-2}-day^{-1})	Ortho-P Site Average (kg-d^{-1})	Ortho-P Site StDev (kg-d^{-1})	Nitrate Site Average (mg-m^{-2}-day^{-1})	Nitrate Site StDev (mg-m^{-2}-day^{-1})	Nitrate Site Average (kg-d^{-1})	Nitrate Site StDev (kg-d^{-1})	Ammonium Site Average (mg-m^{-2}-day^{-1})	Ammonium Site StDev (mg-m^{-2}-day^{-1})	Ammonium Site Average (kg-d^{-1})	Ammonium Site StDev (kg-d^{-1})	Silica Site Average (mg-m^{-2}-day^{-1})	Silica Site StDev (mg-m^{-2}-day^{-1})	Silica Site Average (kg-d^{-1})	Silica Site StDev (kg-d^{-1})
1	Howard Bay	HDB	**1.78**	0.35	**355**	71	**-0.04**	0.02	**-5**	5	**28.08**	13.52	**5616**	2703	No silica samples collected.			
2	Williamson River Plume	WMR	**6.96**	2.90	**1393**	581	**-0.12**	0.02	**-25**	4	**19.49**	5.10	**3897**	1019	No silica samples collected.			
3	Entrance to Ball Bay	EBB	**5.03**	0.80	**1006**	159	**-0.01**	0.01	**-2**	2	**58.73**	37.98	**11745**	7597	**1.29**	0.02	**363**	181
4	Modoc Rim	MRM	**0.78**	0.50	**156**	101	**-0.11**	0.00	**-23**	0	**12.72**	5.60	**2544**	1120	**1.12**	0.07	**224**	14
5	South of Bare Island	SBI	**1.17**	0.80	**235**	161	**-0.05**	0.06	**-9**	12	**9.64**	1.17	**1927**	234	**0.36**	0.46	**72**	93

By comparison, the highest pumping-station flux from the Williamson River ~ **77** kg-d^{-1}
(for **total P**, from Table 11, Synder and Morace, 1997) **28205** kg-yr^{-1}
Riverine flux for **total P** (from Table 2, Miller and Tash, 1967) ~ **461** kg-d^{-1}
168246 kg-yr^{-1}

By comparison, the highest pumping-station flux from the Williamson River ~ **400** kg-d^{-1}
(for **total N**, from Table 11, Synder and Morace, 1997) **146000** kg-yr^{-1}
Riverine flux for **total N** (from Table 2, Miller and Tash, 1967) ~ **1498** kg-d^{-1}
546799 kg-yr^{-1}

Hypothetical Example: If one assumes: (1) an average dissolved ortho-P benthic flux of 2 mg-m^{-2}-day^{-1} from the tabulated values above, and (2) an average water-column depth of 3 meters a **bioturbation-enhancement factor of approximately 15** (or 300/20) would be required to provide 300 micrograms per liter of dissolved ortho-P to the water column in a month to stimulate an AFA bloom.

Table 3. Dissolved-nutrient concentrations (in ppb or micrograms per liter with standard deviations, stdev; n=2) in the water-column of Upper Klamath Lake, OR.

Site	Date	Ortho-P $(ug\text{-}P)\text{-}L^{-1}$	stdev	N+N $(ug\text{-}N)\text{-}L^{-1}$	stdev	NH4 $(ug\text{-}N)\text{-}L^{-1}$	stdev	Si $(ug\text{-}Si)\text{-}L^{-1}$	stdev
HDB	**18-Apr-06**	**1.8**	0.2	**3.0**	0.4	**8.2**	1.1	NA[1]	
	31-May-06	**2.2**	0.9	**8.8**	0.6	**26.6**	6.8	NA	
	2-Aug-06	**94.6**	0.3	**75.5**	0.6	**285.4**	14.1	NA	
	2-May-07	**17.4**	1.2	**156.3**	1.1	**169.2**	10.3	NA	
	10-Jul-07	**122.3**	8.2	**10.2**	0.3	**428.4**	28.0	NA	
WMR	**18-Apr-06**	**30.0**	0.0	**6.2**	0.2	**11.3**	0.4	NA	
	31-May-06	**25.3**	3.8	**9.4**	0.9	**24.7**	9.5	NA	
	2-Aug-06	**83.5**	6.2	**95.8**	0.4	**82.8**	48.8	NA	
	2-May-07	**8.7**	1.0	**108.3**	2.1	**62.7**	2.6	NA	
	10-Jul-07	**96.9**	10.6	**16.4**	1.0	**55.9**	46.4	NA	
EBB	**18-Apr-06**[2]	**4.6**	0.7	**2.8**	0.3	**7.5**	0.1	NA	
	31-May-06	**3.9**	0.9	**15.4**	0.7	**37.8**	13.5	NA	
Shallow	**2-Aug-06**	**130.0**	1.2	**60.5**	3.3	**789.9**	37.5	NA	
	2-May-07	**9.0**	2.2	**162.7**	1.5	**176.5**	8.8	**10900**	100
	10-Jul-07	**84.0**	11.8	**6.6**	0.6	**175.0**	56.6	**14600**	100
Deep	**31-May-06**	**11.0**	0.8	**17.2**	0.4	**66.0**	1.2	NA	
	2-Aug-06	**103.1**	1.2	**51.8**	0.7	**556.2**	4.5	NA	
	2-May-07	**8.0**	1.4	**161.8**	3.7	**193.6**	23.5	NA	
	10-Jul-07	**121.3**	12.5	**13.5**	1.1	**479.1**	53.6	NA	
MRM	**31-May-06**	**9.0**	0.7	**5.3**	0.3	**21.5**	3.7	NA	
	2-Aug-06	**101.7**	1.5	**93.1**	2.6	**72.5**	2.7	NA	
	2-May-07	**8.2**	0.0	**176.2**	0.4	**184.0**	9.2	**10800**	100
	10-Jul-07	**97.7**	8.6	**14.3**	1.0	**10.1**	0.0	**14800**	150
SBI	**31-May-06**	**3.1**	0.8	**14.4**	1.5	**29.6**	5.3	NA	
	2-Aug-06	**133.8**	4.8	**112.7**	1.0	**748.7**	12.0	NA	
	2-May-07	**9.2**	2.4	**169.3**	0.0	**198.2**	13.9	**10800**	100
	10-Jul-07	**95.7**	4.9	**9.3**	1.5	**438.5**	86.3	**14865**	100
MDL	**18-Apr-06**	**1.0**	0.3	**2.0**	0.0	**1.4**	0.0	NA	
MDT									
Shallow	**18-Apr-06**	**2.4**	0.2	**4.5**	1.3	**11.9**	4.2	NA	
Mid-depth	**18-Apr-06**	**2.2**	0.1	**4.7**	1.4	**8.5**	0.7	NA	
Deep	**18-Apr-06**	**2.7**	0.3	**3.7**	1.1	**10.0**	1.7	NA	

[1] "NA" indicates that samples were not analyzed for this constituent.

[2] Ball Bay location sampled April 18, 2006 was approximately 1 km south from EBB, and was too shallow for sampling at multiple depths

Table 4. Dissolved organic carbon (DOC) concentrations (in units of both micromolar and milligrams carbon per liter) in the water-column of Upper Klamath Lake, OR.

Site	Date	Sampling Replicate	DOC (uM)	[1]95% ci	DOC ($mg\text{-}C\text{-}L^{-1}$)	[1]95% ci
HDB	18-Apr-06	A	500	11	6.0	0.1
		B	468	11	5.6	0.1
	1-Jun-06	A	496	7	6.0	0.1
		B	508	3	6.1	0.0
	2-Aug-06	A	715	13	8.6	0.2
		B	745	11	8.9	0.1
	2-May-07	A	444	11	5.3	0.1
		B	439	15	5.3	0.2
	10-Jul-07	A	777	10	9.3	0.1
		B	770	7	9.2	0.1
WMR	18-Apr-06	A	501	14	6.0	0.2
		B	514	3	6.2	0.0
	1-Jun-06	A	512	16	6.1	0.2
		B	505	4	6.1	0.0
	2-Aug-06	A	727	7	8.7	0.1
		B	702	20	8.4	0.2
	2-May-07	A	400	14	4.8	0.2
		B	399	19	4.8	0.2
	10-Jul-07	A	618	11	7.4	0.1
		B	614	8	7.4	0.1
EBB Shallow	[2]18-Apr-06	A	455	6	5.5	0.1
		B	454	6	5.4	0.1
	1-Jun-06	A	504	4	6.0	0.0
		B	501	3	6.0	0.0
	2-Aug-06	A	686	5	8.2	0.1
		B	694	5	8.3	0.1
	2-May-07	A	400	2	4.8	0.0
		B	402	7	4.8	0.1
	10-Jul-07	A	642	19	7.7	0.2
		B	647	4	7.8	0.0
EBB Deep	1-Jun-06	A	506	3	6.1	0.0
		B	497	4	6.0	0.0
	2-Aug-06	A	686	7	8.2	0.1
		B	696	7	8.4	0.1
	2-May-07	A	399	10	4.8	0.1
		B	400	19	4.8	0.2
	10-Jul-07	A	632	8	7.6	0.1
		B	644	14	7.7	0.2
MRM	1-Jun-06	A	483	2	5.8	0.0
		B	498	19	6.0	0.2
	2-Aug-06	A	652	12	7.8	0.1
		B	691	9	8.3	0.1
	2-May-07	A	399	5	4.8	0.1
		B	402	9	4.8	0.1
	10-Jul-07	A	612	19	7.3	0.2
		B	615	4	7.4	0.0
SBI	1-Jun-06	A	497	9	6.0	0.1
		B	516	5	6.2	0.1
	2-Aug-06	A	641	4	7.7	0.0
		B	615	11	7.4	0.1
	2-May-07	A	401	8	4.8	0.1
		B	402	12	4.8	0.1
	10-Jul-07	A	628	5	7.5	0.1
		B	603	25	7.2	0.3
MDL	18-Apr-06	A	436	10	5.2	0.1
		B	442	6	5.3	0.1
MDT Shallow	18-Apr-06	A	487	2	5.8	0.0
		B	480	5	5.8	0.1
Mid-depth	18-Apr-06	A	483	9	5.8	0.1
		B	443	5	5.3	0.1
Deep	18-Apr-06	A	453	9	5.4	0.1
		B	446	4	5.4	0.1

April '06 & May '07 (uM)	($mg\text{-}C\text{-}L^{-1}$)	**June '06 & July '07** (uM)	($mg\text{-}C\text{-}L^{-1}$)	**Aug '06** (uM)	($mg\text{-}C\text{-}L^{-1}$)
399	4.8	483	5.8	615	7.4
399	4.8	496	6.0	641	7.7
399	4.8	497	6.0	652	7.8
400	4.8	497	6.0	686	8.2
400	4.8	498	6.0	686	8.2
400	4.8	501	6.0	691	8.3
401	4.8	504	6.0	694	8.3
402	4.8	505	6.1	696	8.4
402	4.8	506	6.1	702	8.4
402	4.8	508	6.1	715	8.6
436	5.2	512	6.1	727	8.7
439	5.3	516	6.2	745	8.9
442	5.3	603	7.2		
443	5.3	612	7.3		
444	5.3	614	7.4		
446	5.4	615	7.4		
453	5.4	618	7.4		
454	5.4	628	7.5		
455	5.5	632	7.6		
468	5.6	642	7.7		
480	5.8	644	7.7		
483	5.8	647	7.8		
487	5.8	770	9.2		
487	5.8	777	9.3		
500	6.0				
501	6.0				
514	6.2				

	April '06 & May '07 (uM)	($mg\text{-}C\text{-}L^{-1}$)	June '06 & July '07 (uM)	($mg\text{-}C\text{-}L^{-1}$)	Aug '06 (uM)	($mg\text{-}C\text{-}L^{-1}$)
= average	442	5.3	576	6.9	687	8.2
= stdev	38	0.5	86	1.0	36	0.4
= 95% CI	15	0.2	37	0.4	24	0.3
= n	27	27	24	24	12	12

[1] "95% ci" stands for 95% confidence interval

[2] Ball Bay location sampled April 18, 2006 was approximately 1 km south from EBB, and was too shallow for sampling at multiple depths

Table 5. Dissolved trace metal concentrations (in ppb or micrograms per liter) in the water-column of Upper Klamath Lake, OR.

Site	Sampling	Replicate	Cu	[1]95% ci	Cd	[1]95% ci	Zn	[1]95% ci	Ni	[1]95% ci	Fe	[1]95% ci	Pb	[1]95% ci	Mn	[1]95% ci	Co	[1]95% ci
HDB	18-Apr-06	A	**0.475**	0.008	**<DL**		**<DL**		**0.367**	0.003	**45**	5	**0.004**	0.000	**1.0**	0.01	**0.062**	0.000
		B	**0.479**	0.003	**<DL**		**<DL**		**0.371**	0.022	**45**	5	**0.004**	0.000	**0.9**	0.01	**0.063**	0.000
	31-May-06	A	**0.637**	0.002	**<DL**		**<DL**		**0.351**	0.005	**31**	5	**<DL**		**2.2**	0.01	**0.058**	0.002
		B	**0.632**	0.008	**<DL**		**<DL**		**0.363**	0.001	**57**	5	**<DL**		**2.6**	0.02	**0.062**	0.001
	2-Aug-06	A	**0.494**	0.008	**<DL**		**<DL**		**0.355**	0.002	**<DL**		**<DL**		**13.4**	0.12	**0.100**	0.000
		B	**0.487**	0.002	**<DL**		**<DL**		**0.352**	0.002	**<DL**		**<DL**		**15.1**	0.13	**0.103**	0.000
	2-May-07	A	**0.539**	0.003	**<DL**		**<DL**		**0.275**	0.009	**29**	5	**0.008**	0.000	**3.6**	0.06	**0.068**	0.000
		B	**0.536**	0.005	**<DL**		**<DL**		**0.281**	0.013	**24**	5	**0.012**	0.000	**3.4**	0.05	**0.067**	0.000
	10-Jul-07	A	**0.579**	0.015	**<DL**		**<DL**		**0.341**	0.008	**17**	5	**0.005**	0.000	**4.0**	0.02	**0.117**	0.002
		B	**0.596**	0.011	**<DL**		**<DL**		**0.343**	0.003	**12**	5	**0.005**	0.000	**3.8**	0.05	**0.116**	0.001
WMR	18-Apr-06	A	**0.663**	0.014	**<DL**		**<DL**		**0.466**	0.008	**50**	5	**0.003**	0.000	**5.4**	0.00	**0.065**	0.001
		B	**0.694**	0.012	**<DL**		**<DL**		**0.455**	0.013	**46**	5	**0.005**	0.001	**5.3**	0.01	**0.066**	0.001
	31-May-06	A	**0.537**	0.004	**<DL**		**<DL**		**0.336**	0.003	**46**	5	**<DL**		**7.4**	0.06	**0.066**	0.002
		B	**0.540**	0.003	**<DL**		**<DL**		**0.338**	0.005	**39**	5	**<DL**		**6.8**	0.04	**0.067**	0.000
	2-Aug-06	A	**0.564**	0.006	**<DL**		**<DL**		**0.403**	0.009	**<DL**		**<DL**		**28.6**	0.12	**0.107**	0.001
		B	**0.528**	0.005	**<DL**		**<DL**		**0.355**	0.007	**<DL**		**<DL**		**14.0**	0.13	**0.098**	0.002
	2-May-07	A	**0.477**	0.004	**<DL**		**<DL**		**0.245**	0.002	**29**	5	**0.018**	0.000	**1.0**	0.01	**0.054**	0.001
		B	**0.479**	0.001	**<DL**		**<DL**		**0.251**	0.008	**37**	5	**0.026**	0.001	**1.2**	0.01	**0.056**	0.001
	10-Jul-07	A	**0.659**	0.008	**<DL**		**<DL**		**0.364**	0.010	**76**	5	**0.018**	0.001	**9.7**	0.08	**0.124**	0.000
		B	**0.613**	0.006	**<DL**		**<DL**		**0.336**	0.003	**26**	5	**0.005**	0.000	**5.9**	0.05	**0.120**	0.002
EBB Shallow	[2]18-Apr-06	A	**0.602**	0.000	**<DL**		**<DL**		**0.388**	0.005	**44**	5	**0.011**	0.000	**2.8**	0.01	**0.054**	0.001
	31-May-06	A	**0.629**	0.003	**<DL**		**<DL**		**0.341**	0.004	**35**	5	**<DL**		**3.9**	0.01	**0.070**	0.001
		B	**0.644**	0.004	**<DL**		**<DL**		**0.335**	0.001	**38**	5	**<DL**		**4.1**	0.03	**0.063**	0.000
	2-Aug-06	A	**0.475**	0.003	**<DL**		**<DL**		**0.354**	0.005	**<DL**		**<DL**		**22.5**	0.11	**0.101**	0.000
		B	**0.496**	0.002	**<DL**		**<DL**		**0.354**	0.004	**<DL**		**<DL**		**21.5**	0.09	**0.098**	0.001
	2-May-07	A	**0.571**	0.003	**<DL**		**<DL**		**0.257**	0.002	**28**	5	**0.033**	0.000	**3.6**	0.10	**0.069**	0.001
		B	**0.606**	0.003	**<DL**		**<DL**		**0.328**	0.025	**53**	5	**0.047**	0.001	**4.1**	0.05	**0.072**	0.001
	10-Jul-07	A	**0.610**	0.007	**<DL**		**<DL**		**0.328**	0.005	**14**	5	**0.005**	0.000	**5.7**	0.01	**0.111**	0.003
		B	**0.591**	0.003	**<DL**		**<DL**		**0.327**	0.003	**27**	5	**0.012**	0.000	**6.7**	0.11	**0.108**	0.002
EBB Deep	31-May-06	A	**0.613**	0.003	**<DL**		**<DL**		**0.345**	0.002	**38**	5	**<DL**		**13.4**	0.03	**0.067**	0.000
		B	**0.657**	0.009	**<DL**		**<DL**		**0.445**	0.002	**37**	5	**<DL**		**14.0**	0.09	**0.068**	0.000
	2-Aug-06	A	**0.477**	0.002	**<DL**		**<DL**		**0.345**	0.004	**<DL**		**<DL**		**10.3**	0.04	**0.103**	0.002
		B	**0.486**	0.002	**<DL**		**<DL**		**0.364**	0.003	**<DL**		**<DL**		**14.7**	0.07	**0.105**	0.001
	2-May-07	A	**0.555**	0.004	**<DL**		**<DL**		**0.282**	0.015	**23**	5	**0.012**	0.000	**3.4**	0.05	**0.065**	0.000
		B	**0.547**	0.001	**<DL**		**<DL**		**0.261**	0.007	**22**	5	**0.024**	0.000	**3.3**	0.04	**0.062**	0.001
	10-Jul-07	A	Rep A appeared to be contaminated															
		B	**0.486**	0.009	**<DL**		**<DL**		**0.259**	0.008	**16**	5	**<DL**		**4.9**	0.24	**0.088**	0.000
MRM	31-May-06	A	**0.619**	0.007	**<DL**		**<DL**		**0.361**	0.002	**40**	5	**<DL**		**12.0**	0.09	**0.068**	0.001
		B	**0.621**	0.007	**<DL**		**<DL**		**0.361**	0.003	**39**	5	**<DL**		**11.3**	0.05	**0.069**	0.001
	2-Aug-06	A	**0.533**	0.007	**<DL**		**<DL**		**0.355**	0.001	**<DL**		**<DL**		**5.5**	0.02	**0.106**	0.002
		B	**0.571**	0.002	**<DL**		**<DL**		**0.386**	0.004	**<DL**		**<DL**		**5.4**	0.05	**0.149**	0.001
	2-May-07	A	**0.532**	0.004	**<DL**		**<DL**		**0.258**	0.009	**17**	5	**0.043**	0.001	**2.6**	0.03	**0.061**	0.000
		B	**0.520**	0.006	**<DL**		**<DL**		**0.265**	0.002	**21**	5	**0.014**	0.000	**2.7**	0.02	**0.059**	0.001
	10-Jul-07	A	**0.624**	0.004	**<DL**		**<DL**		**0.329**	0.004	**71**	5	**0.012**	0.001	**7.5**	0.08	**0.117**	0.001
		B	**0.620**	0.008	**<DL**		**<DL**		**0.315**	0.002	**32**	5	**0.004**	0.000	**4.6**	0.02	**0.117**	0.001
SBI	31-May-06	A	**0.649**	0.005	**<DL**		**<DL**		**0.370**	0.010	**55**	5	**<DL**		**6.2**	0.02	**0.071**	0.001
		B	**0.627**	0.007	**<DL**		**<DL**		**0.384**	0.008	**40**	5	**<DL**		**5.9**	0.04	**0.066**	0.001
	2-Aug-06	A	**0.496**	0.003	**<DL**		**<DL**		**0.362**	0.010	**<DL**		**<DL**		**25.7**	0.12	**0.098**	0.001
		B	**0.510**	0.006	**<DL**		**<DL**		**0.353**	0.007	**<DL**		**<DL**		**23.6**	0.05	**0.098**	0.001
	2-May-07	A	**0.564**	0.008	**<DL**		**<DL**		**0.279**	0.005	**24**	5	**0.019**	0.004	**1.7**	0.04	**0.075**	0.002
		B	**0.532**	0.006	**<DL**		**<DL**		**0.274**	0.014	**26**	5	**0.013**	0.001	**1.8**	0.02	**0.062**	0.001
	10-Jul-07	A	**0.659**	0.006	**<DL**		**<DL**		**0.381**	0.009	**79**	5	**0.025**	0.001	**11.3**	0.03	**0.123**	0.002
		B	**0.736**	0.009	**<DL**		**<DL**		**0.460**	0.003	**191**	5	**0.063**	0.000	**20.6**	0.08	**0.139**	0.002
MDL	18-Apr-06	A	**0.525**	0.008	**<DL**		**<DL**		**0.343**	0.002	**41**	5	**0.003**	0.001	**0.8**	0.01	**0.048**	0.002
		B	**0.517**	0.004	**<DL**		**<DL**		**0.353**	0.009	**40**	5	**0.003**	0.001	**0.7**	0.00	**0.047**	0.000
MDT Shallow	18-Apr-06	A	**0.555**	0.002	**<DL**		**<DL**		**0.386**	0.006	**45**	5	**0.004**	0.001	**1.9**	0.01	**0.056**	0.001
		B	**0.537**	0.002	**<DL**		**<DL**		**0.378**	0.006	**45**	5	**0.004**	0.001	**1.8**	0.01	**0.055**	0.000
Mid-depth	18-Apr-06	A	**0.558**	0.003	**<DL**		**<DL**		**0.374**	0.006	**41**	5	**0.003**	0.000	**1.9**	0.02	**0.055**	0.001
		B	**0.536**	0.005	**<DL**		**<DL**		**0.372**	0.005	**40**	5	**0.002**	0.000	**2.0**	0.02	**0.054**	0.000
Deep	18-Apr-06	A	**0.542**	0.005	**<DL**		**<DL**		**0.387**	0.004	**42**	5	**0.005**	0.001	**2.4**	0.01	**0.054**	0.001
		B	**0.576**	0.002	**<DL**		**<DL**		**0.395**	0.004	**43**	5	**0.003**	0.000	**2.0**	0.01	**0.054**	0.001
			Cu	error	Cd	error	Zn	error	Ni	error	Fe	error	Pb	error	Mn	error	Co	error
	Detection limits:				~0.002 ppb		~1 ppb				~5 ppb		~0.002 ppb					

[1] "95% ci" stands for 95% confidence interval

[2] Ball Bay location sampled April 18, 2006 was approximately 1 km south from EBB, and was too shallow for sampling at multiple depths

Table 6. Variability of macro- and micronutrient compositions for tributary inputs to Upper Klamath Lake, OR.

May 1, 2007

	Replicate	DOC (mg-L^{-1})	95%ci	DOC (uM)	95%ci	Iron[1] (µg-L^{-1})	95%ci	Total P[2] (µg-L^{-1})	Ortho P[2] (µg-L^{-1})	Diss. silica[2] mg-L^{-1} as SiO2	NWIS Station No.
Spring Creek	A	**0.41**	0.01	**34**	1	**< 5**		94	92	38.4	11494201
	B	**0.39**	0.00	**33**	0	**< 5**		NA	NA	NA	
Sprague River	A	**3.03**	0.01	**252**	1	**31**	1	61	35	28.4	11501000
	B	**3.10**	0.08	**258**	7	**16**	1	NA	NA	NA	
Wood River	A	**1.38**	0.02	**115**	2	**77**	1	97	71	38.1	11504100
	B	**1.32**	0.01	**110**	1	**78**	1	NA	NA	NA	
Williamson River	A	**17.69**	0.42	**1474**	35	**177**	3	41	7	19.0	11493500
	B	**19.73**	0.62	**1644**	52	**179**	2	NA	NA	NA	

Correlation Matrix

	DOC	Fe	Total P	Ortho P	Silica
DOC	1				
Fe	0.91	1			
Total P	-0.86	-0.65	1		
Ortho P	-0.86	-0.75	0.96	1	
Silica	-0.92	-0.75	0.99	0.97	1

[1] If the dissolved iron data is regressed against DOC, the coefficient of determination (r^2) = **0.83**
or the correlation coefficient (r) between dissolved iron and DOC = **0.91**
With the exception of the Sprague River, this correlation between dissolved Fe and DOC data is visibly evident.
By comparison, the correlation coefficients for dissolved iron with Total P, Ortho-P and dissolved silica are -0.54, -0.61, and -0.65, respectively.

[2] Phosphorus and silica stream data from USGS NWIS database [http://nwis.waterdata.usgs.gov/usa/nwis/qwdata].

Jul 9, 2007

	Replicate	DOC (mg-L^{-1})	95%ci	DOC (uM)	95%ci	Iron (µg-L^{-1})	95%ci	Total P (µg-L^{-1})	Ortho P (µg-L^{-1})	Diss. Silica mg-L^{-1} as SiO2	NWIS Station No.
Spring Creek	A	**0.82**	0.03	**68**	3	**< 5**		NA	90	39.6	11494201
	B	**1.32**	0.06	**110**	5	**< 5**			92	38.8	
Sprague River	A	**2.84**	0.04	**237**	4	**72**	0	NA	29	26.3	11501000
	B	**2.69**	0.12	**225**	10	**32**	0		28	26.4	
Wood River	A	**1.65**	0.02	**138**	2	**104**	1	NA	82	NA	11504100
	B	**1.71**	0.10	**142**	9	**97**	2		82	37.3	
Williamson River	**No discharge**										11493500

Correlation Matrix

	DOC	Fe	Total P	Ortho P	Silica
DOC	1				
Fe	0.38	1			
Total P	NA	NA	1		
Ortho P	-0.97	-0.15	NA	1	
Silica	-0.97	-0.16	NA	1.00	1

Table 7. Diffusive flux of dissolved iron in Upper Klamath Lake, OR

	31-May-06		**Dissolved Iron**				
	Water-column temperature =	**14.0 to 15.8** ^{o}C	**Site Average ($mg\text{-}m^{-2}\text{-}day^{-1}$)**	**Site StDev ($mg\text{-}m^{-2}\text{-}day^{-1}$)**	**Site Average ($kg\text{-}d^{-1}$)**	**Site StDev ($kg\text{-}d^{-1}$)**	
Site #	**Site Location**	**Site Code**					
1	Howard Bay	HDB	**0.64**	0.44	**128**	88	
2	Williamson River Plume	WMR	**3.73**	2.55	**747**	511	
3	Entrance to Ball Bay	EBB	**9.39**	5.68	**1879**	1136	Only 2 replicates
4	Modoc Rim	MRM	**2.67**	0.12	**534**	25	Only 2 replicates
5	South of Bare Island	SBI	**4.97**	0.52	**994**	105	

	2-Aug-06		**Dissolved Iron**				
	Water-column temperature =	**19.2 to 20.3** ^{o}C	**Site Average ($mg\text{-}m^{-2}\text{-}day^{-1}$)**	**Site StDev ($mg\text{-}m^{-2}\text{-}day^{-1}$)**	**Site Average ($kg\text{-}d^{-1}$)**	**Site StDev ($kg\text{-}d^{-1}$)**	
Site #	**Site Location**	**Site Code**					
1	Howard Bay	HDB	**0.56**	0.46	**112**	91	
2	Williamson River Plume	WMR	**2.03**	0.33	**405**	66	
3	Entrance to Ball Bay	EBB	**4.60**	2.32	**920**	463	
4	Modoc Rim	MRM	**0.27**	0.25	**55**	50	Only 2 replicates
5	South of Bare Island	SBI	**0.86**	0.38	**172**	77	

	2-May-07		**Dissolved Iron**				
	Water-column temperature =	**12.4 to 12.8** ^{o}C	**Site Average ($mg\text{-}m^{-2}\text{-}day^{-1}$)**	**Site StDev ($mg\text{-}m^{-2}\text{-}day^{-1}$)**	**Site Average ($kg\text{-}d^{-1}$)**	**Site StDev ($kg\text{-}d^{-1}$)**	
Site #	**Site Location**	**Site Code**					
1	Howard Bay	HDB	**2.62**	1.16	**524**	231	Only 2 replicates
2	Williamson River Plume	WMR	**3.92**	0.66	**784**	133	Only 2 replicates
3	Entrance to Ball Bay	EBB	**3.41**	1.83	**682**	365	
4	Modoc Rim	MRM	**4.95**	6.16	**989**	1231	
5	South of Bare Island	SBI	**4.42**	0.78	**885**	157	

	10-Jul-07		**Dissolved Iron**			
	Water-column temperature =	**12.4 to 12.8** ^{o}C	**Site Average ($mg\text{-}m^{-2}\text{-}day^{-1}$)**	**Site StDev ($mg\text{-}m^{-2}\text{-}day^{-1}$)**	**Site Average ($kg\text{-}d^{-1}$)**	**Site StDev ($kg\text{-}d^{-1}$)**
Site #	**Site Location**	**Site Code**				
1	Howard Bay	HDB	**0.50**	0.31	**101**	63
2	Williamson River Plume	WMR	**3.71**	1.93	**742**	385
3	Entrance to Ball Bay	EBB	**3.70**	2.89	**740**	577
4	Modoc Rim	MRM	**0.85**	0.41	**171**	81
5	South of Bare Island	SBI	**0.34**	0.14	**69**	28

average Fe flux in mg/m2/day: **2.9**

ug/L of Fe per day distributed to entire water column: **1.0**

Table 8. Macroinvertebrate taxonomy of benthic assemblages within Upper Klamath Lake, OR[1]

			18-Apr-06					31-May-06					2-Aug-06					2-May-07				
			HDB	MDL	EBB[2]	WMR	MDT	HDB	MRM	EBB	WMR	SBI	HDB	MRM	EBB	WMR	SBI	HDB	MRM	EBB	WMR	SBI
Insecta	Plecoptera	Malenka										44										
	Coleoptera	Dubiraphia larva														89					44	
	Diptera	cf. Chironomus	33863		89		178		44		44	44			44						44	
	Diptera	Chironomini (Harnischia complex)	89		533		5199							1067		11999	1689					
	Diptera	Chironomini sp. A						3111	89	444	1866			133		267	178				222	
	Diptera	Chironomini (e.i.)	6844	44	7421	27908	6622	1289	578			89		133			755				1778	222
	Diptera	Tanytarsini	1378		400	39774	44		444		22353			755		20398	2089		267		8177	1644
	Diptera	Tanypodinae	3200	89	1333	444	1955	89	800	2044	133	889			178		44	578	89	178	89	44
Crustacea	Ostracoda	Ostracoda	2311		2000	1200	44	400	1244	356	2800	978	44	356	44	1733	889	533	3377	44	1955	1467
	Copepoda	Cyclopoida	222	178	267	3200	222	133	133		3022	178				178	89	400	311	755	2089	311
	Copepoda	Calanoida														178	44					
	Copepoda	Harpacticoida		89		1067	31197											12532		133	44	178
	Cladocera	Daphniidae	533										44				44	311	44	356		356
	Cladocera	Chydoridae										44						89		667	311	44
	Amphipoda	Hyalella				44					89											
Acari	Acari	cf. Hygrobates																				
Annelida	Oligochaeta	cf. Sparganophilus															44					
	Oligochaeta	Lumbriculus							89		222	89										
	Oligochaeta	Kincaidiana freidris							89		444								533		44	
	Oligochaeta	Tubificidae	75992	2889	2044	5688	2355	6488	2400	6666	9066	356	755	2711	17643	13599	844	26753	1955	7866	4577	6488
	Hirudinea	Helobdella	89	444		44	1111	489			44	222				311	222	44	133	89		44
	Hirudinea	leech (imm.)						44			2133		178	89	89		44					89
	Polychaeta	Manayunkia			4000	28619			4355		31863	844		17065		144830	9643		15465		56794	
Mollusca	Pelecypoda	cf. Pisidium			178									267		400						
	Pelecypoda	Sphaeriidae or Corbicula (imm.)			44	800			178		444			44		89			44		133	
	Gastropoda	Hydrobiidae			89	89			44		89								44			
	Gastropoda	Planorbidae			44																	
Nematoda		Nematoda	4577	3111	800	2622	2000	222	1644	178	3200	178	222	2977	2977	6044	400	1778	11288	4266	13954	2844
Nematoda		Mermithidae												267			89					
Platyhelmeths		microturbellarians	178	400	133	311	44	1111		400	178											

[1] Definition of acronyms:
e.i. = early instar
imm. = immature
cf. = similar to (compares)

[2] In April 2006, Ball Bay was more centrally sampled approximately 1 km south of its entrace (EBB)

Table 9. Benthic chlorophyll and phaeophytin concentrations (in micrograms per square centimeter; n=3) at Upper Klamath Lake, OR.

Site	Date	Chl-a	stdev	Phaeo-phytin	stdev	Chl-a/ Phaeo+Chl-a ratio	stdev	Water-column Chl-a[1] (µg-L^{-1})	
HDB	18-Apr-06	**5.0**	1.5	**5.3**	2.2	**0.49**	0.18		
	31-May-06	**2.5**	0.5	**6.4**	0.6	**0.28**	0.04	2	9,305 Maxiumum 24 July 2006
	2-Aug-06	**0.8**	0.2	**5.1**	0.1	**0.14**	0.03	198	
	2-May-07	**0.6**	0.3	**13.6**	3.1	**0.04**	0.01		
	10-Jul-07	**1.0**	0.2	**7.0**	0.9	**0.12**	0.02		
WMR	18-Apr-06	**3.9**	0.7	**4.0**	0.7	**0.50**	0.07		
	31-May-06	**5.9**	1.5	**8.1**	1.1	**0.42**	0.07	7	178 Maxiumum 10 July 2006
	2-Aug-06	**3.2**	0.8	**9.0**	1.1	**0.26**	0.03	23	
	2-May-07	**0.5**	0.3	**13.8**	1.5	**0.03**	0.02		
	10-Jul-07	**0.6**	0.2	**7.3**	2.3	**0.07**	0.00		
EBB	18-Apr-06[2]	**5.5**	0.6	**5.6**	0.3	**0.49**	0.02	*	
	31-May-06	**3.7**	0.4	**4.1**	1.1	**0.48**	0.07		
	2-Aug-06	**1.0**	0.2	**14.1**	2.2	**0.07**	0.02		
	2-May-07	**1.0**	0.2	**12.6**	5.3	**0.08**	0.04		
	10-Jul-07	**1.7**	0.5	**12.7**	3.6	**0.12**	0.01		
MRM	31-May-06	**3.0**	0.6	**3.1**	0.5	**0.49**	0.08		
	2-Aug-06	**0.8**	0.3	**4.4**	0.5	**0.15**	0.04		
	2-May-07	**0.4**	0.1	**4.9**	0.4	**0.08**	0.02		
	10-Jul-07	**0.6**	0.1	**3.7**	1.1	**0.16**	0.07		
SBI	31-May-06	**1.0**	0.2	**3.9**	0.4	**0.20**	0.06		
	2-Aug-06	**1.5**	0.2	**5.2**	1.4	**0.23**	0.03		
	2-May-07	**0.5**	0.1	**6.3**	1.2	**0.07**	0.03		
	10-Jul-07	**0.7**	0.4	**5.3**	1.2	**0.12**	0.06		
MDL	18-Apr-06	**2.1**	0.8	**2.8**	1.7	**0.46**	0.23		
MDT	18-Apr-06	**9.6**	3.0	**8.8**	2.9	**0.52**	0.06		

[1] Water-column chlorophyll data from USGS Oregon Water Science Center study led by T. Wood
(Internet access at: http://or.water.usgs.gov/projs_dir/klamath_ltmon/#Anchor-DAT-35519)

[2] Ball Bay location sampled April 18, 2006 was approximately 1 km south from EBB

Table 10. Macronutrients (milligrams per gram of sediment, $mg\text{-}g^{-1}$) and major elements associated with lakebed sediments in pre-bloom conditions (April 2005) in Upper Klamath Lake, OR.

Sample Number	Site	Depth in sediment, cm	Water Content	Total P ($mg\text{-}g^{-1}$)	$MgCl_2$ extracted P ($mg\text{-}g^{-1}$)	Dithionite extracted P ($mg\text{-}g^{-1}$)	1 M HCl extracted P ($mg\text{-}g^{-1}$)	Organic P ($mg\text{-}g^{-1}$)	Percent C	Percent N	Total Fe ($mg\text{-}g^{-1}$)	Dithionite Fe ($mg\text{-}g^{-1}$)	Total Al ($mg\text{-}g^{-1}$)	Total Ca ($mg\text{-}g^{-1}$)
1	EBB	-0.5	0.91	0.99	0.097	0.15	0.09	0.66	8.1	1.0	22	1.0	23	8.2
2	EBB	-1.5	0.90	0.87	0.032	0.13	0.08	0.62	8.1	1.0	20	0.9	25	8.2
3	EBB	-2.5	0.89	0.79	0.029	0.06	0.07	0.62	8.1	1.0	19	0.8	24	7.0
4	EBB	-3.5	0.92	0.80	0.026	0.07	0.08	0.63	8.1	1.0	21	0.8	23	5.4
5	EBB	-4.5	0.92	0.74	0.026	0.04	0.08	0.60	8.2	0.9	26	0.7	26	7.9
6	EBB	-6.0	0.88	0.75	0.029	0.13	0.07	0.51	7.9	1.0	26	0.7	26	7.7
7	EBB	-8.0	0.90	0.78	0.022	0.05	0.08	0.63	8.1	1.0	22	0.8	28	7.9
8	EBB	-10.0	0.90	0.77	0.026	0.04	0.08	0.63	8.1	1.0	23	0.7	27	8.0
9	EBB	-12.0	0.88	0.72	0.025	0.13	0.08	0.49	8.1	1.0	31	0.7	29	10.3
10	EBB	-14.0	0.87	0.69	0.017	0.05	0.08	0.54	7.8	1.0	21	1.2	25	7.7
11	EBB	-16.5	0.88	0.66	0.013	0.00	0.08	0.56	7.8	0.8	21	0.6	26	7.8
12	EBB	-19.5	0.86	0.61	0.014	0.03	0.07	0.49	7.3	0.9	18	0.6	24	7.6
13	EBB	-22.5	0.87	0.56	0.014	0.03	0.07	0.45	7.4	0.9	17	0.6	27	7.8
14	EBB	-25.5	0.89	0.43	0.014	0.03	0.05	0.33	6.4	0.8	15	0.4	21	5.3
15	EBB	-0.5	0.93	1.11	0.112	0.42	0.08	0.49	NA	NA	16	1.0	24	8.2
16	EBB	-1.5	0.91	0.82	0.039	0.19	0.07	0.51	NA	NA	22	0.8	25	7.2
17	EBB	-2.5	0.91	0.82	0.029	0.03	0.07	0.68	NA	NA	18	0.7	23	5.7
18	EBB	-3.5	0.91	0.78	0.018	0.14	0.08	0.55	NA	NA	19	0.8	26	5.2
19	EBB	-4.5	0.91	0.75	0.016	0.17	0.08	0.49	NA	NA	18	0.6	28	7.4
20	EBB	-6.0	0.90	0.75	0.018	0.11	0.08	0.55	NA	NA	19	0.7	28	7.3
21	EBB	-8.0	0.90	0.72	0.015	0.10	0.07	0.52	NA	NA	18	0.6	27	7.1
22	EBB	-10.0	0.89	0.74	0.017	0.12	0.07	0.53	NA	NA	16	0.6	24	4.9
23	SBI	-0.5	0.92	0.89	0.083	0.497	0.08	0.23	6.5	0.9	19	1.6	24	3.8
24	SBI	-1.5	0.91	0.98	0.026	0.291	0.07	0.60	6.2	0.8	17	1.6	23	4.8
25	SBI	-2.5	0.91	0.65	0.013	0.065	0.07	0.50	6.0	0.8	16	1.1	27	4.9
26	SBI	-3.5	0.91	0.58	0.014	0.010	0.06	0.50	6.0	0.8	20	0.9	26	4.9
27	SBI	-4.5	0.90	0.57	0.014	0.010	0.06	0.48	5.8	0.8	14	0.8	25	4.6
28	SBI	-6.0	0.90	0.56	0.010	0.138	0.07	0.34	5.9	0.8	15	0.8	28	4.7
29	SBI	-8.0	0.89	0.54	0.007	0.115	0.07	0.35	6.0	0.8	14	0.8	25	4.8
30	SBI	-10.0	0.89	0.55	0.007	0.033	0.06	0.45	5.8	0.8	16	0.8	26	4.4
31	SBI	-12.0	0.89	0.53	0.008	0.003	0.07	0.45	5.9	0.8	18	0.7	24	2.4
32	SBI	-14.0	0.88	0.54	0.009	0.074	0.06	0.40	5.8	0.8	14	0.8	25	2.4
33	SBI	-16.5	0.87	0.60	0.008	0.017	0.03	0.54	6.0	0.8	16	0.9	26	4.6
34	SBI	-19.5	0.87	0.59	0.010	0.079	0.06	0.44	5.7	0.8	15	0.9	25	2.4
35	SBI	-22.5	0.87	0.52	0.013	0.009	0.07	0.43	5.5	0.8	17	0.6	26	4.4
36	SBI	-25.5	0.88	0.41	0.016	0.033	0.06	0.30	4.6	0.7	15	0.4	22	4.5
37	SBI	-0.5	0.93	0.98	0.069	0.344	0.08	0.49	NA	NA	16	1.5	21	2.4
38	SBI	-1.5	0.92	0.72	0.022	0.139	0.07	0.49	NA	NA	16	1.2	23	4.7
39	SBI	-2.5	0.92	0.67	0.023	0.014	0.07	0.57	NA	NA	15	1.0	26	4.5
40	SBI	-3.5	0.91	0.68	0.013	0.083	0.07	0.51	NA	NA	17	0.8	26	4.7
41	SBI	-4.5	0.91	0.58	0.011	0.068	0.07	0.43	NA	NA	14	0.8	26	4.1
42	SBI	-6.0	0.90	0.56	0.011	0.029	0.06	0.45	NA	NA	14	0.8	25	2.4
43	SBI	-8.0	0.90	0.55	0.010	0.004	0.08	0.46	NA	NA	15	0.6	24	4.6
44	SBI	-10.0	0.90	0.53	0.012	0.009	0.07	0.44	NA	NA	16	0.6	26	4.9
45	HDB	-0.5	0.94	0.75	0.054	0.11	0.09	0.50	7.5	0.9	16	0.8	19	5.1
46	HDB	-1.5	0.93	0.68	0.038	0.12	0.08	0.44	7.2	0.9	14	0.8	20	4.7
47	HDB	-2.5	0.92	0.74	0.035	0.04	0.07	0.59	7.2	0.9	16	0.7	21	2.3
48	HDB	-3.5	0.91	0.69	0.031	0.07	0.08	0.50	7.2	0.9	15	0.6	21	5.7
49	HDB	-4.5	0.91	0.64	0.032	0.08	0.08	0.45	7.2	0.9	17	0.6	21	2.3
50	HDB	-6.0	0.91	0.64	0.028	0.08	0.07	0.46	7.2	0.9	15	0.6	21	6.6
51	HDB	-8.0	0.90	0.53	0.027	0.03	0.08	0.40	6.9	0.8	14	0.4	20	4.0
52	HDB	-10.0	0.89	0.49	0.023	0.02	0.08	0.36	6.9	0.9	15	0.4	20	6.4
53	HDB	-12.0	0.88	0.45	0.021	0.03	0.08	0.32	6.4	0.8	12	0.3	16	3.5
54	HDB	-14.0	0.88	0.45	0.018	0.03	0.08	0.32	6.3	0.6	15	0.3	21	8.3
55	HDB	-16.5	0.87	0.34	0.017	0.03	0.08	0.21	6.0	0.8	13	0.2	19	8.6
56	HDB	-19.5	0.89	0.40	0.016	0.03	0.07	0.28	6.1	0.8	12	0.3	16	7.3
57	HDB	-22.5	0.91	0.34	0.013	0.03	0.07	0.23	5.2	0.6	12	0.2	17	4.7
58	HDB	-25.5	0.91	0.28	0.012	0.03	0.05	0.18	4.7	0.5	11	0.2	18	7.3
59	HDB	-0.5	0.94	0.82	0.079	0.09	0.08	0.57	NA	NA	13	0.8	19	5.4
60	HDB	-1.5	0.92	0.68	0.035	0.03	0.07	0.54	NA	NA	14	0.7	20	7.1
61	HDB	-2.5	0.92	0.66	0.033	0.03	0.07	0.53	NA	NA	15	0.4	22	7.6
62	HDB	-3.5	0.91	0.65	0.033	0.08	0.08	0.46	NA	NA	17	0.5	24	2.2
63	HDB	-4.5	0.91	0.63	0.032	0.01	0.08	0.51	NA	NA	14	0.5	20	4.2
64	HDB	-6.0	0.91	0.54	0.028	0.00	0.08	0.43	NA	NA	12	0.4	17	4.3
65	HDB	-8.0	0.90	0.49	0.021	0.00	0.07	0.39	NA	NA	14	0.3	18	6.6
66	HDB	-10.0	0.89	0.46	0.020	0.03	0.07	0.34	NA	NA	15	0.3	20	4.4
67	MDL	-0.5	0.90	0.63	0.053	0.00	0.08	0.50	4.8	0.6	18	0.1	49	20.6
68	MDL	-1.5	0.88	0.48	0.021	0.00	0.07	0.40	4.4	0.5	18	0.5	50	18.8
69	MDL	-2.5	0.89	0.37	0.012	0.00	0.07	0.29	4.2	0.5	15	0.5	34	17.1
70	MDL	-3.5	0.88	0.41	0.011	0.00	0.07	0.33	4.0	0.5	15	0.4	33	14.4
71	MDL	-4.5	0.88	0.35	0.013	0.00	0.06	0.28	4.3	0.6	13	0.1	29	9.4
72	MDL	-6.0	0.89	0.29	0.008	0.00	0.07	0.21	3.6	0.5	12	0.3	28	7.8
73	MDL	-8.0	0.87	0.23	0.005	0.00	0.07	0.15	3.7	0.5	21	0.3	24	5.3
74	MDL	-10.0	0.91	0.23	0.006	0.00	0.06	0.17	3.7	0.5	10	0.2	23	5.2
75	MDL	-12.0	0.91	0.28	0.009	0.00	0.07	0.21	3.9	0.5	14	0.2	25	6.6
76	MDL	-14.0	0.89	0.28	0.009	0.00	0.07	0.20	3.4	0.5	11	0.2	22	5.5
77	MDL	-16.5	0.86	0.27	0.008	0.00	0.06	0.20	3.6	0.5	11	0.3	26	8.5
78	MDL	-19.5	0.88	0.25	0.010	0.00	0.06	0.18	3.8	0.5	8	0.3	16	2.7
79	MDL	-22.5	0.86	0.23	0.010	0.00	0.07	0.15	3.5	0.5	14	0.3	29	7.9
80	MDL	-25.5	0.86	0.39	0.011	0.00	0.06	0.32	3.4	0.4	13	0.3	27	7.7
81	MDL	-0.5	0.91	0.43	0.048	0.00	0.08	0.30	NA	NA	14	0.7	37	12.2
82	MDL	-1.5	0.90	0.49	0.028	0.00	0.07	0.40	NA	NA	14	0.6	39	14.3
83	MDL	-2.5	0.89	0.33	0.015	0.00	0.07	0.25	NA	NA	13	0.5	32	11.2
84	MDL	-3.5	0.89	0.37	0.010	0.00	0.07	0.29	NA	NA	13	0.4	31	9.8
85	MDL	-4.5	0.89	0.30	0.009	0.00	0.07	0.22	NA	NA	12	0.3	32	8.5
86	MDL	-6.0	0.89	0.31	0.009	0.00	0.06	0.24	NA	NA	12	0.3	29	8.0
87	MDL	-8.0	0.90	0.43	0.011	0.00	0.08	0.34	NA	NA	12	0.3	29	6.9
88	MDL	-10.0	na	0.30	0.010	0.00	0.07	0.22	NA	NA	11	0.3	24	6.4

[1] "NA" indicates that samples were not analyzed for this constituent.

Table 11. Macronutrients (milligrams per gram of sediment, mg-g^{-1}) and major elements associated with lakebed sediments during the AFA bloom (July 2005) in Upper Klamath Lake, OR.

Sample Number	Site	Depth in sediment, cm	Water Content	Total P (mg-g^{-1})	$MgCl_2$ extracted P (mg-g^{-1})	Dithionite extracted P (mg-g^{-1})	1 M HCl extracted P (mg-g^{-1})	Organic P (mg-g^{-1})	Percent C	Percent N	Total Fe (mg-g^{-1})	Dithionite Fe (mg-g^{-1})	Total Al (mg-g^{-1})	Total Ca (mg-g^{-1})
89	EBB	-0.5	0.93	0.88	0.083	0.33	0.07	0.39	7.9	1.0	22	0.7	26	7.9
90	EBB	-1.5	0.91	0.84	0.031	0.22	0.05	0.54	7.5	0.8	17	0.5	25	7.6
91	EBB	-2.5	0.91	0.97	0.025	0.00	0.05	0.90	7.5	0.8	15	0.5	25	6.6
92	EBB	-3.5	0.91	1.01	0.035	0.07	0.05	0.86	7.8	0.9	16	0.5	25	6.4
93	EBB	-4.5	0.91	0.98	0.029	0.00	0.05	0.90	8.1	0.9	16	0.6	28	6.8
94	EBB	-6.0	0.90	0.89	0.030	0.00	0.06	0.80	8.0	0.9	17	0.5	28	5.9
95	EBB	-8.0	0.90	0.93	0.029	0.00	0.05	0.85	8.1	0.8	16	0.5	23	6.3
96	EBB	-10.0	0.89	0.98	0.031	0.00	0.05	0.90	7.8	0.9	16	0.5	27	6.4
97	EBB	-12.0	0.89	0.86	0.026	0.00	0.05	0.79	7.4	0.7	14	0.4	38	13.9
98	EBB	-14.0	0.88	0.76	0.027	0.00	0.05	0.68	7.6	0.8	15	0.4	25	5.8
99	EBB	-16.5	0.87	0.63	0.025	0.00	0.05	0.55	7.7	0.8	21	0.4	28	6.8
100	EBB	-19.5	0.87	0.69	0.024	0.00	0.05	0.61	7.1	0.7	23	0.4	28	6.9
101	EBB	-22.5	0.88	0.68	0.015	0.00	0.05	0.62	7.0	0.8	13	0.2	22	5.9
102	EBB	-25.5	0.90	1.07	0.014	0.00	0.05	1.00	6.9	0.8	67	0.1	28	9.1
103	EBB	-0.5	0.93	0.76	0.075	0.15	0.06	0.48	NA[1]	NA	16	0.7	26	7.6
104	EBB	-1.5	0.91	0.83	0.041	0.08	0.05	0.66	NA	NA	17	0.6	29	8.0
105	EBB	-2.5	0.91	0.77	0.028	0.07	0.05	0.62	NA	NA	17	0.7	30	8.1
106	EBB	-3.5	0.91	0.77	0.030	0.03	0.05	0.65	NA	NA	15	0.5	2	0.5
107	EBB	-4.5	0.91	0.78	0.028	0.04	0.05	0.66	NA	NA	31	0.4	53	13.2
108	EBB	-6.0	0.91	0.78	0.029	0.05	0.05	0.65	NA	NA	16	0.5	27	7.7
109	EBB	-8.0	0.90	0.90	0.029	0.04	0.05	0.78	NA	NA	15	0.4	21	5.9
110	EBB	-10.0	0.90	0.76	0.032	0.05	0.05	0.62	NA	NA	59	0.4	25	6.8
111	SBI	-0.5	0.93	0.62	0.092	0.24	0.05	0.25	6.0	0.6	15	1.2	22	7.0
112	SBI	-1.5	0.92	0.61	0.035	0.08	0.04	0.46	6.3	0.7	13	1.2	20	5.5
113	SBI	-2.5	0.90	0.55	0.023	0.02	0.04	0.47	5.9	0.6	17	1.1	21	5.8
114	SBI	-3.5	0.90	0.61	0.019	0.04	0.04	0.52	5.9	0.6	13	1.0	20	8.4
115	SBI	-4.5	0.90	0.58	0.018	0.00	0.05	0.51	5.6	0.6	14	1.2	24	7.2
116	SBI	-6.0	0.89	0.53	0.021	0.07	0.05	0.40	6.0	0.6	13	0.6	25	7.6
117	SBI	-8.0	0.89	0.54	0.018	0.00	0.05	0.48	5.8	0.6	13	0.5	25	7.3
118	SBI	-10.0	0.88	0.50	0.014	0.00	0.05	0.44	5.8	0.6	13	0.5	20	6.2
119	SBI	-12.0	0.89	0.45	0.023	0.00	0.05	0.38	5.6	0.6	14	0.4	21	0.0
120	SBI	-14.0	0.88	0.49	0.019	0.00	0.05	0.43	5.0	0.5	13	0.4	20	5.4
121	SBI	-16.5	0.88	0.58	0.012	0.00	0.05	0.52	5.6	0.6	13	1.0	23	5.7
122	SBI	-19.5	0.87	0.49	0.018	0.00	0.05	0.42	5.0	0.5	13	0.4	23	5.8
123	SBI	-22.5	0.87	0.62	0.019	0.00	0.05	0.54	5.1	0.5	14	0.4	25	6.9
124	SBI	-25.5	0.88	0.55	0.016	0.00	0.04	0.49	5.1	0.5	12	0.2	22	6.0
125	SBI	-0.5	0.93	0.67	0.088	0.33	0.05	0.20	NA	NA	15	1.7	22	7.8
126	SBI	-1.5	0.91	0.65	0.028	0.05	0.04	0.54	NA	NA	14	0.8	25	9.6
127	SBI	-2.5	0.91	0.64	0.025	0.01	0.05	0.56	NA	NA	13	0.7	22	6.9
128	SBI	-3.5	0.91	0.59	0.029	0.02	0.05	0.49	NA	NA	13	0.5	21	7.5
129	SBI	-4.5	0.91	0.64	0.030	0.03	na	0.58	NA	NA	15	0.6	24	5.9
130	SBI	-6.0	0.90	0.77	0.024	0.01	na	0.74	NA	NA	13	0.4	24	7.4
131	SBI	-8.0	0.90	0.72	0.031	na	0.00	0.69	NA	NA	15	0.5	25	6.9
132	SBI	-10.0	0.89	0.70	0.000	0.01	0.00	0.69	NA	NA	14	0.5	24	8.2
133	HDB	-0.5	0.94	0.72	0.102	0.14	0.04	0.44	7.2	0.9	14	0.7	24	8.7
134	HDB	-1.5	0.93	0.66	0.056	0.03	0.05	0.53	7.2	0.9	14	0.4	21	15.5
135	HDB	-2.5	0.93	0.76	0.060	0.00	0.04	0.66	7.1	0.9	14	0.4	24	9.2
136	HDB	-3.5	0.92	0.58	0.051	0.05	0.04	0.44	7.7	0.9	14	0.3	26	11.3
137	HDB	-4.5	0.92	0.51	0.049	0.09	0.04	0.32	7.6	0.9	14	0.4	24	13.3
138	HDB	-6.0	0.91	0.57	0.050	0.05	0.05	0.43	6.9	0.9	0	0.3	0	0.0
139	HDB	-8.0	0.90	0.45	0.039	0.03	0.07	0.31	7.2	0.9	14	0.4	22	11.3
140	HDB	-10.0	0.89	0.42	0.031	0.00	0.04	0.34	6.5	0.8	13	0.3	21	8.4
141	HDB	-12.0	0.89	0.44	0.025	0.00	0.04	0.38	6.7	0.8	13	0.3	21	8.5
142	HDB	-14.0	0.88	0.84	0.026	0.00	0.04	0.77	6.0	0.7	14	0.2	24	9.7
143	HDB	-16.5	0.88	0.59	0.021	0.00	0.06	0.51	7.3	0.9	18	0.2	24	8.4
144	HDB	-19.5	0.88	0.70	0.023	0.00	0.04	0.63	5.8	0.7	15	0.1	23	7.9
145	HDB	-22.5	0.90	0.75	0.013	0.00	0.04	0.70	5.4	0.7	12	0.7	19	7.3
146	HDB	-25.5	0.90	0.76	0.01	0.0	0.07	0.68	4.4	0.5	12	NA	20	7.5
147	HDB	-0.5	0.94	0.76	0.053	0.18	0.05	0.47	NA	NA	9	0.4	18	6.8
148	HDB	-1.5	0.93	0.65	0.034	0.12	0.04	0.47	NA	NA	14	0.4	22	8.2
149	HDB	-2.5	0.92	0.60	0.031	0.00	0.04	0.53	NA	NA	13	0.3	21	7.8
150	HDB	-3.5	0.92	0.68	0.029	0.02	0.04	0.59	NA	NA	13	0.4	24	8.4
151	HDB	-4.5	0.92	0.66	0.031	0.03	0.04	0.56	NA	NA	13	0.3	21	7.6
152	HDB	-6.0	0.91	0.75	0.037	0.00	0.04	0.67	NA	NA	24	0.4	19	3.7
153	HDB	-8.0	0.90	0.70	0.041	0.00	0.04	0.61	NA	NA	14	0.3	19	5.2
154	HDB	-10.0	0.90	0.44	0.030	0.00	0.05	0.36	NA	NA	25	0.3	23	6.0
155	MDL	-0.5	0.91	0.76	0.052	0.03	0.09	0.59	4.9	0.6	15	0.2	40	14.3
156	MDL	-1.5	0.88	0.45	0.016	0.00	0.00	0.43	4.2	0.5	15	0.4	37	13.8
157	MDL	-2.5	0.88	0.51	0.012	0.00	0.07	0.42	3.9	0.5	12	0.1	34	17.4
158	MDL	-3.5	0.91	0.30	0.015	0.00	0.00	0.29	3.6	0.4	46	0.3	50	23.5
159	MDL	-4.5	0.88	0.34	0.014	0.00	0.08	0.25	4.1	0.5	14	0.3	38	13.3
160	MDL	-6.0	0.88	0.38	0.015	0.00	0.00	0.37	4.1	0.5	13	0.2	33	12.3
161	MDL	-8.0	0.88	0.35	0.016	0.00	0.07	0.26	3.9	0.5	13	0.3	34	12.0
162	MDL	-10.0	0.88	0.29	0.007	0.00	0.06	0.22	3.6	0.4	14	0.3	37	12.9
163	MDL	-12.0	0.87	0.24	0.009	0.00	0.06	0.17	3.7	0.4	13	0.2	35	12.5
164	MDL	-14.0	0.86	0.29	0.009	0.00	0.05	0.23	3.8	0.5	12	0.2	29	9.6
165	MDL	-16.5	0.85	0.33	0.010	0.00	0.05	0.27	3.6	0.5	34	0.1	28	8.7
166	MDL	-19.5	0.86	0.31	0.011	0.00	0.06	0.24	4.1	0.5	12	0.1	26	7.3
167	MDL	-22.5	0.88	0.24	0.011	0.00	0.07	0.16	4.2	0.5	14	0.2	31	9.5
168	MDL	-25.5	0.87	0.30	0.011	0.00	0.07	0.22	4.2	0.5	16	0.2	38	12.1
169	MDL	-0.5	0.92	0.74	0.074	0.00	0.07	0.60	NA	NA	15	0.1	30	10.0
170	MDL	-1.5	0.88	0.56	0.035	0.00	0.04	0.49	NA	NA	13	0.1	23	6.2
171	MDL	-2.5	0.87	0.50	0.020	0.00	0.04	0.44	NA	NA	12	0.1	20	5.0
172	MDL	-3.5	0.88	0.49	0.017	0.06	0.07	0.34	NA	NA	15	0.9	35	12.7
173	MDL	-4.5	0.88	0.41	0.016	0.00	0.08	0.31	NA	NA	14	0.4	39	16.4
174	MDL	-6.0	0.88	0.45	0.015	0.00	0.09	0.35	NA	NA	15	0.4	43	16.1
175	MDL	-8.0	0.88	0.35	0.014	0.00	0.07	0.27	NA	NA	15	0.2	38	13.7
176	MDL	-10.0	0.88	0.30	0.011	0.00	0.07	0.22	NA	NA	13	0.2	34	11.4

[1] "NA" indicates that samples were not analyzed for this constituent.

Table 12. Precision and recovery for sediment Standard Reference Material NIST SRM 2710 Montana Soil

	NIST SRM 2710				
Element	**Reported (mg g^{-1})**	**Reported Stdev**	**Measured (mg g^{-1})**	**Stdev (n=5)**	**Percent recovery**
P	1.06	0.15	1.09	0.07	103
Fe	33.8	1	32.8	2.7	97
Al	64.4	0.8	64.5	2.6	100
Ca	12.5	0.3	12.4	0.5	99