Report for 2001MN3381B: Eutrophication and Remediation in Context: High-Resolution Study

There are no reported publications resulting from this project.

Report Follows:

Eutrophication and remediation in context: High-resolution study of the past 200 years in the sedimentary record of Lake McCarrons (Roseville, Minnesota)

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Summary

Lakes in urban settings receive major inputs of nutrients and salt from the lawns and roads that surround them. Increased biological productivity and salinization of lake bottom waters cause degradation of water quality in these valuable municipal resources. Monitoring efforts provide water quality information with high temporal resolution; however, due to logistical and budgetary constraints, monitoring rarely captures more than a few years' data; hence, these snapshots may not accurately represent the high interannual variability of physical and chemical parameters in lakes.

This study uses sediment cores and certain water chemistry analyses to generate a high-resolution record of historic and pre-European changes in the chemistry and productivity of Lake McCarrons, Roseville, Minnesota, with the goal of placing recent (1985-2001) monitoring data in a long-term context. Geochemical and isotopic parameters recorded in lake sedimentary components over time are used as proxies for processes and changes in the water column; a minimal number of water analyses are used to calibrate the system with respect to the isotopic proxies and to answer specific questions germane to the sediment study.

Results to date indicate that Lake McCarrons has undergone cycles of increased biological productivity in this century, and that productivity is as high now as it has been at any time during this period. Sediment data also suggest that the degree of bottom-water anoxia has increased over the past 40 years; this observation is further supported by water chemistry data indicating that the lake does not fully mix at fall and spring overturn, behavior which would feed back and support the development of greater anoxia. Data currently in hand will be supplemented with high-temporal-resolution analyses covering the past 2-3 centuries, as well as for selected intervals representing periods thousands of years ago. We hope that this information is useful to lake managers making decisions on remediatory measures with reference to the "natural" state of the lake.

Introduction

Cultural eutrophication of urban lakes is a significant problem worldwide. The tension between shoreline development and the preservation of natural systems leads to expensive and sometimes divisive remediation efforts, the degree of success of which may not be known for years. Monitoring is a time- and labor-intensive effort, which can provide a high-resolution view of lake dynamics, but only on a short time scale. The historical record of lake level, productivity, anoxia, and chemistry, where it exists, is short and incomplete; water quality modelers then have only a few years of data with which models can be compared or validated. Long-term trends are easily masked by year-to-year variability in water quality; natural cycles are extremely hard to detect over the course of a few years, the typical duration of most monitoring projects. However, broad trends exert a significant influence on water quality assessments and remediation efforts.

The study of lakes through their sedimentary records provides a lower-resolution but much longer-term picture of lake evolution: geochemical and biological sediment components provide an array of information about past changes in chemistry, flora and fauna, and water level. In lakes that are annually laminated (varved), a history of the lake year by year may be constructed from this information. Where sediments are not laminated, deposition rates are estimated, and a quasi-annual record is produced.

This study is in the process of generating a high-resolution record in a number of geochemical proxies (stable isotopes, nutrients, minerals, etc.) for the past 200 years in Lake McCarrons, a eutrophic Minnesota urban lake, based on a high-quality sediment core from 16 m water depth. This analysis will be supplemented by approximately

50 additional analyses performed on a 4.1-meter core taken in 1999 that is now curated at the Limnological Research Center (LRC) Core Repository. Combined, these studies will provide the context for long-term (thousands of years) and medium-term (hundreds of years, including >50 years before European settlement) natural variability and rates of change in lake water quality, as well as illuminating trends that had their inception long before any human impact on the lake system.

Analytical work

Water column analyses

During the summers of 2001 and 2002, water samples and basic limnological data were collected every 2-4 weeks. Water samples were taken at three depths in the lake (2 m below the water surface; 1 m above the sediment surface, and ~1 m below the thermocline) for major ions and carbon stable isotopic composition ($\delta^{13}C$) of dissolved inorganic carbon. At the same time measurements of dissolved oxygen, temperature, and pH were made at selected depths, and Secchi depth was measured.

Sediment analyses

A sediment core from 16 m water depth was used for the study. Before sampling, digital images of the core were taken, and the boundaries between putative annual layers (cyclic packages of one dark [winter] and one light [summer] layer) were marked on these images using Photoshop (see Figure 1). For each layer, at least two smear slides (consisting of a small amount of sediment spread on a microscope slide and embedded in optical cement) were taken: one each from the dark and light layers, and one from any additional visible discrete layers. These slides are used to estimate abundance of sediment components such as algal organic matter, diatoms, and minerals such as calcite (precipitated in the water column) and quartz sand (washed in from the shoreline).

Based on the above determinations of how layers represent individual years' deposition, the laminated portion of the core (the top ~50 cm) was sectioned into 89 pieces, following the contacts between the dark (below) and light (above) layers. Numbered as "v" samples (for "varved," e.g., v01, v02, ..., v89), these are taken to represent the 89 years of sedimentation preceding the year 2000, as the core was taken in the winter of 2000-2001. All of the "v" samples are included in the analyses described below. Below the top ~50 cm, the sediments are massive (i.e., not laminated or poorly laminated). Eighty-four cm of this portion of the core were cut into 0.5 cm sections, and every other sample was analyzed (e.g., 1.0-1.5 cm and 2.0-2.5 cm but not 1.5-2.0 cm). Only data for the "v" samples are included in this report.

Sediment analyses conducted thus far include (1) carbon coulometry to determine weight percentage of carbonate, (2) elemental analysis to determine weight percent organic carbon, nitrogen, and sulfur, and (3) stable isotopic analysis to determine $\delta^{13}C$ and $\delta^{18}O$ of carbonate. In progress are (4) biogenic silica measurements to determine weight percent diatom frustules, (5) stable isotopic analysis to determine $\delta^{13}C$ of organic matter, and (6) scanning electron microscopy (SEM) to investigate size, preservation, and crystallinity of calcite grains over time. The sedimentary phosphorus analysis budgeted in the original proposal has been put on hold because of the consideration that, due to its redox-sensitive mobility and biological importance, it is likely not a true measure of surface-water P concentrations (e.g., Engstrom and Wright 1984). The remaining work, along with an evaluation of the site for an additional study (using fossil diatoms to infer P, Cl, and pH values; discussed later in this report), is slated to be completed during the remainder of the grant period.

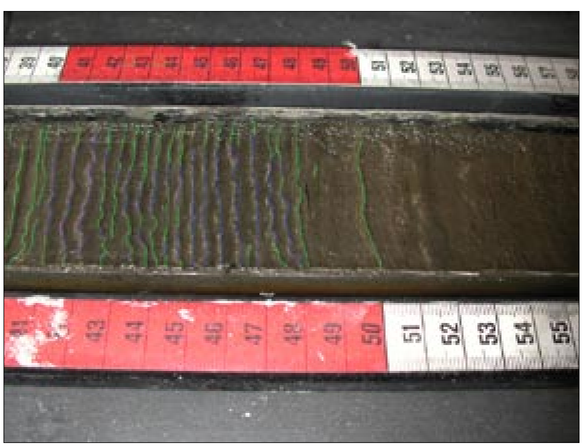

Figure 1. Portion of Lake McCarrons core at McC-01-MP showing demarcations of annual layers. Blue lines indicate clear boundaries; green lines indicate contacts in which we feel less confidence. Note the transition at ~48 cm from laminated to massive sediment.

Results to date

Because the study is still in the process of generating data, discussion of results and interpretation is limited in scope. The preliminary water and sediment data are nonetheless promising.

Water chemistry

Major ions

The proposal for this study hypothesized that Lake McCarrons is meromictic or oligomictic (completely mixing never or only infrequently). It is well known from Metropolitan Council studies (Met Council 1988, 1997; West-Mack and Stefan 2000a, 2000b) that the lake is strongly thermally stratified during the summer; a thermister chain recording temperatures at 12 depths was deployed for several ice-free seasons. The Met Council reports do not demonstrate conclusively whether or not the lake does completely mix, in part because thermister measurements were sparse in the hypolimnion (on the order of 2-3.5 m spacing rather than the 1 m spacing of sensors in the epilimnion). Concentrations of conservative elements (i.e., those that do not participate in precipitation-dissolution reactions at concentrations found in the lake) such as Cl^- and Na^+ were used in this study as a measure of the degree of mixing of surface and deep waters. If the lake is mixed, and no great quantity of dilute water enters preferentially into any given layer, the concentration of a conservative ion should be the same throughout the water column. As shown in Figure 2, however, Cl^- concentrations are significantly higher in the hypolimnion than in the epilimnion throughout summer 2001 (data for 2002, and for Na^+ in 2001 and 2002, are similar). This suggests that lake bottom waters are not being entrained when the lake overturns in spring and fall. Concentrations of Cl^- throughout the lake are elevated to 20-50 times typical natural values, presumably due to road salt inputs; it is possible that cold overland or wetland runoff high in dissolved road salt plunges into the hypolimnion in the spring, causing these higher hypolimnetic values. High levels of salt in the hypolimnion may also contribute to the density difference that retards mixing.

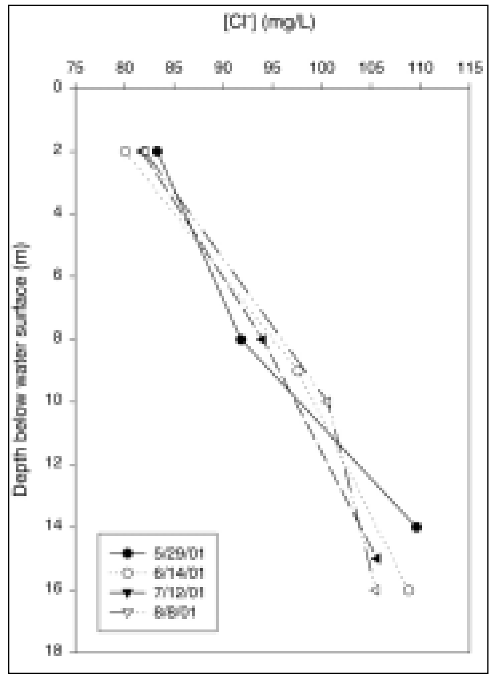

Figure 2. Chloride concentrations in Lake McCarrons

d¹³C of dissolved inorganic carbon (DIC)

In general, $\delta^{13}C$ values become more positive ("heavier") under algal productivity (due to preferential uptake of ^{12}C) and more negative ("lighter") under degradation of organic matter (due to the release of the same light carbon); the $\delta^{13}C$ value of DIC is also imparted to carbonate minerals and organic matter that become part of the sedimentary record. Figure 3 shows a profile of $\delta^{13}C_{DIC}$ values in Lake McCarrons taken on August 9, 2002, and Figure 4 shows the evolution of surface, intermediate, and deep water values for the growing seasons of 2001 and 2002 (end of summer 2002 data are pending). Note the increase of deep water values above intermediate (upper hypolimnion) values: this trend implies microbial methane production in the bottom waters, an indication of severe anoxia.

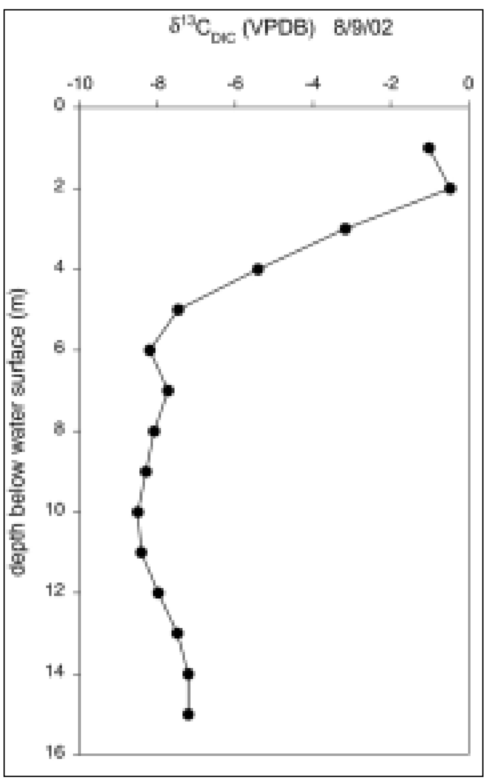

Figure 3. Profile of carbon stable isotopic value of dissolved inorganic carbon in Lake McCarrons

Sediment analysis

Figure 5 shows results to date of analysis of the laminated portion of the sediment core. These data, when fully compiled, will be compared with historical and climatological data for the area to investigate

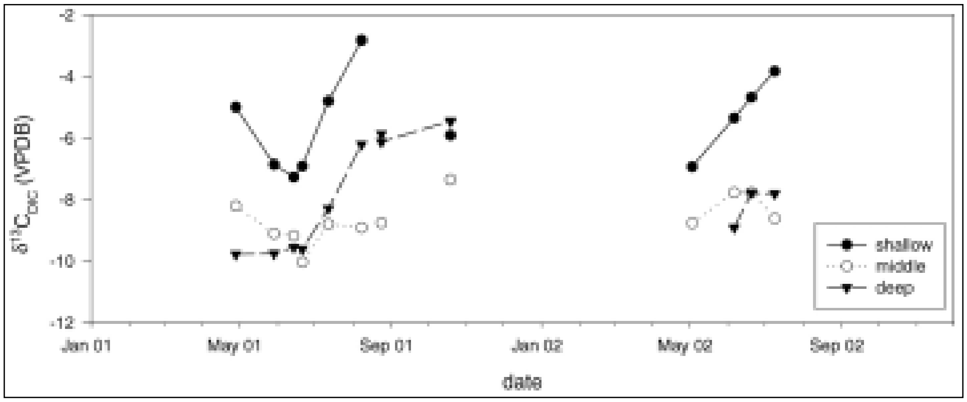

Figure 4. Seasonal changes in carbon stable isotopic value of dissolved inorganic carbon in Lake McCarrons

the "fit" and utility of the sediment record for reconstructing prehistoric changes. One important task remaining is the transformation of the percentage data (organic carbon, calcite, and biogenic silica) to accumulation rate data, based on bulk density measurements and incorporation of the "non-v" (unlaminated section) samples of the core. This analysis provides a more realistic picture of changes in style of sedimentation, as percentage changes may be caused simply by dilution of one component by another. From the data in hand, it is apparent that the lake has undergone cyclic swings in biological productivity over the past century, as shown by variations in the carbon isotopic signature of calcite, and that the $\delta^{13}C$ values are as high in the most recent sediments of the core as the highest values recorded during the century. Note that neither the passage of the Clean Water Act in 1972 (which in some other lakes is a significant event in the sedimentary record) nor the installation in 1985 of a detention pond to trap inflowing nutrients appears to have had any immediate effect on the state of the lake as recorded in the sedimentary components plotted here. This apparent lack of response warrants further study, but it is likely that the biogenic silica data (measuring diatom abundance) and the $\delta^{13}C$ of organic matter (measuring phytoplankton productivity), or both, will show a response to these forcings. As noted above, these analyses are underway.

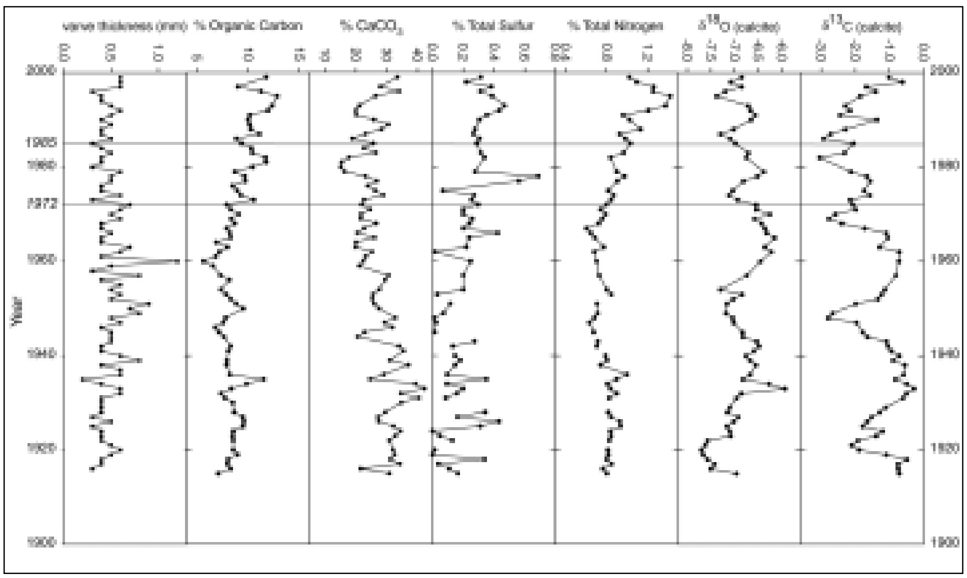

Figure 5. Geochemical and isotopic data from varved section of Lake McCarrons core McC-01-IMP

Student training

Amy Myrbo, Geology and Geophysics Ph.D. candidate, conceived of and wrote the proposal, and is responsible for conducting the project. Two undergraduates, Chris Merkes, a University of Minnesota genetics major, and Aimee Wendt, a St. Cloud State geology major who worked as an intern in the Limnological Research Center during the summer of 2002, have been involved in both field and laboratory work, and Aimee presented a poster on the project at an intern poster session in the geology department in August 2002.

Publications/presentations to date

- LiMNology Retreat February 2001 presentation: "Sedimentary-Historical Context of Eutrophication and Remediation in Urban Lake McCarrons: Would Your Granny Care?"
- Upcoming poster at 3rd International Limnogeology Congress, Tucson, late March 2003, working title "Sedimentary-Historical Context of Eutrophication and Remediation in Urban Lake McCarrons."

- Informal presentation on thesis research, of which this project is a major component, at evening Quaternary Paleoecology seminar, April 2001.

References

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