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

The Transition of Benthic Nutrient Sources after Planned Levee Breaches Adjacent to Upper Klamath and Agency Lakes, Oregon

By James S. Kuwabara, Brent R. Topping, James L. Carter, Francis Parchaso, Jason M. Cameron, Jessica R. Asbill, Steven V. Fend, John H. Duff, and Anita C. Engelstad

Open File Report 2010-1062

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Suggested citation:
Kuwabara, J.S., Topping, B.R., Carter, J.L., Parchaso, F., Asbill, J.R., Cameron, J.M., Asbill, J.R., Fend, S.V., Duff, J.H., and Engelstad, A.C., 2010, The transition of benthic nutrient sources after planned levee breaches adjacent to Upper Klamath and Agency Lakes, Oregon: U.S. Geological Survey Open-File Report 2010-1062, 27 p. [http://pubs.usgs.gov/of/2010/1062/].

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Conversion Factors, Abbreviations, and Acronyms

Conversion Factors

Multiply	By	To obtain
cubic foot per sec (ft^3 s^{-1})	35.31	cubic meter per sec (m^3 s^{-1})
degree Centigrade (^oC)	1.8 and add 32	degree Fahrenheit (^oF)
foot (ft)	0.3048	meter (m)
liter (L)	1000	milliliter (mL)
inch (in)	2.54	centimeter (cm)
millimole (mmole)	1000	micromole (µmole)
micromolar (µM)	molecular weight	microgram per liter (µg-L^{-1})
microgram per liter (µg-L^{-1})	0.001	milligram per liter (mg-L^{-1})
micron (µm)	1,000,000	meter (m)
mile (mi)	1.609	kilometer (km)

Abbreviations and Acronyms

Abbreviations and Acronyms	Meaning
BRD	Biological Resources Discipline, USGS
DO	Dissolved oxygen
%	percent
ORP	Oxidation-reduction potential
PSU	Practical Salinity Unit
SD	Standard deviation
SRP	Dissolved (soluble) reactive phosphate
USBR	U.S. Bureau of Reclamation
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WRD	Water Resources Discipline, USGS
WSC	Water Science Center, USGS

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Executive Summary

Four sampling trips were coordinated after planned levee breaches that hydrologically reconnected both Upper Klamath Lake and Agency Lake, Oregon, to adjacent wetlands. Sets of nonmetallic pore-water profilers were deployed during these trips in November 2007, June 2008, May 2009, and July 2009 (fig. 1; table 1). Deployments temporally spanned the annual cyanophyte bloom of *Aphanizomenon flos–aquae* (AFA) and spatially involved three lake and four wetland sites. Profilers, typically deployed in triplicate at each lake or wetland site, provided 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 groundwater 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 taxonomic and geochemical analyses of bottom-sediments taken from Upper Klamath Lake (UKL) in prior studies.

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 the Interior supported an additional full deployment of pore-water profilers in November 2007 and July 2009, immediately following the levee breaches and after the crash of the annual summer AFA bloom.

As observed consistently since 2006, benthic flux of 0.2-micron filtered, soluble 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 from a negligible value (-0.19$\pm$0.91 milligrams per square meter per day; mg m^{-2} d^{-1}; table 2) within wetlands of the Upper Klamath National Wildlife Refuge to 74$\pm$48 mg m^{-2} d^{-1} at the newly restored wetland site removed from the levee breach (TNC1); both observed in May 2009 before the annual AFA bloom. When areally averaged (13 km^2 for the newly restored wetlands), an SRP flux to the overlying water column is determined of approximately 87,000 kilograms (kg) over the 3-month AFA bloom season that exceeds the magnitude of riverine inputs (42,000 kg for the season; see Benthic flux of macronutrients below). Elevated SRP benthic flux at TNC1 relative to all other lake and wetland sites (including TNC2 near the breached levee) in 2009 suggests that the restored wetlands, at least chemically, remain in a transition period after

engineered blasts on October 30, 2007, restored hydrologic connectivity between lake and wetland environments. As reported in previous lake studies (Kuwabara and others, 2009a), ammonium fluxes to the water column were consistently positive, with the exception of two measurements at the restored wetland sites (TNC1 and TNC2) immediately following the levee breaches in November 2007. The flux of ammonia, particularly at elevated pH in the overlying water column, has toxicological implications for endangered fish populations in both lake and wetland environments (Kuwabara and others, 2009). For dissolved nitrate, with the exception of a single positive flux measurement at TNC1 in June 2008 (0.16 ± 0.02 mg m^{-2} d^{-1}), consistently negative (consumed by the sediment) or undetectable nitrate-flux values were observed (-21 ± 12 mg m^{-2} d^{-1} to undetectable fluxes due to concentrations for dissolved nitrate <0.03 milligrams per liter (mg L^{-1}) in both porewaters and overlying waters near the sediment-water interface). Such negative fluxes for dissolved nitrate are typical of microbial transformations, such as dinitrification (dissimilatory nitrate reduction), that benthically consume nitrate from the water column. The diffusive-flux measurements reported herein serve as conservative (under-) estimates of benthic flux, because solute transport across the sediment-water interface can be enhanced by other processes, including bioturbation, bioirrigation, groundwater advection, and wind resuspension. They do, however, provide lower bounds to indicate the potential importance of this internal solute source.

In the water column, the average molar ratio for dissolved inorganic nitrogen to phosphorus was 3.4 ± 2.9, well below the Redfield Ratio of 16 (table 3; Redfield, 1934). This condition favors nitrogen-fixing primary producers like AFA. Soluble reactive phosphorus (SRP) concentrations were lower than detection limits (<0.03 mg-P L^{-1}) at all lake and wetland sites in November 2007 following the planned levee breaches (table 3). As indicated in previous studies (Kuwabara and others, 2007, 2009), SRP concentrations for 2009 sampling trips indicate higher concentrations at the end of the annual AFA bloom (July 2009) relative to before (May 2009) for all six lake and wetland sites. This observation suggests the possibility of another limiting factor or factors. Wetland samples from the newly restored wetland areas (sites TNC1 and TNC2) in July 2009 yielded the highest SRP concentrations (0.21 and 0.20 mg-P L^{-1}, respectively), providing additional evidence that the newly restored wetlands remain in a period of chemical transition. Dissolved-nitrate concentrations were consistently low, with detectable concentrations (>0.03 mg-N L^{-1}) only observed after the annual AFA bloom. As previously reported in studies of Upper Klamath Lake (Kuwabara and others, 2007), concentrations for dissolved ammonium, silica, and organic carbon, like that of SRP, were higher after the annual AFA bloom compared to before (tables 3 and 4) at all six lake and wetland sites.

To our knowledge, the flux of trace elements across the sediment water interface has heretofore not been quantified and reported for any part of the Klamath River Basin. Using calculations based on Fick's law, as for nutrients above, we present what is believed to be the first benthic-flux estimates for the lake and wetland sites (fig. 1) for the biologically reactive metals iron (Fe), manganese (Mn), and copper (Cu). Other metals discussed in the water-column section below (cadmium, cobalt, copper, nickel, and zinc) did not exhibit statistically significant gradients, so fluxes were negligible and not tabulated (table 5).

Both Fe and Mn exhibited dramatic concentration differences between overlying waters and porewaters, with the deepest porewater sample at 10 cm often being two or more orders of magnitude higher than the overlying sample. Calculations based on these gradients yielded flux estimates for Fe ranging from -0.08 ± 0.12 mg m^{-2} d^{-1} in the Wildlife Refuge in May 2009 to 61 ± 76 mg m^{-2} d^{-1} at site TNC2, also in May 2009. The elevated error estimate about the TNC

mean flux is a reflection of small-scale (within site) variability. The disparity between Fe fluxes in the Wildlife Refuge (WET) and sites within the newly restored wetlands (TNC1 and TNC2) suggests an ongoing transition for areas inundated in 2007 by the planned levee breaches. Dissolved-iron fluxes observed at wetland sites in this study (9.39±16.74 mg m^{-2} d^{-1}, n=12) were more variable than for lake sites (5.45±3.81 mg m^{-2} d^{-1}, n=10). The maximum diffusive Fe flux observed in this study (61±76 mg m^{-2} d^{-1}) generates an areally averaged benthic flux of 789±985 kg d^{-1} that is comparable in magnitude to the highest measurement of riverine inputs (257 kg d^{-1}) determined during spring high flow in May 2009 (table 6). It also exceeds previous estimates of riverine-Fe inputs by orders of magnitude (areally averaged at 0.7±0.1 mg m^{-2} d^{-1} during spring high flow and 0.3±0.1 mg m^{-2} d^{-1} during summer low flow; Kuwabara and others, 2009). Like iron, dissolved-manganese flux estimates were typically positive and ranged from -0.01±0.02 mg m^{-2} d^{-1} in the Wildlife Refuge in November 2007 to 8.78±4.91 mg m^{-2} d^{-1} at site WMR, near the Williamson River delta (fig. 1) in July 2009. The maximum diffusive Mn flux observed in this study (8.78±4.91 mg m^{-2} d^{-1}) generates an areally averaged benthic flux of 1,756±983 kg d^{-1}, which exceeds by more than an order of magnitude the highest measurement of riverine inputs (13 kg d^{-1}) determined during spring high flow in May 2009 (table 6). In summary, benthic flux of iron and manganese may serve as a significant source of these essential micronutrients to the lake water column. However, for other trace metals, including those that could retard algal growth (for example, dissolved copper and zinc), water-column and porewater concentrations are low and relatively constant across the sediment-water interface.

Benthic invertebrates are extremely abundant in Upper Klamath Lake and the Williamson River delta (fig.1). Densities per site within the delta ranged from a low of 178 individuals m^{-2} approximately a week after the levee breach to 32,519 individuals m^{-2} in July 2009 (table 7). Although chironomids dominated delta sites sampled in 2009, oligochaetes (primarily tubificids) typically dominated the benthos at other sites during the study. Given the densities of invertebrates in the ecosystem and their behavioral activity at the sediment-water interface, it is likely they have a substantial influence on solute cycling via metabolic activity and bioturbation (fig. 2, benthic-invertebrate video).

In summary, both the lake and wetland benthic environments substantively contribute to both macro- and micronutrients in the water column. The wetland areas undergoing restoration and those being used for water storage function very differently relatively to the established Wildlife Refuge. It may therefore be prudent, in terms of developing long-term management strategies for water quality in the Upper Klamath Basin, to extend examination of these historically perturbed wetlands as they transition toward more traditional seasonal function with regard to nutrient (both metal and ligand) fluxes.

Potential Management Implications

Long-term biological goals of maintaining or restoring fisheries resources in Upper Klamath Lake and the downstream Klamath River Basin below are dependent on solute transport through benthic and pelagic food webs. The base of those food webs, from which trophic transfer begins, is dependent on the availability of nutrients to primary producers. In order to meet water-quality objectives for the lake (for example, to reduce the impact of nutrient cycling on endangered fish populations), an understanding of the processes governing nutrient transport and distribution is required to explain temporal and spatial trends in benthic and pelagic community composition. The structure and abundance of these communities are in turn linked to solute accumulation within the lake and wetlands as well as solute loads downstream. In hypereutrophic Upper Klamath Lake, predominance of the nitrogen-fixing cyanophyte *Aphanizomenon flos–*

aquae (AFA) suggests limitation by a solute other than nitrogen. Hence, this study provides measurements of benthic sources of dissolved macro- and micronutrients that may be significant relative to potentially regulated allochthonous sources. Because wetland areas became hydrologically connected to both Upper Klamath and Agency Lakes after the engineered levee breaches of October 30, 2007, this study focuses on the benthic nutrient sources from these wetlands undergoing restoration after decades of agricultural use. The rate at which benthic fluxes from these restored wetlands converge to those observed for established wetlands or adjacent lake habitats may also be of management interest. In addition to phosphorus, we examine the consistency of significant ammonia fluxes from the sediments in these wetland areas, as was previously reported for the lake. The information provided herein is intended to help evaluate proposed management and remediation strategies for the basin and appropriate response times for those remediation efforts. Deployment of nonmetallic porewater profilers, designed and fabricated for previous studies of Upper Klamath Lake (Kuwabara and others, 2009) has been, with minimal modifications, applied to adjacent wetland environments. Benthic-flux measurements in the wetland areas begin to locate and quantify major nutrient sources for subsequent assessments of restoration activities in the lake and basin in general.

Background

In hypereutrophic Upper Klamath Lake, Oregon (fig. 1), organic carbon generated by massive cyanophyte blooms that is not transported out of the lake, ultimately settles to the bed of the lake or, to some extent, wetland habitats and imposes a benthic demand for oxygen. Such a demand poses an environmental stress for endangered fish populations (Wood and others, 2006). Although phosphorus (P) may typically serve as the limiting nutrient for those nitrogen-fixing cyanophytes, our previous lake studies indicated that internal loading of dissolved micronutrients (for example, iron) should also be further examined. We therefore present water-column and benthic-flux information for both macro- and micronutrients that maybe critical to source management for the basin (U.S. Fish and Wildlife Service, Klamath Falls Fish and Wildlife Office, Ecosystem Restoration; http://www.fws.gov/klamathfallsfwo/ero/er.html). With increasing recognition of the ecosystem services provided by wetlands, this study serves as a rare opportunity to quantify the temporal and spatial scales associated with wetland reclamation and restoration projects after levee breaches (whether planned or due to unanticipated weather or flooding).

During the past century, massive phytoplankton blooms dominated by *Aphanizomenon flos–aquae* (AFA) have occurred each summer in Upper Klamath Lake (UKL). After buoyant AFA layers (scums) are concentrated by wind over the lake surface and cells senesce, biomass settles and dissolved oxygen is depleted in the water column and lakebed. Such hypoxia may affect the distribution of lake fauna, including endangered populations of the shortnose sucker (*Chasmistes brevirostris*) and Lost River sucker (*Deltistes luxatus*), and thereby affect the recruitment and survival of these species. The sustainability of sucker populations is linked to the water-quality in the lake and to the nutrient sources that regulate the intensity of AFA blooms and the succession of algal assemblages before and after those blooms. Of particular significance is the appearance of the non-nitrogen-fixing, hepatotoxin-producing cyanobacterium *Microcystis aeruginosa* (Kann, 2006). Though not taxonomically abundant relative to AFA, *M. aeruginosa* has been consistently detected in both Agency and Upper Klamath Lakes. Sources and distributions of microcystin in Upper Klamath Lake are currently being investigated by other collaborating U.S.Geological Survey (USGS) projects within the Biological Resources

Discipline and the Oregon Water Science Center.

Problematic algal blooms are fueled by external and internal loads of particle-reactive solutes (for example, ligands like phosphorus as orthophosphate or metals like iron). As these solutes repartition and change in chemical speciation, benthic sources of these nutrients may play a major role in phytoplankton dynamics and succession (Kuwabara and others, 2009). As we enter the fifth decade after Miller and Tash (1967) concluded about Upper Klamath Lake that "[i]t is imperative to know the extent to which nutrients in the sediments can interchange with the overlying water," we provide benthic-flux determinations for macro- and micronutrients in Upper Klamath Lake and adjacent wetland environments following the planned levee breaches by The Nature Conservancy on October 30, 2007.

Objectives

In support of science-based restoration/management strategies for Upper Klamath Lake and downstream ecosystems, this study provides measurements of the benthic fluxes of dissolved macronutrients and trace elements between the bed material and overlying water column at three lake and four wetland sites following a planned levee breaches that hydrologically reconnected Upper Klamath and Agency Lakes to adjacent wetlands. Benthic-chlorophyll and water-column solute measurements were made at each site to help place results from this study in proper context. Because some of the macronutrients (for example, SRP and ammonia) and many of the trace elements (for example, cadmium, copper, iron, manganese, nickel and zinc) are surface reactive, we hypothesize that benthic nutrient sources could be significant relative to previously quantified fluvial sources within these predominantly shallow water habitats (<3 m in depth).

Results and Discussion:

Ancillary water-column parameters (from datalogger profiles).—Measurement of ancillary parameters (for example, temperature, specific conductivity, pH) at the profiler deployment sites provides a basic physical and chemical context that may help interpret benthic-flux results (table 1). Except for the mid-lake north (MDN) site (~4 m depth), the sites where profilers were deployed were shallow (<3 m depth), with minimal haloclines or thermoclines. Specific conductivity values displayed a narrow range (0.04 to 0.12 millisiemens per cm; mS cm^{-1}) and an unsurprising trend of lowest values during the prebloom and early-bloom deployments (June 2008 and May 2009) and elevated values during the postbloom samplings (November 2007 and July 2009). Consistent temperature ranges reflect seasonal air-temperature patterns affecting the shallow water column at the seven lake and wetland sites (fig. 1; 6.0 to 7.6^{o}C in November 2007 and 23.0 to 25.1^{o}C in July 2009). Observed seasonal ranges are consistent with previous and ongoing monitoring of Upper Klamath Lake (Wood and others, 2006). For pH, with the exception of the National Wildlife Refuge site (WET; pH range 4.9 to 7.3 over the 4 deployment days), pH was typically above 7 and as high as 9.5. Profiles were routinely taken within the 3 hours after sunrise (just before profiler retrieval), and therefore even higher pH values may be expected (for example, >9.5 pH values reported by Wood and others (2006)) as solar energy elevates later in the day and phytoplankton accelerate their removal of dissolved inorganic carbon from the water column. Falter and Cech (1991) reported a maximum pH tolerance for the shortnose sucker of 9.55$\pm$0.43. As pH increases, the chemical speciation and partitioning of biologically reactive solutes are significantly affected. For example, as pH rises above 9.3, the negative logarithm of the acid dissociation constant for ammonium, uncharged and toxic ammonia (NH_3; Arillo and others, 1981; Randall and Tsui, 2002) becomes more

thermodynamically stable relative to the ammonium ion (NH_4^+). Secondly, as pH elevates, adsorbed anions (for example, orthophosphate) repartition from the particulate to the more biologically available, dissolved phase (Sigg and Stumm, 1981; Goldberg, 1985; Fisher and Wood, 2001). As pH increases, essential trace elements (for example, iron and manganese) in an oxic environment become less soluble (and hence less bioavailable to primary producers) because precipitates and adsorbed forms become more stable (Hogfeldt, 1982; Kuwabara and others, 1986).

Benthic flux of macronutrients.—Upon retrieving the porewater profilers from sites TNC1 and TNC2 following the levee breaches, a concentration gradient for dissolved organic carbon (DOC) was visibly apparent (fig. 3; table 8). DOC fluxes were greatest at these newly restored sites (as high as 712±498 mg m^{-2} d^{-1} at the newly restored wetland site, TNC1). Such inputs of DOC, primarily as humic substances, may serve to inhibit primary production by constraining nutrient bioavailability or by producing toxic photolytic byproducts (Jones and others, 1993, Kim and Wetzel, 1993; Klug, 2002; Haggard, 2008; Lindenberg and Wood, 2009). By contrast, both lake sites displayed a negative DOC flux immediately following the levee breaches. Over the past two years, those DOC fluxes have decreased to the point where, the DOC flux was negative postbloom at TNC2, as at the lake sites. However, the flux at TNC1, within the restored-wetland area but away from the levee breach, still indicated a large positive flux (55±55 mg m^{-2} d^{-1}, table 8).

As observed consistently since 2006, 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). The SRP benthic flux ranged from a negligible value (-0.19±0.91 mg m^{-2} d^{-1}; table 2) within the established wetland refuge (indexed site WET) to 74±48 mg m^{-2} d^{-1} at the newly restored wetland site (TNC1; inundated with the new floodwaters on October 30, 2007, and somewhat removed (>100 m away) from the levee breach). Both extreme SRP-flux values were determined from samples collected in May 2009 before the annual AFA bloom. The magnitude of such SRP fluxes is not anomalous for wetland environments. Using flux chambers, Duff and others (2009) observed SRP fluxes from the Wood River wetland of 72±36 mg m^{-2} d^{-1} before the summer bloom in 2005, decreasing to insignificant levels (19±60 mg m^{-2} d^{-1}) by August after the bloom. When areally averaged (13 km^2 for the newly restored wetlands; Snyder and Morace, 1997; Congressional Research Service, 2005), an SRP flux to the overlying water column is determined of approximately 87,000 kilograms (kg) over the 3-month AFA bloom season that exceeds the magnitude of riverine inputs to the whole system (42,000 kg for the season). Aldous and others (2007) observed a total P release of 1 to 9 g m^{-2} from restored-wetland soils, mostly during the first 48 hours of soil-core incubation. They observed no significant total-P release was observed beyond the initial 62 days of core incubation. If one averages those fluxes over the 62-day initial period (an underestimate relative to the fluxes observed during the first 48 hours of incubation), those observed total-P fluxes would be approximately 16 to 145 mg m^{-2} d^{-1} of total P (or 210 to 1,887 kg d^{-1} of total P over the 13 km^2 area of the restored wetlands). Elevated SRP benthic flux at TNC1 relative to all other lake and wetland sites (including TNC2 near the breached levee) in 2009 suggest that the restored wetlands, at least chemically, remain in a transition period after engineered blasts on October 30, 2007, restored hydrologic connectivity between lake and wetland environments.

The flux of ammonia, particularly at elevated pH in the overlying water column, has toxicological implications for endangered fish populations in both lake and wetland

environments (Kuwabara and others, 2009). This potential water-quality problem related to fish toxicity was again observed in this study. As reported in previous lake studies (Kuwabara and others, 2009), ammonium fluxes to the water column were consistently positive except for two measurements at the restored wetland sites (TNC1 and TNC2) immediately following the levee breaches in November 2007 (-0.39±0.28 and -0.96±0.30 mg m^{-2} d^{-1}, respectively). Martin and Saiki (1999) determined in their fish-cage studies of the Lost River sucker (*Deltistes luxatus*) that elevated concentrations of unionized ammonia may be contributing to the precipitous decline of sucker populations in Upper Klamath Lake, although depletion of dissolved oxygen in the water column (a factor that covaries with ammonia) exerted a much stronger influence on sucker mortality. Minimum and maximum ammonium fluxes in the wetlands bracket those observed for the lake sites, with the highest ammonia fluxes observed in the established wetland site (WET; 306±38 mg m^{-2} d^{-1}). Consistent with previous ammonium-flux estimates for the lake (Kuwabara and others, 2009), dissolved ammonium during this study displayed positive benthic fluxes of 5 to 35 mg m^{-2} d^{-1} (1,000 to 6,900 kg d^{-1}), considerably higher than riverine inputs (90±20 kg d-1). Following the November 2007 sampling, ammonium fluxes at TNC1 and TNC2 subsequently shifted to positive fluxes (that is, out of the benthos, consistent with all other lake and wetland sites), with highest values observed after the AFA bloom in July 2009. For dissolved nitrate, with the exception of one significant positive flux measurement at TNC1 in June 2008 (0.16±0.02 mg m^{-2} d^{-1}), consistently negative (consumed by the sediment) or undetectable nitrate-flux values were observed (-21±12 mg m^{-2} d^{-1} to undetectable fluxes due to concentrations for dissolved nitrate <0.03 milligrams per liter (mg L^{-1}) in both porewaters and overlying waters near the sediment-water interface). Negative nitrate fluxes have been consistently observed in Upper Klamath Lake (Kuwabara and others, 2009) and typically represent a benthic microbial demand for dissimilatory nitrate reduction.

SRP (primarily as dissolved orthophosphate) is a particle-reactive solute, meaning that it can form surface complexes on a variety of mineral and biotic surfaces (Sigg and Stumm, 1981; Goldberg, 1985; Kuwabara and others, 1986; Ruttenberg, 1992). 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, 2003). Because the dominant phytoplankton taxon, AFA, is a nitrogen-fixing cyanophyte, it may be reasonable to initially assume that phosphorus may serve as the limiting nutrient (Istvánovics, 2008). The implications of dissolved micronutrient results (that is, coordinated benthic flux, water-column, and tributary-inlet data) suggest that they also be carefully considered as potential regulators of primary productivity.

Dissolved (0.2-µm filtered) nutrients in the water column.—Soluble reactive phosphorus (SRP) was lower than detection limits (<0.03 mg-P L^{-1}) at all lake and wetland sites in November 2007 following the planned levee breaches (table 3). In June 2008, during the bloom following the levee breaches, SRP was again below detection limits in the lake and consistently <0.1 mg-P L^{-1} at all three wetland sites. Consistent with previous studies (Kuwabara and other, 2007; Kuwabara and others, 2009), SRP concentrations from 2009 sampling trips indicate higher concentrations at the end of the annual AFA bloom (July 2009) relative to before (May 2009) for all six lake and wetland sites. This observation suggests the possibility of other limiting factor or factors. It is, however, worth noting that benthic interactions affecting water-column solute concentrations are subject to short-term (subseasonal) variability in shallow lakes like Upper Klamath Lake, contrasting with seasonal nutrient trends typical of deep, stratified lakes (Wetzel,

2001). The magnitude of that short-term variability is currently being quantified, but represents another temporal scale of nutrient inputs to the lake water column (see nutrients discussion). Wetland samples from the newly restored wetland areas (sites TNC1 and TNC2) in July 2009 yielded the highest SRP concentrations (0.21 and 0.20 mg-P L^{-1}, respectively) providing additional evidence that the newly restored wetlands remain in a period of chemical transition. Dissolved-nitrate concentrations were consistently low, with detectable concentrations (>0.03 mg-N L^{-1}) only observed after the annual AFA bloom. In contrast to other sampling dates when 75 percent of samples contained <0.03 mg-N L^{-1} (that is, below the detection limit), samples collected in November 2007 following the levee breaches exhibited elevated nitrate concentrations that ranged from 0.14 to 0.18 mg L^{-1}. As previously reported in studies of Upper Klamath Lake (Kuwabara and others, 2007), dissolved-ammonium and silica, like SRP, were higher after the annual AFA bloom compared to before (table 3) at all six lake and wetland sites where comparable data are available.

Benthic flux of trace elements.—Apart from the authors' initial studies (Kuwabara and others, 2007), the flux of trace elements across the sediment-water interface has heretofore not been quantified and reported for any part of the Klamath River Basin. Using calculations based on Fick's law, as for nutrients above, we present what is believed to be the first benthic-flux estimates for the lake and wetland sites (fig. 1) for the metals iron (Fe), manganese (Mn), and copper (Cu) (table 5).

Both Fe and Mn exhibited dramatic concentration differences between overlying waters and porewaters, with that in the deepest porewater sample at 10 cm often being two orders of magnitude higher than in the overlying sample. Calculations based on these gradients yielded flux estimates for Fe ranging from -0.08$\pm$0.12 mg m^{-2} d^{-1} in the Wildlife Refuge in May 2009 to 61$\pm$76 mg m^{-2} d^{-1} at site TNC2, also in May 2009. The elevated error estimate about the TNC mean flux is a reflection of small-scale (within site) variability in concentration gradients; the triplicate flux estimates were 15.4, 18.5 and 148 mg m^{-2} d^{-1}, all three higher than any other site mean in this study (table 5). As mentioned in the prior section on macronutrient fluxes, the disparity between Fe fluxes in the Wildlife Refuge (WET) and sites within the newly restored wetlands (TNC1 and TNC2) suggest an ongoing transition for areas inundated in 2007 by the planned levee breaches. Dissolved-iron fluxes observed at wetland sites in this study (9.39$\pm$16.74 mg m^{-2} d^{-1}, n=12) were more variable than for lake sites (5.45$\pm$3.81 mg m^{-2} d^{-1}, n=10). Fe-flux estimates at lake sites were similar to those reported in previous studies (Kuwabara and others, 2009), with higher fluxes at the Williamson River delta site (WMR) than at the Modoc Rim site (MRM). By comparison, maximum Fe-flux estimates for oligotrophic Coeur d'Alene Lake, Idaho, were an order of magnitude lower (1.1 mg m^{-2} d^{-1}; Kuwabara and others, 2000), as estimated by core incubations. The maximum diffusive Fe flux observed in this study (61$\pm$76 mg m^{-2} d^{-1}) generates an areally averaged benthic flux of 789$\pm$985 kg d^{-1} that exceeds the highest measurement of riverine inputs (257 kg d^{-1}) determined during spring high flow in May 2009 (table 6). It also exceeds previous estimates of riverine Fe inputs by an order of magnitude (areally averaged at 0.7$\pm$0.1 mg m^{-2} d^{-1} during spring high flow and 0.3$\pm$0.1 mg m^{-2} d^{-1} during summer low flow; Kuwabara and others, 2009). Iron benthic fluxes reported here could be an underestimate, because diffusive porewater flux estimates do not account for bioturbation or bioirrigation by macroinvertebrates, which are likely to enhance solute flux (fig. 2). Conversely, diffusive iron fluxes could overestimate the transport of bioavailable iron into the water column. Reduced iron species prevalent in the deeper samples could become more particle-reactive as they reach an oxidized water column. Elevated dissolved-iron concentration gradients within the

newly restored wetland areas may represent remobilized iron in dense, decomposing agricultural remnants, as observed before the levee breaches, but trace-element analysis of bed sediment would be required to confirm this hypothesis.

As with iron fluxes, dissolved-manganese flux estimates were typically positive and ranged from -0.01±0.02 mg m^{-2} d^{-1} in the Wildlife Refuge in November 2007 to 8.78±4.91 mg m^{-2} d^{-1} at WMR in July 2009. The average of all Mn flux estimates for this study (1.4±2.1 mg m^{-2} d^{-1}, n=22 ; table 5) is two orders of magnitude lower than that reported for Lake Coeur d'Alene, Idaho (190±59 mg m^{-2} d^{-1}, n=12), an oligotrophic lake with surficial sediment deposits of iron and manganese oxyhydroxides (Kuwabara and others, 2000, 2003). The maximum diffusive Mn flux observe in this study (8.78±4.91 mg m^{-2} d^{-1}) generates an areally averaged benthic flux of 1,756±983 kg d^{-1} that exceeds by more than an order of magnitude the highest measurement of riverine inputs (13 kg d^{-1}) determined during spring high flow in May 2009 (table 6).

In contrast to iron and manganese fluxes, dissolved-copper and dissolved-zinc fluxes were generally negligible or slightly negative. If management of primary productivity is desirable, this observation may be unfortunate in Upper Klamath Lake, because both dissolved copper and zinc have algicidal properties (Kuwabara and Leland, 1986; Stauber and Florence, 1987; table 5). Other metals discussed in the water-column section below (Co, Ni, Pb, and Zn), like Cu, did not exhibit statistically significant concentration gradients near the sediment-water interface, hence the diffusive fluxes would also be negligible.

In summary, benthic flux of iron and manganese serves as a significant source of these essential micronutrients to the lake water column. However, for other trace metals, including those that could retard algal growth (for example, dissolved copper and zinc), water-column and porewater concentrations are low and relatively constant across the sediment-water interface.

Dissolved (0.2-micron filtered) trace metals in the water column.—Low trace-metal concentrations in volcanic pumice, that dominates inorganic sediments of Upper Klamath Lake, generate consistently low particulate trace-metal concentrations relative to other lacustrine environments (Martin and Rice, 1981). Although information about dissolved, and hence more biologically available, trace metals in the Upper Klamath Lake is sparse (Kuwabara and others, 2007, 2009), they also reflect a trace-metal-depleted environment in the dissolved phase. Data described herein extend this sparse information base to include dissolved trace-metal concentrations in the wetlands adjacent to Upper Klamath and Agency Lakes. For all dissolved metals, the overlying-water concentrations (collected approximately 1 cm above the sediment water interface by the porewater profilers, see section on Methods) compared favorably with surface-grab samples (collected approximately 1 m below the surface; table 9). As previously reported for Upper Klamath Lake, many of those metals (for example, Cd, Co, Pb, and Zn) were present at dissolved concentrations below or near detection limits (Kuwabara and others, 2009; table 9). Concentration gradients across the sediment-water interface for these metals were not observed, and hence diffusive fluxes are not tabulated.

For dissolved copper, concentrations in the water column were well above detection limits (>0.002 µg L^{-1}) but consistently below 1 µg L^{-1} and exhibited a range of 0.054±0.002 µg L^{-1} at the Wildlife Refuge site (WET) in May 2009 to 0.620±0.031 µg L^{-1} in the Agency Ranch wetland (ALR) in June 2008. In particular, samples from the WET site were routinely lowest in dissolved Cu for any given date among sites. Temporally, samples during the prebloom conditions of May 2009 were lowest in dissolved Cu at each site, except for the mid-lake north (MDN) site. Consistently low dissolved-Cu concentrations were observed among lake and

hydrologically reconnected TNC1 and TNC2 sites as well as within sites near the sediment-water interface (tables 5 and 9). Hence the dissolved-Cu benthic flux, like those for Cd, Co, Pb, and Zn, was also negligible (table 5).

Dissolved iron, an essential micronutrient for primary productivity, varied greatly in concentration from undetectable (<5 µg L^{-1}) levels at MRM in November 2007 after the levee breaches, to 235±19 µg L^{-1} in Agency Lake Ranch (site ALR) in June 2008. In particular, for all sampling dates, the average dissolved-iron concentrations in sampled wetland sites exceeded those for lake sites. This is not surprising, because for each sampling date the highest iron fluxes were observed in the wetlands, with one exception. In June 2008, a relatively low iron diffusive flux of 1.24±0.65 mg m^{-2} d^{-1} at wetland site ALR was associated with the highest sample concentration of 248±7 µg L^{-1}. We hypothesize that by that sampling date dissolved iron in the water column of Agency Lake Ranch (site ALR), used for water storage, approached chemical equilibrium with the porewater at the time of our single sampling. Soon after, this storage reservoir was drained into Agency Lake to help maintain lake levels. This release would thereby represent an additional source of dissolved iron to the lake.With only one set of profiler deployments at site ALR, however, more frequent sampling of this storage area is required to test this hypothesis. As previously reported, dissolved iron entering the lake via riverine inputs was well correlated (0.82 to 0.98) with dissolved organic carbon (DOC) over all sampling dates (table 6). This relationship was not observed for riverine manganese or copper.

Highest concentrations for dissolved manganese, another essential micronutrient, were consistently observed in July 2009 relative to other sampling dates. Concentrations ranged from undetectable levels (<0.02 µg L^{-1}) at MDN in May 2009 before the AFA bloom to 59.6±0.19 µg L^{-1} at the same site postbloom in July of that year. Similar to the lake sites, wetland sites WET and TNC1 displayed an increase in dissolved Mn between prebloom and postbloom samplings, but TNC2, closest to the levee breach, did not display an increase.

The water-column data presented in this report are coordinated with seasonal porewater profiler deployments, but it should be noted that since spring 2008, ongoing collaborative work with the Oregon Water Science Center is generating weekly trace-metal concentrations for the water column as well as in phytoplankton to track the redistribution and potential depletion of solutes during the annual cyanophyte bloom. Such temporal resolution is critical to understanding nutrient dynamics in the lake because, unlike deeper holomictic lakes, the benthos in Upper Klamath Lake, with the exception of the western trench area, is directly and constantly interacting with the euphotic zone. Therefore, variability in dissolved trace-metal concentrations can reflect processes (for example, wind directions and geostrophic currents) that operate over multiple time scales.

Benthic chlorophyll.—Benthic chlorophyll measurements provide an indication of the settled carbon load to the sediment bed as phytoplanktonic densities cycle through seasonal variations in productivity. This study includes measurements of benthic chlorophyll for the lake and wetland sites associated with profiler deployments.

The benthic chlorophyll distributions within the system are notable for two trends: first, that seasonal variability of chlorophyll-*a* is not obvious and second, that degraded or senescent algae (as measured by pheophytin concentrations) are much more abundant than viable cells as indicated by chlorophyll-*a*. Furthermore, seasonal trends that likely relate to the algal bloom in the warm months are best demonstrated by the pheophytin concentrations. For example, during the November 2007 sampling, when cold weather and low-light conditions constrained phytoplankton biomass, site means for benthic chlorophyll concentrations (table 10) in the lake

sites (MRM and WMR) were 0.6±0.2 µg cm^{-2} and 0.3±0.3 µg cm^{-2}, respectively, with pheophytin concentrations of 2.4±0.4 µg cm^{-2} and 5.2±0.8 µg cm^{-2}, respectively. During other sampling in the warmer months, benthic chlorophyll was essentially unchanged, with a lake maximum of 1.6+1.9 µg cm^{-2} (WMR, July 28, 2009), while pheophytin concentrations seemed to reflect the settling out and degradation of algal blooms (average of all lake sites (MRM, WMR and MDN) for May 26, 2009, and July 28, 2009: 10.2±6.1 µg cm^{-2}). Based on the elevated algal biomass generated in the water column of hypereutrophic aquatic systems like Upper Klamath Lake, one might expect a greater seasonal signal for benthic chlorophyll. Alternatively, settled, viable cells may be advected away from our sampling sites, perhaps to the lake trench on the western boundary, the only feature of the lake exceeding 10 m in depth.

The strength of the seasonal trend in pheophytin instead of chlorophyll concentrations was even more pronounced in the data for established and newly flooded wetlands. On November 1, 2007, WET, TNC1, and TNC2 sites exhibit benthic chlorophyll concentrations of <0.1 µg cm^{-2}, 1.0±0.6 µg cm^{-2} and 0.2±0.5 µg cm^{-2}, respectively, and pheophytin concentrations of 5.8±3.5 µg cm^{-2}, 1.5±0.8 µg cm^{-2} and 4.0±1.1 µg cm^{-2}, respectively. Moving forward in time to May 26, 2009, these benthic chlorophyll concentrations are essentially unchanged at <0.1 µg cm^{-2}, 0.4±1.1 µg cm^{-2} and <0.1 µg cm^{-2} at WET, TNC1, and TNC2, respectively, while pheophytin concentration have increased significantly to 101.6±13.9 µg cm^{-2}, 34.0±1.2 µg cm^{-2} and 15.6±1.8 µg cm^{-2}, respectively. Comparative benthic-pheophytin concentrations for other lakes are scarce, but Wolfe and others (2006) determined a concentration of 5 µg g^{-1} in sediments from Lake Louise, Colorado, which converts to approximately 6 µg cm^{-2} assuming (1) a typical sediment density of 2.5 g cm^{-3} and (2) a sample depth of 0.5 cm, where the pheopigments are primarily distributed. This value is consistent with studies of oligotrophic Camp Far West Reservoir in California, where a concentration range of 6.5 to 20.2 µg cm^{-2} was observed (J.S. Kuwabara, unpublished data), and with published estuarine concentration ranges from 1 to 24 µg cm^{-2} (Light and Beardall, 1998; Kuwabara and others, 2009).

The ratio of benthic chlorophyll to the sum of pheophytin plus benthic chlorophyll represents a coarse indicator of the reproductive status of the benthic algal community. Because pheopigments represent degradation products of chlorophyll, observed ratios consistently <0.2 (table 10) suggest the degradation or senescence of phytoplankton cells that settle to the sediment bed or an active benthic fauna that consumes benthic algae to generate feces rich in pheopigments (Thompson and others, 1981; Light and Beardall, 1998; U.S. Environmental Protection Agency, 2000).

Growth and subsequent settling of phytoplankton augment the benthic carbon source that supports microbial and macroinvertebrate assemblages near the sediment-water interface. 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).

Benthic invertebrate communities.—Among samples collected, >90 percent of all organisms were members of the Oligochaeta (49.2 percent), Chironomidae (34.0 percent), and Hirudinea (leeches) (7.8% percent). Both high spatial and temporal (between-year as well as within-year) differences among sites existed in the distribution of invertebrates (table 7).

Open-water sites located along the eastern shore of Upper Klamath Lake (MRM and WMR) showed high temporal differences in invertebrate distributions seasonally and among years. During autumn 2007, total invertebrate densities exceeded 10,000 individuals m^{-2}, and chironomids were dominant at both sites. However, during early summer 2008 and late spring

2009 total invertebrate densities were approximately one-quarter as high as during autumn 2007, and invertebrates between oligochaetes and chironomids was more evenly distributed. During midsummer 2009, total densities were approximately one-third as high as autumn 2007, and both oligochaetes and leeches dominated the benthos at MRM. MDN was the only midlake site sampled. Total invertebrate densities were moderate, and the assemblage was dominated by tubificid oligochaetes, similar to a site (EBB) sampled during the previous study (Kuwabara and others, 2007). During 2009, the percentage of leeches at MDN was higher (19 percent) in July compared to May (7 percent).

Variability in invertebrate distributions among wetland sites was likely a function of variation in location, between-year and seasonal effects, and the influence of vegetation on sampling efficiency. Unlike the open-water sites sampled in the autumn of 2007, the WET site sampled at that time had extremely high densities of invertebrates, with oligochaetes accounting for more than 93 percent of the organisms present. Similar density, with dominance by oligochaetes, was also observed during May 2009. Although there were equally high total densities during July 2009, chironomids made up a much larger portion of the assemblage. In contrast to the above three samples, relatively few invertebrates were collected from the WET site sampled in June 2008. This may have resulted from those grabs being collected from an area within the marsh dominated by water mares tail (*Hippuris vulgaris*), and not in the tules as during other sampling periods.

Substantial changes in invertebrate densities and distributions occurred at the sites (TNC1 and TNC2) located within the newly flooded Williamson River delta over the sampling period. At approximately a week after the levee breach, relatively few invertebrates were present at either site (mean between sites was approximately 500 individuals m^{-2}). Although the benthos was dominated by oligochaetes, in contrast to lake and wetland sites which are dominated by Tubificidae, the newly flooded sites were dominated by Enchytraeidae, which likely were of terrestrial origin (that is, the land before being inundated). Densities of invertebrates at the delta sites quickly increased from June 2008 through July 2009. However, unlike lake sites, which tend to be dominated by tubificids, the delta sites are dominated by chironomids. Two possible explanations include (1) less than optimal tubificid habitat because of the presence of coarse sediment in the delta and (2) rapid colonization of the delta by chironomids because of their greater vagility (capacity to disperse) as adults.

A single collection was made at ALR, the managed water-storage site. Total invertebrate densities were very low. Although the fauna was dominated by oligochaetes, only a few tubificids were present, the majority of individuals were *Lumbriculus* sp., a member of the Lumbriculidae well known for rapid colonization. This represented the only occurrence of Lumbriculidae in the study.

It is clear that invertebrates are an important component of the ecosystem within greater Upper Klamath Lake. Their contribution to carbon processing and solute fluxes is likely dependent on their temporal distribution among habitats and their life histories. Invertebrates contribute to solute fluxes in two important ways. First, they can contribute both phosphorus and nitrogenous wastes through normal metabolic activity (Devine and Vanni, 2002). Second, through bioturbation, they can modify solute partitioning between the water column and sediment (Boudreau and Jorgensen, 2001). Consequently, diffusive-flux estimates mentioned above may be significantly enhanced by these two biologically driven processes (fig. 2).

Methods

The protocol described in this section focuses on method applications in the sampling of porewater for dissolved solutes in Upper Klamath Lake and adjacent wetland habitats.

A nonmetallic porewater profiler, designed for nutrient and trace-metal sampling (patent application 12/107,331; Kuwabara and others, 2009), was used for this study. In addition to water just above the sediment-water interface (approximately 1 cm), samplers collected interstitial water from five depths within the top 10 centimeters of the sediment, with fritted polypropylene probes at approximately 1, 2, 3.3, 5.5, and 10 cm depth, to characterize dissolved-solute vertical gradients using six independent sampling circuits. Each sampling circuit collected filtered (0.2 µm) water into 50-mL acid-washed, all-plastic syringes. After being lowered onto the sediment, the device was tripped mechanically to begin sample collection and then 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 closed with a valve, double-bagged in argon, and refrigerated in darkness for sample processing, splitting, and later chemical analyses.

Flux calculations, based on Fick's Law, assume that the process is diffusion controlled with solute-specific diffusion coefficients (Li and Gregory, 1974; Applin 1987; Rebreanu and others, 2008). Hence, the calculated benthic flux of dissolved solutes based on porewater profiles can be enhanced by bioturbation, bioirrigation, wind resuspension, and potential groundwater inflows (Kuwabara and others, 2009).

At each profiler-deployment site, dataloggers provided water-column profiles of ancillary parameters (pH, salinity, temperature, dissolved oxygen, and oxidation-reduction potential), monitored at 15-second intervals. Samples for determination of benthic chlorophyll were also obtained by subcoring replicate Ekman grab samples.

Sampling methods have been previously described (Kuwabara and others, 2003, 2009), but details are provided below. At each site, the following samples were collected, unless otherwise noted.

Biological Parameters

1. **Benthic chlorophyll-a.** At each profiler-deployment site, surficial sediment (that is, the top centimeter of bed material) was collected from a fresh Ekman grab and stored refrigerated in a plastic Petri dish within a sealed plastic bag. Each dish was subsampled in triplicate for benthic chlorophyll-*a.* The surficial sediment for each replicate (0.785 cm^2) was collected on a glass-fiber filter and buffered with 1 milliliter of a supersaturated magnesium carbonate suspension (10 g L^{-1}). Water was removed from the buffered samples by vacuum at less than 5 pounds per square inch (psi) 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).

2. **Benthic invertebrate sampling.** After water-column sampling was completed at each sampling site, three Ekman grabs (15×15 centimeter cross section by approximately 10 cm deep) were collected for macroinvertebrate taxonomic analyses. Samples were sieved in the field (500-micrometer mesh) and fixed with 10-percent buffered formalin. Samples were later transferred to 70-percent

ethanol. Invertebrates were sorted at 10× magnification and identified to the lowest practicable taxonomic level. Samples were stained with Rose Bengal to facilitate sorting and/or randomly subsampled when necessary.

Chemical Parameters

1. **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 were determined for dissolved (0.2-micron filtered) nitrate (EPA method 353.1), ammonia (EPA method 350.1), orthophosphate (SRP; EPA method 365.2), and silica (EPA method 370.1) by batch automated spectrophotometry (Aquakem 250, Thermo Scientific).

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 and filtered (0.7-micron baked glass-fiber filter) for analysis by high-temperature catalytic combustion (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 trace elements.** Water-column samples were collected in duplicate in 250-mL acid-washed high-density polyethylene bottles, filtered (0.2-µm polycarbonate membrane) using clean technique (Fitzwater and others, 1982), and acidified (pH 2) to provide dissolved trace-metal information for the saline waters by inductively coupled plasma mass spectrometry (ICP-MS; Topping and Kuwabara, 1999; Topping and Kuwabara, 2003). Porewater samples were filtered in-line and acidified before analysis.

Acknowledgments

The authors are grateful for critical logistical support from S. Vanderkooi and other personnel from the U.S. Geological Survey (USGS) Field Office in Klamath Falls, Oregon, and from the USGS Oregon Water Science Center. Participation in field studies by R. Carlson, D. Ciotti, A. Dolan-Caret, S. Foster, K. Kannarr, and M. Lindenberg was critical to its successful completion. We thank The Nature Conservancy for their cooperation and access to the newly-restored wetland sites. The Klamath Falls Office of the U.S. Bureau of Reclamation (Funding Agreement Number 06AA204159) and the USGS Toxic Substances Hydrology Program are also acknowledged for support of this ongoing work.

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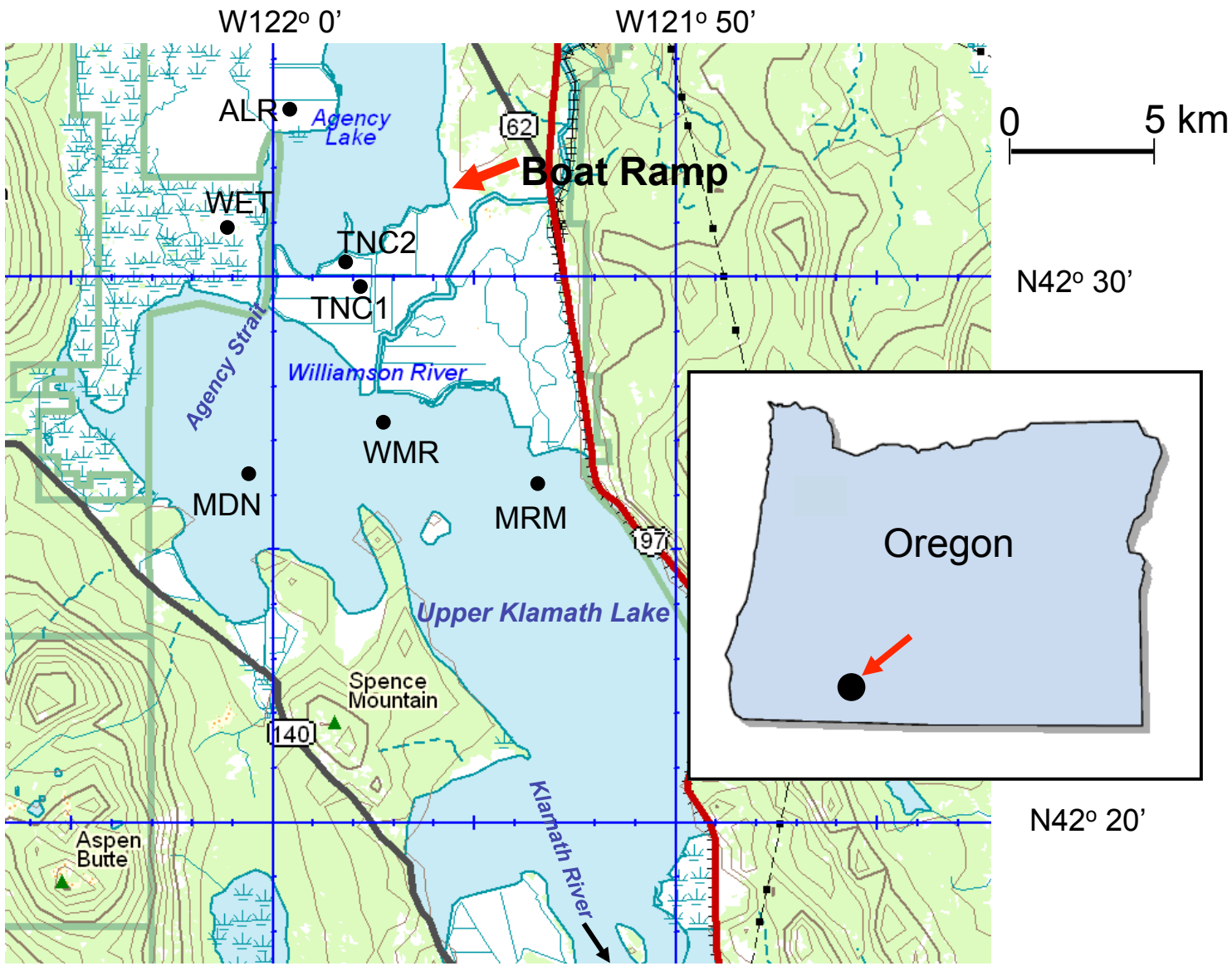
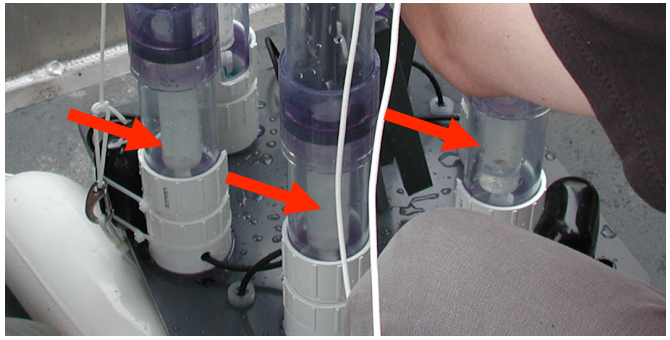


Figure 1. Lake and wetland sampling locations for this study.

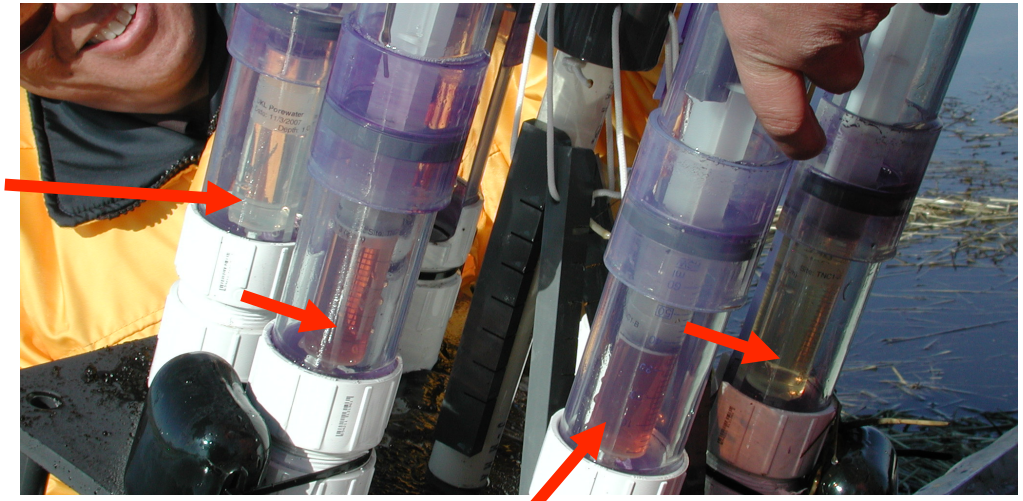
Figure 2. Diffusion models can underestimate benthic flux in productive ecosystems like Upper Klamath Lake because the fixed-boundary assumption is not met. Instead, this video depicts how bioturbation generates turbulent mixing at the boundary (that is, the sediment-water interface).

Filtered lake and refuge porewaters are all clear.



Filtered porewaters from restored wetlands after levee breaches are not.

Overlying water



Note color gradient with depth

Figure 3. Filtered porewaters from restored wetlands appear very different from lake and refuge porewaters (see table 8).

Table 1. Location of water-quality sites used in this study (see also Figure 1), including ranges for ancillary parameters*.

November 1, 2007 - Initial Wetland Sampling after levee breaches + Inlet Tributaries

Descriptive Site Names	Site Name Abbreviation	USGS Site identification number	Northing	Easting	North Latitude (degree/min/sec)	West Longitude (degree/min/sec)	North Latitude (degree/decimal min)	West Longitude (degree/decimal min)	Approximate Full-Pool Depth (m)	Parameter ranges for depth profiles during each deployment: Profile date	Max depth measured (m)	Specific Conductivity Range (mS cm^{-1})	Temperature Range (°C)	pH Range	Estimated wetted area (km^2)**	References	
Lake - near Modoc Rim	MRM	422437121515200	4695750	593431	42° 24' 37.3"	121° 51' 52.4"	42° 24.623'	121° 51.874'	3	11/1/07	1.4	0.11 - 0.11	6.6 - 6.7	7.8 - 7.9	200	Wood and others. 2006	MRM
										6/25/08	2.6	0.09 - 0.09	17.8 - 21.0	7.6 - 9.0		Gannett and others, 2007	
										5/26/09	2.9	0.10 - 0.10	17.6 - 17.8	7.1 - 7.7			
										7/28/09	1.9	0.10 - 0.10	23.0 - 23.2	6.4 - 7.8			
Lake - near Williamson River Outlet	WMR	422719121571400	4700676	586118	42° 27' 19.4"	121° 57' 13.6"	42° 27.323'	121° 57.227'	2	11/1/07	0.6	0.12 - 0.12	6.8 - 6.8	7.4 - 7.6			WMR
										6/25/08	1.7	0.09 - 0.09	18.6 - 21.2	9.4 - 9.5			
										5/26/09	2.1	0.10 - 0.11	18.5 - 18.6	7.8 - 8.2			
										7/28/09	1.1	0.10 - 0.11	24.4 - 24.5	8.0 - 8.5			
Lake - Mid-lake North	MDN	422622122004000	4698813	581334	42° 26' 21.5"	122° 0' 40.0"	42° 26.358'	122° 0.667'	4	5/26/09	3.9	0.10 - 0.11	17.3 - 18.1	7.7 - 8.1			MDN
										7/28/09	3.0	0.11 - 0.14	23.1 - 24.3	5.2 - 7.2			
National Wildlife Refuge (Established vegetated wetland)***	WET	-	4707345	581228	42° 30' 58.1"	122° 0' 40.3"	42° 30.969'	122° 0.671'	0.5	11/1/07	0.2	0.05 - 0.05	6.0 - 6.2	6.2 - 7.3	56	Snyder and Morace. 1997	WET
										6/25/08	0.2	0.04 - 0.04	16.9 - 16.9	6.3 - 6.3			
										5/26/09	0.6	0.07 - 0.08	15.2 - 16.5	4.9 - 5.3			
										7/28/09	0.3	0.10 - 0.10	22.7 - 22.8	5.6 - 5.8			
Newly Flooded Nature Conservancy Lands (away from breach)	TNC1	-	4705665	585571	42° 30' 1.98"	121° 57' 30.9"	42° 30.033'	121° 57.515'	2	11/1/07	0.4	0.05 - 0.05	7.2 - 7.3	6.7 - 7.3	13	Snyder and Morace. 1997	TNC1
										6/25/08	2.0	0.10 - 0.10	18.8 - 19.0	8.6 - 9.3			
										5/26/09	2.3	0.08 - 0.08	19.1 - 19.2	7.9 - 8.7			
										7/28/09	1.5	0.09 - 0.09	24.0 - 25.1	8.8 - 9.2			
Newly Flooded Nature Conservancy Lands (near breach)	TNC2	-	4707320	656463	42° 30' 15.7"	121° 57' 44.6"	42° 30.261'	121° 57.743'	2	11/1/07	0.3	0.05 - 0.05	7.2 - 7.3	6.5 - 7.2			TNC2
										5/26/09	2.2	0.08 - 0.09	17.6 - 18.5	6.5 - 8.1			
										7/28/09	1.7	0.09 - 0.10	23.0 - 25.0	7.9 - 9.1			
Agency Ranch Water Storage (Wetland)	ALR	-	4711467	582624	42° 33' 11.2"	121° 59' 37.0"	42° 33.187'	121° 59.617'	2	6/25/08	0.2	0.06 - 0.06	16.1 - 16.2	6.6 - 6.9	40	Congressional Research Service, 2005	ALR
Spring Creek	Spring	423837121524300	4710531	592079	42° 38' 37.0"	121° 52' 43.0"	42° 38.617'	121° 52.717'	0.5								
Sprague River	Sprg	11501000	4715128	594481	42° 35' 4.98"	121° 50' 55.0"	42° 35.083'	121° 50.917'	0.5								
Wood River	WoodT	11504100	4721762	582433	42° 38' 45.0"	121° 59' 40.0"	42° 38.750'	121° 59.667'	0.5								
Williamson River	WMT	11493500	4732419	595496	42° 44' 25.0"	121° 50' 0.0"	42° 44.417'	121° 50.000'	0.5								

* NAD 27 CONUS datum

** These areas were used to areally average the benthic-flux measurements at each lake or wetland site.

*** Coordinates are provided for the deploment location central to the refuge under high lake level conditons. As summer progresses and water levels decrease, access to this site decreases to the point where the November 2007 deployments were within 2 meters of the lake-wetland boundary.

Table 2. Summary of dissolved-macronutrient fluxes for Upper Klamath Lake and adjacent wetlands, Oregon.

[SD, standard deviation; n/a, not available; n/d, not detectable; reps, replicate sampler deployments]

1-Nov-07			Ortho-P				Nitrate				Ammonium			
Water-column temperature =	6.1 to 7.3 °C													
Site Location	Site Code	reps	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})
Lake - Modoc Rim	MRM	3	**0.67**	0.40	**133**	80	**-0.09**	0.06	**-18**	13	**4.93**	0.32	**987**	64
Lake - Williamson River Plume	WMR	3	**0.63**	0.52	**126**	104	**-0.21**	0.04	**-41**	9	**5.44**	0.48	**1,089**	97
Established Wetlands - NWR	WET	3	**0.35**	0.31	**19**	17	**0.02**	0.02	**1**	1	**0.58**	0.31	**33**	17
New wetland away from levy	TNC1	3	**4.23**	0.98	**55**	13	**-0.15**	0.05	**-2**	1	**-0.39**	0.28	**-5**	4
New wetland near levy	TNC2	3	**0.66**	0.46	**9**	6	**-0.04**	0.05	**-1**	1	**-0.96**	0.30	**-12**	4

25-Jun-08			Ortho-P				Nitrate				Ammonium				Silica			
Water-column temperature =	16.1 to 18.9 °C																	
Site Location	Site Code	reps	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})
Lake - Modoc Rim	MRM	3	**2.02**	1.48	**404**	296	**-0.27**	0.17	**-54**	33	**4.94**	0.77	**988**	154	**31.7**	n/a	**6,337**	n/a
Lake - Williamson River Plume	WMR	3	**2.59**	1.43	**518**	285	**-0.17**	0.07	**-35**	15	**8.92**	2.66	**1,783**	531	**n/a**	n/a	n/a	n/a
Established Wetlands - NWR	WET	3	**0.55**	0.42	**31**	24	**0.01**	0.03	**1**	2	**1.38**	0.21	**77**	12	**6.65**	5.79	**372**	324
New wetland away from levy	TNC1	3	**7.39**	0.02	**96**	0	**0.16**	0.02	**2**	0	**7.98**	0.34	**104**	4	**874.15**	n/a	**11,364**	n/a
Managed water storage	ALR	3	**0.57**	0.18	**23**	7	**0.00**	0.00	**0**	0	**1.29**	0.72	**52**	29	**10.82**	3.90	**433**	156

28-May-09			Ortho-P				Nitrate				Ammonium				Silica			
Water-column temperature =	15.2 to 19.1 °C																	
Site Location	Site Code	reps	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})
Lake - Modoc Rim	MRM	2	**1.82**	1.76	**364**	352	**n/d**	n/d	**n/d**	n/d	**9.30**	0.49	**1,859**	98	**109.5**	17.6	**21,901**	3,515
Lake - Williamson River Plume	WMR	2	**17.91**	1.37	**3,581**	275	**n/d**	n/d	**n/d**	n/d	**11.26**	3.26	**2,252**	652	**269.9**	72.0	**53,981**	14,393
Lake - Mid-Lake North	MDN	1	**1.26**		**252**	78	**n/d**	n/d	**n/d**	n/d	**7.25**	n/a	**1,450**	n/a	**63.8**	Only 1 profile	**12,770**	Only 1 profile
Established Wetlands - NWR	WET	3	**-0.19**	0.91	**-11**	51	**n/d**	n/d	**n/d**	n/d	**n/d**	n/d	**n/d**	n/d	**6.59**	2.35	**369**	132
New wetland away from levy	TNC1	3	**74.50**	48.15	**968**	626	**n/d**	n/d	**n/d**	n/d	**1.65**	0.85	**92**	48	**298.01**	47.38	**3,874**	616
New wetland near levy	TNC2	3	**2.71**	1.00	**35**	13	**n/d**	n/d	**n/d**	n/d	**6.78**	1.89	**88**	25	**198.73**	168.57	**2,584**	2,191

29-Jul-09			Ortho-P				Nitrate				Ammonium				Silica			
	23.0 to 24.5 °C																	
Site Location	Site Code	reps	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})	Site Average (mg-m $^{-2}$-day^{-1})	Site SD (mg-m $^{-2}$-day^{-1})	Site Average (kg-d^{-1})	Site SD (kg-d^{-1})
Lake - Modoc Rim	MRM	2	**1.60**	1.21	**321**	243	**-21.04**	12.25	**-4,209**	2450	**15.57**	3.17	**3,115**	633	**16.1**	0.6	**3,226**	127
Lake - Williamson River Plume	WMR	2	**4.32**	1.49	**863**	298	**-14.06**	1.79	**-2,812**	358	**28.51**	16.61	**5,703**	3,323	**277.7**	57.6	**55,536**	11,526
Lake - Mid-Lake North	MDN	2	**0.98**	2.20	**195**	440	**n/d**	n/d	**n/d**	n/d	**34.59**	4.16	**6,919**	832	**115.3**	64.2	**23,058**	12,840
Established Wetlands - NWR	WET	3	**44.82**	16.57	**2,510**	928	**n/d**	n/d	**n/d**	n/d	**305.72**	38.07	**17,120**	2,132	**203.28**	22.25	**11,384**	1,246
New wetland away from levy	TNC1	3	**5.06**	2.16	**66**	28	**n/d**	n/d	**n/d**	n/d	**16.07**	14.03	**209**	182	**-15.21**	164.89	**-198**	2,144
New wetland near levy	TNC2	3	**2.76**	0.93	**36**	12	**n/d**	n/d	**n/d**	n/d	**7.18**	2.06	**93**	27	**26.21**	6.11	**341**	79

Table 3. Dissolved-nutrient concentrations in the water column at profiler deployment sites (in ppm or milligrams per liter).
[SD, standard deviation; na, not available; 2 replicate samples collected]

		Ortho-P (mg-P)-L^{-1}	SD	NO_3+NO_2 (mg-N)-L^{-1}	SD	NH4 (mg-N)-L^{-1}	SD	Si (mg-Si)-L^{-1}	SD	N:P **molar** ratio
MRM	**1-Nov-07**	**<0.03**	na	**0.16**	0.01	**0.15**	0.01	na	na	na
	25-Jun-08	**<0.03**	na	**<0.03**	na	**<0.05**		na	na	na
	26-May-09	**0.05**	0.01	**<0.03**	na	**0.15**	0.01	**10.1**	0.1	**6.3**
	28-Jul-09	**0.12**	0.01	**0.12**	0.01	**0.36**	0.01	**32.4**	0.2	**8.7**
WMR	**1-Nov-07**	**<0.03**	na	**0.14**	0.01	**1.07**	0.53	**46.0**	1.6	na
	25-Jun-08	**<0.03**	na	**<0.03**	na	**<0.05**	na	na	na	na
	26-May-09	**0.06**	0.01	**<0.03**	na	**<0.05**	na	**10.4**	0.1	na
	28-Jul-09	**0.14**	0.01	**0.08**	0.01	**0.45**	0.02	**32.2**	0.2	**8.7**
MDN	**26-May-09**	**<0.03**	na	**<0.03**	na	**0.13**	0.02	**6.7**	0.0	na
	28-Jul-09	**0.15**	0.01	**0.06**	0.04	**1.39**	0.02	**31.4**	0.1	**21.5**
WET	**1-Nov-07**	**<0.03**	na	**0.18**	0.01	**0.08**	0.01	**38.1**	0.2	na
	25-Jun-08	**0.03**	0.01	**<0.03**	na	**<0.05**	na	**21.1**	0.3	na
	26-May-09	**0.08**	0.04	**<0.03**	na	**<0.05**	na	**19.1**	0.6	na
	28-Jul-09	**0.15**	0.02	**<0.03**	na	**0.61**	0.02	**31.4**	0.3	**9.1**
TNC1	**1-Nov-07**	**<0.03**		**0.16**	0.01	**0.11**	0.08	**34.0**	0.0	na
	25-Jun-08	**0.08**	0.01	**<0.03**	na	**<0.05**	na	**27.0**	0.4	na
	26-May-09	**0.08**	0.02	**<0.03**		**0.30**	0.26	**20.7**	0.1	**7.9**
	28-Jul-09	**0.21**	0.03	**0.06**	0.04	**0.15**	0.01	**39.7**	0.7	**1.6**
TNC2	**1-Nov-07**	**<0.03**	na	**0.16**	0.01	**0.39**	0.47	na	na	na
	26-May-09	**0.08**	0.01	**<0.03**	na	**<0.05**	na	**18.4**	0.1	na
	28-Jul-09	**0.20**	0.01	**<0.03**	na	**0.14**	0.02	**40.0**	0.7	**1.6**
ALR	**25-Jun-08**	**0.03**	0.01	**<0.03**	na	**0.04**	0.02	**16.6**	0.0	**2.8**
										7.6 **= average**
										6.1 = SD

Table 4. Dissolved organic carbon (DOC) concentrations (in units of both micromolar and milligrams carbon per liter) in the water-column at profiler deployment sites.
[95% ci, 95-percent confidence interval]

		Sampling Replicate	DOC (uM)	95% ci	DOC (mg-C-L^{-1})	95% ci
MRM	**1-Nov-07**	A	**467**	22	**5.6**	0.3
		B	**460**	21	**5.5**	0.3
	25-Jun-08	A	**473**	4	**5.7**	0.1
		B	**436**	4	**5.2**	0.0
	26-May-09	A	**440**	4	**5.3**	0.0
		B	**417**	5	**5.0**	0.1
	28-Jul-09	A	**530**	8	**6.4**	0.1
		B	**516**	9	**6.2**	0.1
WMR	**1-Nov-07**	A	**518**	14	**6.2**	0.2
		B	**507**	7	**6.1**	0.1
	25-Jun-08	A	**473**	1	**5.7**	0.0
		B	**444**	1	**5.3**	0.0
	26-May-09	A	**446**	6	**5.4**	0.1
		no rep				
	28-Jul-09	A	**544**	4	**6.5**	0.0
		B	**563**	4	**6.8**	0.0
MDN	**26-May-09**	A	**412**	8	**4.9**	0.1
		no rep				
	28-Jul-09	A	**571**	7	**6.8**	0.1
		B	**570**	8	**6.8**	0.1
WET	**1-Nov-07**	A	**479**	15	**5.8**	0.2
		B	**476**	14	**5.7**	0.2
	25-Jun-08	A	**1,268**	1	**15.2**	0.0
		B	**1,258**	7	**15.1**	0.1
	26-May-09	A	**807**	10	**9.7**	0.1
		B	**814**	7	**9.8**	0.1
	28-Jul-09	A	**883**	2	**10.6**	0.0
		B	**894**	14	**10.7**	0.2
TNC1	**1-Nov-07**	A	**307**	5	**3.7**	0.1
		B	**293**	10	**3.5**	0.1
	25-Jun-08	A	**642**	0	**7.7**	0.0
		B	**615**	12	**7.4**	0.1
	26-May-09	A	**476**	3	**5.7**	0.0
		B	**481**	10	**5.8**	0.1
	28-Jul-09	A	**599**	23	**7.2**	0.3
		B	**563**	5	**6.8**	0.1
TNC2	**1-Nov-07**	A	**287**	2	**3.4**	0.0
		B	**291**	11	**3.5**	0.1
	26-May-09	A	**464**	5	**5.6**	0.1
		B	**479**	7	**5.7**	0.1
	28-Jul-09	A	**506**	6	**6.1**	0.1
		B	**499**	7	**6.0**	0.1
ALR	**25-Jun-08**	A	**715**	13	**26.7**	0.0
		B	**745**	11	**26.0**	0.4

Table 5. Diffusive flux of dissolved trace elements in Upper Klamath Lake and adiacent wetlands, Oregon.

[reps, replicate sampler deployments]

[Dissolved-zinc fluxes were also determined but not tabulated because they were consistently below detection limits (that is, concentration gradients for dissolved zinc were not observed)]

1-Nov-07			Dissolved Iron				Dissolved Manganese				Dissolved Copper			
Water-column temperature =	6.1 to 7.3 °C													
Site Location	Site Code	reps	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 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 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 ($kg\text{-}d^{-1}$)
Lake - Modoc Rim	MRM	3	**1.49**	0.13	**297**	27	**1.14**	0.45	**229**	91	**0.00**	0.00	**0**	0
Lake - Williamson River Plume	WMR	3	**5.07**	3.64	**1,013**	727	**0.96**	0.35	**193**	71	**0.00**	0.00	**0**	0
Established Wetlands - NWR	WET	3	**0.25**	0.12	**14**	7	**-0.02**	0.06	**-1**	3	**-0.14**	0.24	**-8**	14
New wetland away from levee	TNC1	3	**7.47**	1.62	**97**	21	**2.63**	0.57	**34**	7	**1.81**	0.73	**23**	9
New wetland near levee	TNC2	3	**1.96**	1.43	**26**	19	**1.76**	0.83	**23**	11	**0.26**	0.07	**3**	1

25-Jun-08			Dissolved Iron				Dissolved Manganese				Dissolved Copper			
Water-column temperature =	16.1 to 18.9 °C													
Site Location	Site Code	reps	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 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 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 ($kg\text{-}d^{-1}$)
Lake - Modoc Rim	MRM	3	**6.11**	4.58	**1,223**	917	**0.73**	0.53	**145**	106	**0.00**	0.00	**-1**	1
Lake - Williamson River Plume	WMR	3	**8.32**	6.90	**1,665**	1,380	**2.67**	1.09	**534**	217	**0.00**	0.00	**-1**	1
Established Wetlands - NWR	WET	3	**-0.03**	0.05	**-1**	3	**0.04**	0.08	**2**	5	**0.00**	0.00	**0**	0
New wetland away from levee	TNC1	3	**5.29**	2.77	**69**	36	**0.31**	0.22	**4**	3	**0.00**	0.00	**0**	0
Managed water storage	ALR	3	**1.24**	0.65	**49**	26	**0.21**	0.15	**8**	6	**0.00**	0.00	**0**	0

28-May-09			Dissolved Iron				Dissolved Manganese				Dissolved Copper			
Water-column temperature =	15.2 to 19.1 °C													
Site Location	Site Code	reps	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 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 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 ($kg\text{-}d^{-1}$)
Lake - Modoc Rim	MRM	2	**3.98**	0.10	**797**	20	**0.68**	0.59	**136**	118	**0.00**	0.00	**0**	0
Lake - Williamson River Plume	WMR	2	**13.69**	12.00	**2,738**	2,399	**2.02**	2.26	**405**	452	**0.00**	0.00	**0**	0
Lake - Mid-Lake North	MDN	1	**1.73**	1.98	**347**	396	**0.28**	0.34	**55**	68	**0.00**	0.00	**0**	0
Established Wetlands - NWR	WET	3	**-0.08**	0.12	**-4**	6	**0.20**	0.15	**11**	8	**0.00**	0.00	**0**	0
New wetland away from levee	TNC1	3	**12.30**	4.19	**160**	54	**5.82**	0.73	**76**	10	**0.00**	0.00	**0**	0
New wetland near levee	TNC2	3	**60.68**	75.78	**789**	985	**0.96**	0.54	**12**	7	**0.00**	0.00	**0**	0

29-Jul-09			Dissolved Iron				Dissolved Manganese				Dissolved Copper			
Water-column temperature =	23.0 to 24.5 °C													
Site Location	Site Code	reps	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 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 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 ($kg\text{-}d^{-1}$)
Lake - Modoc Rim	MRM	2	**3.41**	1.57	**681**	315	**2.70**	1.36	**540**	272	**0.00**	0.00	**-1**	0
Lake - Williamson River Plume	WMR	2	**8.34**	7.21	**1,669**	1,443	**8.78**	4.91	**1,756**	983	**0.00**	0.00	**-1**	0
Lake - Mid-Lake North	MDN	2	**2.34**	2.36	**468**	472	**0.19**	0.19	**39**	37	**0.00**	0.00	**0**	0
Established Wetlands - NWR	WET	3	**11.68**	1.10	**654**	282	**0.71**	0.08	**40**	19	**0.00**	0.00	**0**	0
New wetland away from levee	TNC1	3	**7.93**	9.47	**103**	123	**1.14**	1.12	**15**	15	**0.00**	0.00	**0**	0
New wetland near levee	TNC2	3	**3.92**	0.67	**51**	9	**0.32**	0.09	**4**	1	**0.00**	0.00	**0**	0

average Fe flux in mg/m2/day:	**7.6**	**1.6**	**0.1**
ug/L of Fe per day distributed to entire water column:	**2.7**	**0.6**	**0.0**

Table 6. Riverine flux estimates for dissolved nutrients into Upper Klamath Lake, Oregon.
[95% ci, confidence interval (95th percentile)]

Nov 3, 2007

	Replicate	DOC (mg-L^{-1})	95%ci	DOC (uM)	95%ci	Iron (Fe) (ug-L^{-1})	95%ci	Manganese (Mn) (ug-L^{-1})	95%ci	Copper (Cu) (ug-L^{-1})	95%ci	SRP (ug-L-1)	Diss. Silica mg-L-1 as SiO2	NWIS Station No.	Discharge (ft^3-s^{-1})	Discharge (L-d^{-1})	DOC (kg-d^{-1})	Site averaged DOC (kg-d^{-1})	SRP (kg-d^{-1})	Site averaged SRP (kg-d^{-1})	Silica (kg-d^{-1})	Site averaged Silica (kg-d^{-1})	Fe Load (kg-d^{-1})	Site averaged Fe Load (kg-d^{-1})	Mn Load (kg-d^{-1})	Site averaged Mn Load (kg-d^{-1})	Cu Load (kg-d^{-1})	Site averaged Cu Load (kg-d^{-1})
Spring Creek	A	**0.7**	0.2	**54**	19	**11**	1	**0.3**	0.1	**0.048**	0.001	84	n/a	11494201	280	6.85E+08	446	378	57	60	n/a		7	7	0.2	0.2	0.000	0.000
	B	**0.5**	0.2	**38**	17	**9**	1	**0.4**	0.1	**0.051**	0.002	91			280	6.85E+08	311		63				6		0.3		0.000	
Sprague River	A	**2.0**	0.1	**169**	12	**97**	1	**5.3**	0.1	**0.368**	0.003	42	n/a	11501000	304	7.44E+08	1,506	1431	31	36	n/a		72	70	3.9	3.8	0.000	0.000
	B	**1.8**	0.2	**152**	16	**92**	1	**5.0**	0.1	**0.354**	0.001	56			304	7.44E+08	1,356		41				69		3.7		0.000	
Wood River	A	**1.5**	0.3	**127**	23	**87**	1	**7.0**	0.1	**0.167**	0.001	69	n/a	11504100	150	3.67E+08	561	472	25	26	n/a		32	31	2.6	2.5	0.000	0.000
	B	**1.0**	0.2	**87**	20	**82**	1	**6.7**	0.1	**0.159**	0.002	70			150	3.67E+08	382		26				30		2.5		0.000	
Williamson River	No discharge													11493500														
														Estimated riverine flux (kg-d^{-1}) =				**2281**		**122**				**108**		**7**		**0**

= Estimated riverine flux (kg-d^{-1})

Correlation Matrix

	DOC	Fe	Mn	Cu	OrthoP
DOC	1				
Fe	0.91	1			
Mn	0.72	0.93	1		
Cu	0.95	0.84	0.60	1	
Ortho P	-0.96	-0.87	-0.66	-0.96	1

Jun 25, 2008

	Replicate	DOC (mg-L^{-1})	95%ci	DOC (uM)	95%ci	Iron (Fe) (ug-L^{-1})	95%ci	Manganese (Mn) (ug-L^{-1})	95%ci	Copper (Cu) (ug-L^{-1})	95%ci	Ortho P (ug-L^{-1})	Diss. Silica mg-L^{-1} as SiO2	NWIS Station No.	Discharge (ft^3-s^{-1})	Discharge (L-d^{-1})	DOC (kg-d^{-1})	Site averaged DOC (kg-d^{-1})	SRP (kg-d^{-1})	Site averaged SRP (kg-d^{-1})	Silica (kg-d^{-1})	Site averaged Silica (kg-d^{-1})	Fe Load (kg-d^{-1})	Site averaged Fe Load (kg-d^{-1})	Mn Load (kg-d^{-1})	Site averaged Mn Load (kg-d^{-1})	Cu Load (kg-d^{-1})	Site averaged Cu Load (kg-d^{-1})
Spring Creek	A	**0.4**	0.1	**32**	8	**< 5**		**< 0.2**		**0.044**	0.004	93	n/a	11494201	293	7.17E+08	277	301	67	67	n/a		4	4	0.1	0.1	0.032	0.031
	B	**0.5**	0.1	**38**	8	**< 5**		**< 0.2**		**0.043**	0.005	94			293	7.17E+08	324		67				4		0.1		0.031	
Sprague River	A	**3.7**	0.1	**306**	8	**144**	1	**1.0**	0.1	**0.692**	0.011	44	n/a	11501000	408	9.98E+08	3,665	3747	44	44	n/a		144	141	1.0	1.0	0.690	0.688
	B	**3.8**	0.1	**320**	8	**137**	1	**1.1**	0.1	**0.687**	0.017	44			408	9.98E+08	3,828		44				137		1.1		0.686	
Wood River	A	**1.2**	0.1	**103**	8	**114**	1	**6.8**	0.1	**0.250**	0.006	74	n/a	11504100	164	4.01E+08	494	457	30	30	n/a		46	45	2.7	2.7	0.100	0.099
	B	**1.0**	0.1	**87**	8	**111**	1	**6.6**	0.1	**0.246**	0.009	75			164	4.01E+08	420		30				44		2.6		0.099	
Williamson River	A	**25.9**	0.2	**2159**	13	**421**	2	**2.1**	0.1	**0.483**	0.053	20	n/a	11493500	21	5.14E+07	1,331	1398	1	1	n/a		22	21	0.1	0.1	0.025	0.024
	B	**28.5**	0.1	**2375**	11	**413**	4	**1.7**	0.1	**0.457**	0.023	19			21	5.14E+07	1,464		1				21		0.1		0.023	
														Estimated riverine flux (kg-d^{-1}) =				**5902**		**142**				**211**		**4**		**1**

= Estimated riverine flux (kg-d^{-1})

Correlation Matrix

	DOC	Fe	Mn	Cu	Ortho P
DOC	1				
Fe	0.96	1			
Mn	-0.18	0.01	1		
Cu	0.36	0.52	-0.09	1	
Ortho P	-0.84	-0.92	0.11	-0.80	1

May 26, 2009

	Replicate	DOC (mg-L^{-1})	95%ci	DOC (uM)	95%ci	Iron (Fe) (ug-L^{-1})	95%ci	Manganese (Mn) (ug-L^{-1})	95%ci	Copper (Cu) (ug-L-1)	95%ci	Ortho P (ug-L^{-1})	Diss. Silica mg-L^{-1} as SiO2	NWIS Station No.	Discharge (ft^3-s^{-1})	Discharge (L-d^{-1})	DOC (kg-d^{-1})	Site averaged DOC (kg-d^{-1})	SRP (kg-d^{-1})	Site averaged SRP (kg-d^{-1})	Silica (kg-d^{-1})	Site averaged Silica (kg-d^{-1})	Fe Load (kg-d^{-1})	Site averaged Fe Load (kg-d^{-1})	Mn Load (kg-d^{-1})	Site averaged Mn Load (kg-d^{-1})	Cu Load (kg-d^{-1})	Site averaged Cu Load (kg-d^{-1})
Spring Creek	A	**0.6**	0.1	**49**	4	**< 5**		**< 0.2**		**0.079**	0.001	159	46	11494201	293	7.17E+08	419	476	114	115	32,932	33,313	4	4	0.1	0.1	0.056	0.047
	B	**0.7**	0.1	**62**	4	**< 5**		**< 0.2**		**0.051**	0.000	164	47		293	7.17E+08	532		117		33,694		4		0.1		0.037	
Sprague River	A	**4.4**	0.1	**363**	5	**148**	2	**8.2**	0.1	**0.684**	0.005	155	35	11501000	545	1.33E+09	5,814	5460	207	226	47,305	47,496	197	199	11.0	10.9	0.912	0.911
	B	**3.8**	0.1	**319**	6	**151**	1	**8.1**	0.1	**0.682**	0.003	184	36		545	1.33E+09	5,106		245		47,688		202		10.8		0.909	
Wood River	A	**0.7**	0.1	**62**	8	**96**	1	**6.6**	0.1	**0.176**	0.005	182	43	11504100	164	4.01E+08	298	298	73	70	17,257	17,291	39	39	2.7	2.6	0.071	0.072
	B	**0.7**	0.1	**62**	8	**97**	1	**6.5**	0.1	**0.181**	0.004	168	43		164	4.01E+08	297		67		17,324		39		2.6		0.073	
Williamson River	A	**37.8**	0.6	**3153**	48	**518**	11	**21.2**	0.1	**0.549**	0.013	155	23	11493500	43	1.05E+08	3,980	4014	16	13	2,433	2,518	54	54	2.2	2.2	0.058	0.057
	B	**38.5**	0.3	**3206**	27	**513**	4	**21.4**	0.2	**0.525**	0.016	99	25		43	1.05E+08	4,047		10		2,603		54		2.3		0.055	
														Estimated riverine flux (ko-d^{-1}) =				**10247**		**425**				**296**		**16**		**1**

= Estimated riverine flux (ko-d^{-1})

Correlation Matrix

	DOC	Fe	Mn	Cu	Ortho P	Silica
DOC	1					
Fe	0.98	1				
Mn	0.94	0.99	1			
Cu	0.47	0.59	0.64	1		
Ortho P	-0.73	-0.66	-0.62	-0.23	1	
Silica	-0.92	-0.97	-0.97	-0.77	0.59	1

Jul 28, 2009

	Replicate	DOC (mg-L^{-1})	95%ci	DOC (uM)	95%ci	Iron (Fe) (ug-L^{-1})	95%ci	Manganese (Mn) (ug-L^{-1})	95%ci	Copper (Cu) (ug-L^{-1})	95%ci	Ortho P (ug-L^{-1})	Diss. Silica mg-L^{-1} as SiO2	NWIS Station No.	Discharge (ft^3-s^{-1})	Discharge (L-d^{-1})	DOC (kg-d^{-1})	Site averaged DOC (kg-d^{-1})	SRP (kg-d^{-1})	Site averaged SRP (kg-d^{-1})	Silica (kg-d^{-1})	Site averaged Silica (kg-d^{-1})	Fe Load (kg-d^{-1})	Site averaged Fe Load (kg-d^{-1})	Mn Load (kg-d^{-1})	Site averaged Mn Load (kg-d^{-1})	Cu Load (kg-d^{-1})	Site averaged Cu Load (kg-d^{-1})
Spring Creek	A	**0.6**	0.1	**52**	6	**< 5**		**< 0.2**		**0.016**	0.002	181	46	11494201	280	6.85E+08	426	396	124	115	31,232	31,119	3	3	0.1	0.1	0.011	0.010
	B	**0.5**	0.1	**44**	8	**< 5**		**< 0.2**		**0.014**	0.003	156	45		280	6.85E+08	365		107		31,006		3		0.1		0.010	
Sprague River	A	**2.4**	0.1	**197**	8	**118**	1	**16.8**	0.2	**0.880**	0.013	80	30	11501000	119	2.91E+08	689	702	23	23	8,703	8,605	34	34	5	5	0.256	0.251
	B	**2.5**	0.1	**204**	5	**114**	1	**17.3**	0.2	**0.843**	0.005	79	29		119	2.91E+08	714		23		8,506		33		5		0.245	
Wood River	A	**1.1**	0.1	**94**	8	**99**	2	**10.0**	0.1	**0.175**	0.004	88	44	11504100	150	3.67E+08	414	417	32	39	16,239	16,261	36	37	4	4	0.064	0.065
	B	**1.1**	0.1	**95**	8	**101**	2	**10.1**	0.1	**0.178**	0.007	124	44		150	3.67E+08	420		46		16,283		37		4		0.065	
Williamson River	**No discharge**													11493500					0	0	0	0						
														Estimated riverine flux (kg-d^{-1}) =				**1514**		**178**				**74**		**9**		**0**

= Estimated riverine flux (kg-d^{-1})

Correlation Matrix

	DOC	Fe	Mn	Cu	Ortho P	Silica
DOC	1					
Fe	0.82	1				
Mn	0.95	0.96	1			
Cu	0.99	0.74	0.90	1		
Ortho P	-0.84	-0.93	-0.94	-0.79	1	
Silica	-0.97	-0.66	-0.85	-0.99	0.73	1

Table 7. Density (individuals m^{-2}) of benthic invertebrates collected at profiler deployment sites.
[SD, standard deviation; n, replicate samples]

		Total			Oligochaetes			Chironomids			Leeches		
Date	Site	Density	n	SD	Density	n	SD	Density	n	SD	Density	n	SD
3-Nov-2007	MRM	15,956	1	0	1,689	1	0	12,133	1	0	622	1	0
	WMR	10,178	1	0	1,807	1	0	5,363	1	0	385	1	0
	WET	27,733	1	0	25,822	1	0	1,111	1	0	133	1	0
	TNC1	178	1	0	163	1	0	0	1	0	0	1	0
	TNC2	993	3	673	919	3	607	15	3	26	0	3	0
25-Jun-2008	MRM	2,978	1	0	756	1	0	978	1	0	933	1	0
	WMR	3,511	5	1,308	1,760	5	602	1,067	5	682	649	5	168
	WET	844	1	0	326	1	0	15	1	0	0	1	0
	TNC1	1,719	3	245	163	3	168	1,556	3	89	0	3	0
	ALR	889	1	0	859	1	0	30	1	0	0	1	0
27-May-2009	MRM	3,970	1	0	1,333	1	0	919	1	0	267	1	0
	WMR	6,030	1	0	2,533	1	0	2,741	1	0	370	1	0
	MDN	8,385	1	0	7,763	1	0	0	1	0	622	1	0
	WET	28,563	1	0	26,133	1	0	830	1	0	504	1	0
	TNC1	6,800	3	2,883	4,385	3	2,066	2,326	3	845	0	3	0
	TNC2	4,207	1	0	504	1	0	3,230	1	0	59	1	0
28-Jul-2009	MRM	5,793	1	0	1,837	1	0	356	1	0	1,748	1	0
	WMR	5,111	1	0	726	1	0	133	1	0	4,148	1	0
	MDN	9,170	1	0	7,437	1	0	0	1	0	1,704	1	0
	WET	16,741	1	0	6,119	1	0	9,185	1	0	607	1	0
	TNC1	32,519	3	4,925	8,904	3	1,146	20,341	3	4,512	415	3	566
	TNC2	26,044	1	0	5,378	1	0	11,956	1	0	3,822	1	0

Table 8. Diffusive flux of dissolved organic carbon (DOC) in Upper Klamath Lake and adjacent wetlands, Oregon.

Site name		11/3/07 Site Average (mg-m^{-2}-day^{-1})	11/3/07 Site StDev (mg-m^{-2}-day^{-1})	11/3/07 Site Average (kg/day)	11/3/07 Site StDev (kg/day)	6/25/08 Site Average (mg-m^{-2}-day^{-1})	6/25/08 Site StDev (mg-m^{-2}-day^{-1})	6/25/08 Site Average (kg/day)	6/25/08 Site StDev (kg/day)	5/28/09 Site Average (mg-m^{-2}-day^{-1})	5/28/09 Site StDev (mg-m^{-2}-day^{-1})	5/28/09 Site Average (kg/day)	5/28/09 Site StDev (kg/day)	7/29/09 Site Average (mg-m^{-2}-day^{-1})	7/29/09 Site StDev (mg-m^{-2}-day^{-1})	7/29/09 Site Average (kg/day)	7/29/09 Site StDev (kg/day)
Lake - Modoc Rim	MRM	**-2.33**	2.86	**-466**	571	**-3.60**	4.18	**-720**	836	**-2.43**	2.92	**-486**	584	**-8.37**	5.23	**-1,675**	1,047
Lake - Williamson River Plume	WMR	**-4.24**	4.64	**-849**	927	**8.99**	4.85	**1,799**	970	**3.21**	2.80	**643**	560	**-10.10**	5.75	**-2,021**	1,150
Lake - Mid-Lake North	MDN									**1.14**	1.08	**227**	216	**-3.23**	2.23	**-647**	446
Established Wetlands - NWR	WET	**4.68**	5.77	**262**	323	**6.91**	4.34	**387**	243	**0.87**	5.23	**49**	293	**45.87**	36.31	**2,569**	2,034
Newly flooded wetland	TNC1	**711.99**	498.34	**9,256**	6478	**31.05**	30.80	**404**	400	**66.76**	28.76	**868**	374	**55.38**	54.95	**720**	714
Newly flooded wetland	TNC2	**105.24**	16.22	**1,368**	211					**217.17**	14.31	**2,823**	186	**-11.83**	9.41	**-154**	122
Managed water storage	ALR					**0.37**	7.63	**15**	305								
Water-column temps				**6.1**	**7.3**			**16.1**	**18.9**			**15.2**	**19.1**			**23.0**	**24.5**
				Low (˚C)	**High (˚C)**			**Low (˚C)**	**High (˚C)**			**Low (˚C)**	**High (˚C)**			**Low (˚C)**	**High (˚C)**

Table 9. Dissolved trace metal concentrations (in ppb or micrograms per liter) in the water-column of Upper Klamath Lake and adjacent wetlands, Oregon.

	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	
MRM	1-Nov-07	A	0.422	0.003	0.002	0.001	<DL		0.356	0.020	<DL		0.006	0.001	2.5	0.02	0.066	0.001	MRM
		B	Rep B appeared contaminated																
	25-Jun-08	A	0.554	0.008	0.003	0.002	<DL		0.313	0.022	17	1	0.043	0.003	0.5	0.05	0.063	0.001	
		B	0.541	0.012	<DL		<DL		0.459	0.086	18	1	0.040	0.002	0.6	0.05	0.067	0.002	
	26-May-09	A	0.380	0.009	<DL		<DL		0.210	0.002	24	1	0.015	0.001	1.7	0.02	0.029	0.001	
		B	0.402	0.008	<DL		<DL		0.210	0.006	24	1	0.014	0.001	2.1	0.02	0.029	0.002	
	28-Jul-09	A	0.470	0.002	<DL		<DL		0.390	0.022	10	1	0.004	0.001	10.8	0.46	0.078	0.003	
		B	0.407	0.006	<DL		<DL		0.450	0.019	31	1	0.009	0.001	11.5	0.40	0.074	0.001	
WMR	1-Nov-07	A	0.423	0.005	0.003	0.001	<DL		0.464	0.017	31	1	0.020	0.001	11.2	0.03	0.088	0.001	WMR
		B	0.406	0.007	0.005	0.001	<DL		0.424	0.011	<DL		0.007	0.001	10.1	0.07	0.085	0.001	
	25-Jun-08	A	0.494	0.006	<DL		<DL		0.318	0.022	17	1	0.033	0.001	0.5	0.03	0.069	0.001	
		B	0.510	0.010	<DL		<DL		0.414	0.082	21	1	0.044	0.002	1.1	0.06	0.074	0.002	
	26-May-09	A	0.338	0.005	<DL		<DL		0.199	0.011	27	1	0.003	0.001	2.3	0.02	0.037	0.002	
		B	0.330	0.002	<DL		<DL		0.150	0.004	28	1	0.003	0.001	2.6	0.03	0.037	0.001	
	28-Jul-09	A	0.328	0.003	<DL		<DL		0.326	0.007	32	1	<DL		39.3	1.01	0.086	0.002	
		B	0.305	0.006	<DL		<DL		0.309	0.011	12	1	<DL		36.4	1.35	0.083	0.002	
MDN	26-May-09	A	0.346	0.001	<DL		<DL		0.247	0.021	26	1	<DL		<DL		0.026	0.001	MDN
		B	0.355	0.008	<DL		<DL		0.342	0.021	24	1	<DL		<DL		0.027	0.001	
	28-Jul-09	A	0.292	0.008	<DL		<DL		0.343	0.011	15	1	<DL		59.6	0.19	0.081	0.002	
		B	0.271	0.012	<DL		<DL		0.334	0.017	14	1	<DL		42.6	0.71	0.075	0.002	
WET	1-Nov-07	A	0.372	0.010	0.002	0.001	<DL		0.287	0.022	12	1	0.010	0.001	3.7	0.01	0.066	0.002	WET
		B	0.395	0.006	0.003	0.001	<DL		0.337	0.014	45	1	0.029	0.001	4.5	0.04	0.070	0.002	
	25-Jun-08	A	0.064	0.010	<DL		<DL		0.202	0.154	22	1	<DL		0.2	0.01	0.022	0.001	
		B	0.035	0.009	<DL		<DL		0.037	0.022	30	1	<DL		0.2	0.00	0.024	0.003	
	26-May-09	A	0.054	0.002	<DL		<DL		0.067	0.012	33	1	0.004	0.001	3.9	0.04	0.019	0.001	
		B	0.057	0.001	<DL		<DL		0.075	0.019	35	1	0.003	0.001	4.1	0.05	0.020	0.001	
	28-Jul-09	A	0.122	0.003	<DL		<DL		0.354	0.032	227	3	0.014	0.000	56.0	0.38	0.127	0.004	
		B	0.112	0.008	<DL		<DL		0.353	0.030	229	3	0.015	0.001	50.3	0.39	0.129	0.005	
TNC1	1-Nov-07	A	0.447	0.006	0.002	0.001	<DL		0.212	0.012	30	1	0.011	0.001	7.1	0.02	0.031	0.001	TNC1
		B	0.448	0.004	0.002	0.001	<DL		0.230	0.007	39	1	0.015	0.001	7.0	0.06	0.031	0.001	
	25-Jun-08	A	0.489	0.015	0.007	0.005	<DL		0.259	0.009	86	1	0.041	0.001	0.5	0.01	0.073	0.001	
		B	0.499	0.020	0.011	0.002	<DL		0.294	0.020	79	2	0.043	0.004	0.6	0.01	0.071	0.001	
	26-May-09	A	0.350	0.001	<DL		<DL		0.174	0.017	37	1	<DL		1.6	0.00	0.035	0.001	
		B	0.362	0.004	<DL		<DL		0.182	0.003	38	1	<DL		1.5	0.02	0.035	0.001	
	28-Jul-09	A	0.373	0.011	<DL		<DL		0.847	0.044	25	1	0.005	0.001	10.3	0.07	0.093	0.002	
		B	0.324	0.001	<DL		<DL		0.381	0.027	22	1	0.002	0.001	9.9	0.11	0.089	0.002	
TNC2	1-Nov-07	A	0.429	0.007	0.003	0.001	1.3	0.3	0.218	0.003	35	1	0.017	0.001	5.9	0.02	0.030	0.001	TNC2
			No replicate available																
	26-May-09	A	0.335	0.007	<DL		<DL		0.179	0.014	40	1	<DL		5.0	0.05	0.036	0.001	
		B	0.339	0.010	<DL		<DL		0.169	0.011	42	1	<DL		4.9	0.05	0.037	0.001	
	28-Jul-09	A	0.358	0.010	<DL		<DL		0.351	0.016	27	1	0.004	0.001	5.0	0.01	0.082	0.001	
		B	0.391	0.008	<DL		<DL		0.346	0.019	29	1	0.005	0.001	4.5	0.06	0.088	0.001	
ALR	25-Jun-08	A	0.572	0.022	<DL		<DL		0.080	0.029	221	3	0.009	0.003	15.7	0.06	0.133	0.007	ALR
		B	0.620	0.031	<DL		<DL		0.092	0.083	248	7	0.022	0.003	17.5	0.18	0.146	0.005	
			Cu	error	Cd	error	Zn	error	Ni	error	Fe	error	Pb	error	Mn	error	Co	error	
Detection limits:			~0.002 ppb		~0.002 ppb		~1 ppb		~0.005 ppb		~5 ppb		~0.002 ppb		~0.02 ppb		~0.005 ppb		

[1] "95% ci" stands for 95% confidence interval about the mean of triplicate measurements.

Table 10. Benthic chlorophyll and phaeophytin concentrations in lake and wetland surficial sediments (in micrograms per square centimeter) at Upper Klamath Lake, Oregon.

[SD, standard deviation; Chl-a, chlorophyll-a concentrations; Pheo, pheophytin concentration; 3 replicate samples

		Chl-a	SD	Pheo-phytin	SD	Chl-a/ Pheo+Chl-a ratio	SD
MRM	**1-Nov-07**	**0.6**	0.2	**2.4**	0.4	**0.19**	0.08
	26-May-09	**-1.6**	2.2	**11.2**	3.7	**-0.15**	0.20
	28-Jul-09	**0.3**	0.1	**6.9**	1.6	**0.04**	0.02
WMR	**1-Nov-07**	**0.3**	0.3	**5.2**	0.8	**0.06**	0.05
	26-May-09	**0.1**	0.1	**18.8**	3.2	**0.01**	0.01
	28-Jul-09	**1.6**	1.9	**14.9**	4.1	**0.10**	0.14
MDN	**26-May-09**	**0.2**	0.2	**12.0**	2.2	**0.01**	0.02
	28-Jul-09	**0.1**	0.2	**7.2**	0.9	**0.01**	0.02
WET	**1-Nov-07**	**0.0**	1.1	**5.8**	3.5	**0.00**	0.26
	26-May-09	**-3.9**	8.1	**101.6**	13.9	**-0.04**	0.08
	28-Jul-09	**3.6**	3.1	**47.7**	1.8	**0.07**	0.06
TNC1	**1-Nov-07**	**1.0**	0.6	**1.5**	0.8	**0.41**	0.29
	26-May-09	**0.4**	1.1	**34.0**	1.2	**0.01**	0.03
	28-Jul-09	**0.4**	0.4	**6.6**	0.9	**0.06**	0.05
	1-Nov-07	**0.2**	0.5	**4.0**	1.1	**0.05**	0.13
	26-May-09	**-0.1**	1.9	**15.6**	1.8	**-0.01**	0.13
	28-Jul-09	**1.0**	0.3	**8.5**	1.8	**0.11**	0.05