Internal Nutrient Recycling in Marion Reservoir

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Abstract

Historically, lake and reservoir management has focused on controlling external nutrient inputs. However, it is becoming increasingly clear that internal mechanisms can also contribute to the processes of eutrophication. We assessed internal nutrient (phosphorus) release rates in Marion Reservoir, Kansas, using a laboratory sediment core incubation study. Sediment cores were collected from the reservoir and exposed to either anoxic (no oxygen) or oxic conditions and phosphorus release rates were then measured over a seven day period. Our results show that under anoxic conditions large quantities of phosphorus can be released from the lake sediment. The average release rate from all of the anoxic cores combined was 20.7 $\pm$ 4.9 mg P/m^2/day. We also presented data to show that Marion Reservoir exhibited brief periods of anoxia near its sediment surface indicating that it has the potential for internal nutrient recycling. As such, our results strongly suggest that internal sources can contribute to eutrophication in Marion Reservoir and highlights the importance of considering internal sources in management and restoration efforts for this reservoir.

Introduction

Historically, lake management efforts have focused on controlling external nutrient loading (e.g., Walker and Havens, 2003; Havens and Walker, 2002). However, it is becoming increasing clear that internal mechanisms can also contribute to the processes of eutrophication (for a review of internal nutrient recycling see Sondergaard *et al*., 2001). For example, large quantities of nutrients can accumulate in lake sediments (Carpenter *et al*., 1998) and then be released back into the water column over time. While a number of environmental factors have been shown to influence internal nutrient release rates (Bostrom *et al*., 1988; Sondergaard *et al*., 2001), release is often associated with anoxic (no oxygen) conditions (Nurnberg, 1984; Nurnberg and Peters 1984). Specifically, as the water above the sediment becomes anoxic the redox-potential at the water-sediment surface is reduced and iron (Fe) (III) is converted to Fe (II) resulting in a release of soluble reactive phosphorus (PO_4^{3}-; dissolved phosphorus that is available for algal uptake) back into the water column (Bostrom *et al*., 1988).

If a reservoir exhibits high sediment nutrient release rates or conditions that favor high release rates (i.e., anoxic hypolimnion), then it is likely that reductions in external loading alone will not have an immediate effect on nutrient concentrations in the water column (Marsden, 1989). Surprisingly, little is known about internal nutrient recycling in lakes and reservoirs of the Central Plains region of the United States. Many of these water bodies are located in agriculturally dominated watersheds and experience at least brief periods of anoxia (e.g., Wang *et al*., 2005). Therefore, there appears to be a high potential for internal nutrient recycling in these important systems. The purpose of this experiment was to assess this potential in a large drinking water reservoir in Kansas. We

conducted laboratory sediment core incubations to quantify nutrient release rates from anoxic sediments collected from four different locations in the reservoir. We also positioned a dissolved oxygen probe near the sediment-water interface of the reservoir to determine if it experienced periods of anoxia. Finally, we included results from a previously unpublished laboratory bioassay experiment that was designed to assess nutrient limitation of algal growth in the reservoir. The bioassay was included in the current study so that we could predict how nutrient pulses released internally from the sediment might impact algal biomass in the reservoir.

Methodology

Marion Reservoir is a large (surface area – 24.9 km^2), multiple purpose reservoir that serves as a drinking water source to a number of communities in east-central Kansas. Unpublished nutrient and chlorophyll data indicate that the reservoir is eutrophic to hypereutrophic, and that it often experiences dense surface accumulations of blue-green algae and resulting taste and odor events (Dzialowski *et al*., unpublished data).

In situ Near-Sediment Dissolved Oxygen Measurements

A Hydrolab multiprobe unit equipped with a dissolved oxygen probe was positioned near the sediment surface in the main basin of the reservoir (Figure 1). The probe was used to measure oxygen concentrations near the sediment surface at 1-hour intervals. The probe was maintained in the reservoir from July 6 to August 3, 2007.

We originally intended to place the probe 1-m above the sediment surface. However, the water level of the reservoir was elevated when the probe was placed in the reservoir. Therefore, we placed the probe 2-m above the sediment surface because we did not want it to come into contact with the sediment as the water level dropped over time.

Sediment Core Incubations

A laboratory sediment core incubation study was conducted at the Environmental Bioassay Research Facility (EBRF – Dzialowski *et al*., 2005) at the Central Plains Center for BioAssessment (CPCB). Although, nitrogen (N) can also be released from the sediment (i.e., Nowlin *et al*., 2005), we focused specifically on phosphorus (P) release rates in this study. Twenty-four sediment cores were collected from the reservoir using a 5 cm diameter Wildco Sediment Corer. A total of six cores were collected from each of the four locations throughout the reservoir in order to assess spatial differences in phosphorus release rates. These locations included the main basin (2 sites), the transition zone between the main basin and the riverine zone, and the riverine zone (Figure 1). Cores were returned to the laboratory and were processed within 24 hours.

The reservoir water was drained off of the top of each core and replaced with filtered lake water (0.7 μm) so that there were no confounding influences of phytoplankton or zooplankton on nutrient release rates (Elser *et al*., 1990). All cores were initially bubbled with air to allow for all of the phosphorus in the water column to settle into the sediment under oxic conditions.

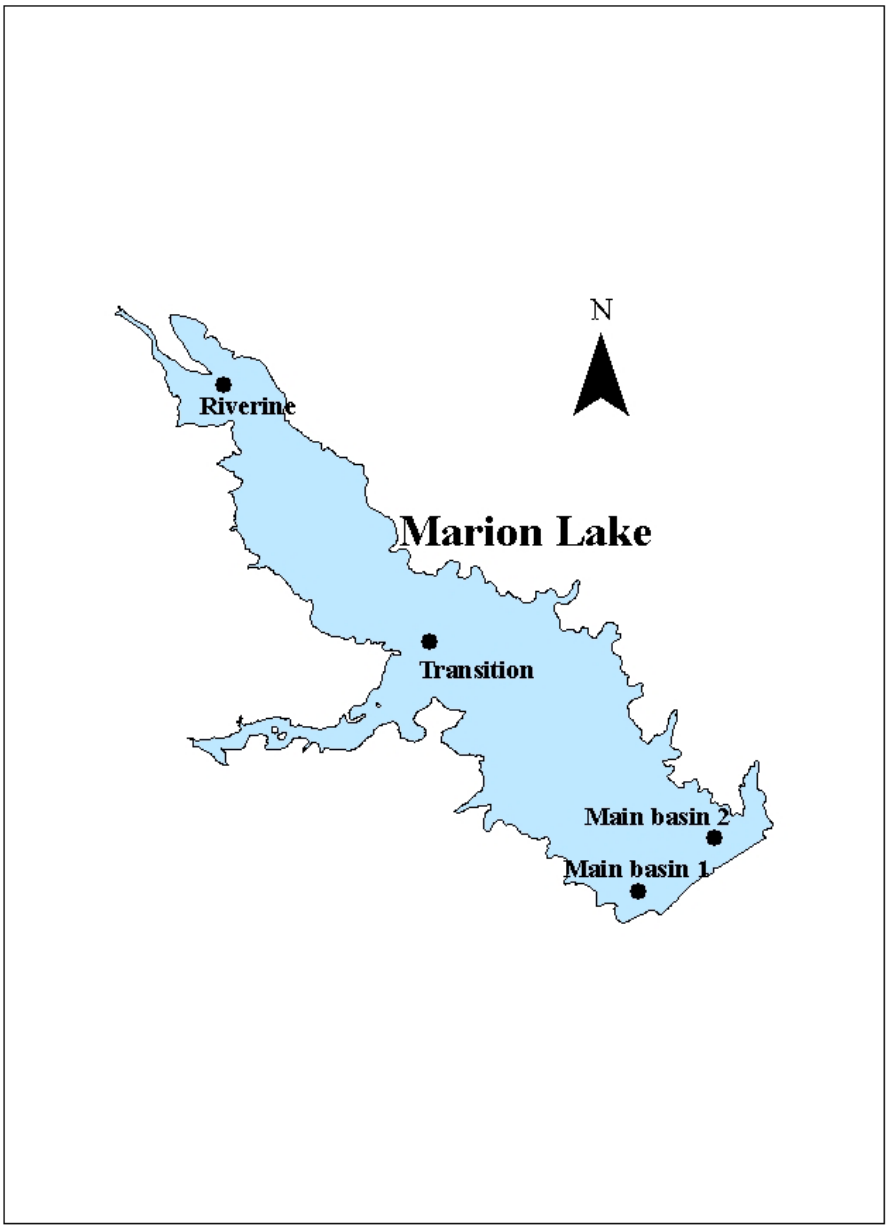

Figure 1. Four sediment sampling locations of Marion Reservoir. The Hydrolab probe was deployed at the Main Basin 1, approximately 2 m above sediment surface.

Phosphorus release was examined using a 2 x 4 experimental design consisting of two core types (anoxic and oxic) from the four reservoir locations. Each core was bubbled with either nitrogen gas to create anoxic conditions, or bubbled with air to create oxic (control) conditions. The incubation experiment was replicated with triplicate cores for each treatment for seven days in a growth chamber at 20°C that was kept dark throughout the experiment. Water samples (10 mL) were collected from the cores daily and analyzed for dissolved P concentrations (PO_4^{3-}; using Method 4500-P in APHA *et al*., 2005). Filtered lake water was added to the test cores daily to account for sample loss.

P-release rates were calculated for each core (both anoxic and oxic) using the increase in PO_4^{3-} from day one to day six. Two-way Analysis of Variance (ANOVA) was then used to determine if there were significant differences in release rates between anoxic and oxic cores (i.e., core effect) and in release rates from the four locations in the reservoir (i.e., location effect).

Laboratory Nutrient Bioassay Study

A laboratory bioassay experiments was conducted to assess nutrient limitation of algal growth in Marion Reservoir. Approximately 20-liters of surface water was collected from the main basin of the reservoir and returned to the EBRF where it was coarsely filtered (200 μm) to remove most macrozooplankton. A control (no nutrients added) and three nutrient addition treatments were established in triplicate 1-L bioassay bottles: N addition (KNO_3 added at a concentration of 57 μmol L^{-1}); P addition (KH_2PO_4 added at a concentration of 6.5 μmol L^{-1}); and N and P addition (both KNO_3 and KH_2PO_4

added at the same concentrations used in the single nutrient treatments). Once the treatments were established, the openings of the bioassay bottles were covered and then exposed to 200 μE m^{-2} s^{-1} of light provided by a bank of fluorescent lights on a 12-hour light/dark cycle in an incubator. The bioassay experiment was maintained for 9 days. *In vivo* fluorescence, which is commonly used as a measure of algal biomass in bioassay experiments (Elser *et al*., 1990), was measured daily in each bioassay bottle using a Turner Model 10 Fluorometer.

Repeated Measures Analysis of Variance (RM-ANOVA) was used to determine if there were significant effects of the nutrient treatments on algal growth (i.e., fluorescence). When significant treatment effects were observed, Tukey's HSD (P=0.05) was used to determine which treatments were different from the control treatment.

Results

In situ Near-Sediment Dissolved Oxygen Measurements

Near sediment dissolved oxygen concentrations varied throughout the study (Figure 2). However, anoxic conditions (dissolved oxygen – 0.0 mg/L) were not observed in the reservoir (Figure 2). The lowest dissolved oxygen concentration that was observed was 0.8 mg/L. However, the probe was placed approximately 2 m above the sediment surface due to high water level at the time of deployment.

Sediment Core Incubations

Phosphorus release rates were significantly higher from anoxic cores than they were from oxic cores (significant core effect, F=450.83, $P<0.001$, Figure 3). There were, however, no spatial differences in the release rates from the cores collected at the four reservoir sites (Tukey's P>0.05 in all comparisons between the four sites with respect to anoxic cores). The average release rate from all of the anoxic cores combined was 20.7 $\pm$ 4.9 mg P/m^2/day.

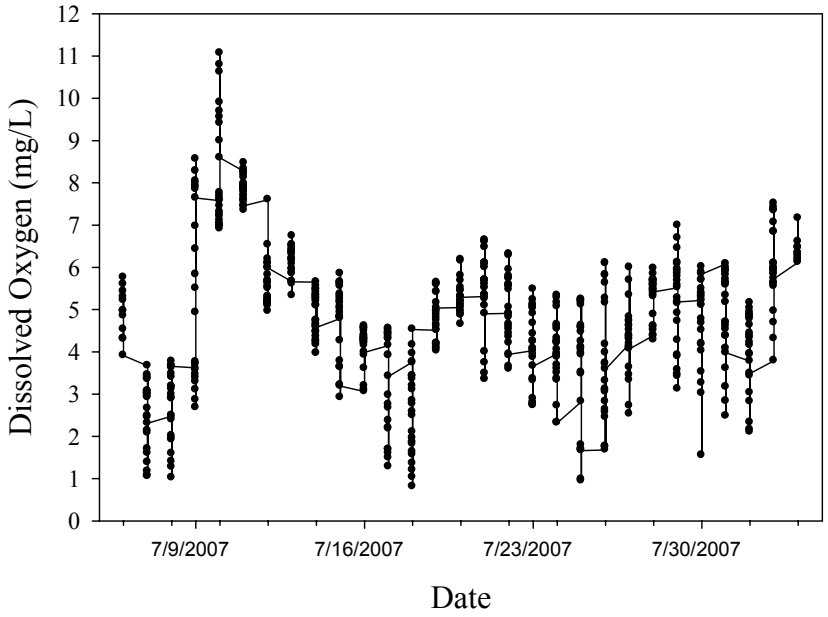

Figure 2. Dissolved oxygen concentrations measured near the sediment-water interface of Marion Reservoir. A dissolved oxygen probe that recorded measurements at hourly intervals was placed roughly 2-m above the sediment surface.

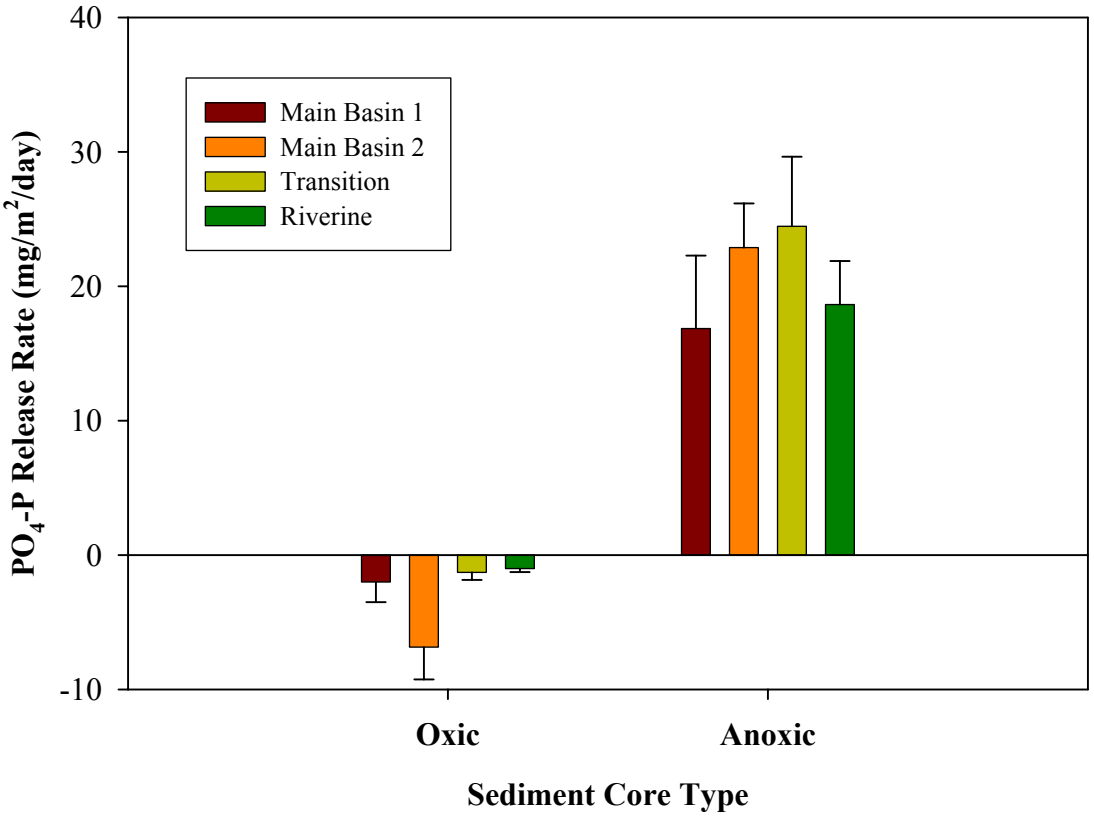

Figure 3. P-release rates from each of the four Marion Reservoir sites. Sediment cores were collected and returned to the laboratory where they were exposed to oxic and anoxic conditions. There were no statistical differences in release rates between the four sites under anoxic conditions; however, there were highly significant differences between the oxic and anoxic cores (see text for *P*-values).

Laboratory Nutrient Bioassay Study

Algal biomass did not increase in the P-addition treatment relative to the control treatment (Tukey's $P>0.05$ comparing fluorescence in the control and P-addition treatment; Figure 4). In contrast, algal biomass was significantly higher in both the N-addition and N+P addition treatments than it was in the control treatment (Tukey's $P<0.05$ comparing the N-addition and N+P addition treatments with the control). The reservoir was determined to be N-limited because the addition on N+P did not lead to a

greater increase in algal biomass relative to the increase observed for the addition of N alone (Tukey's P>0.05 comparing fluorescence in the N-addition and N+P addition treatments).

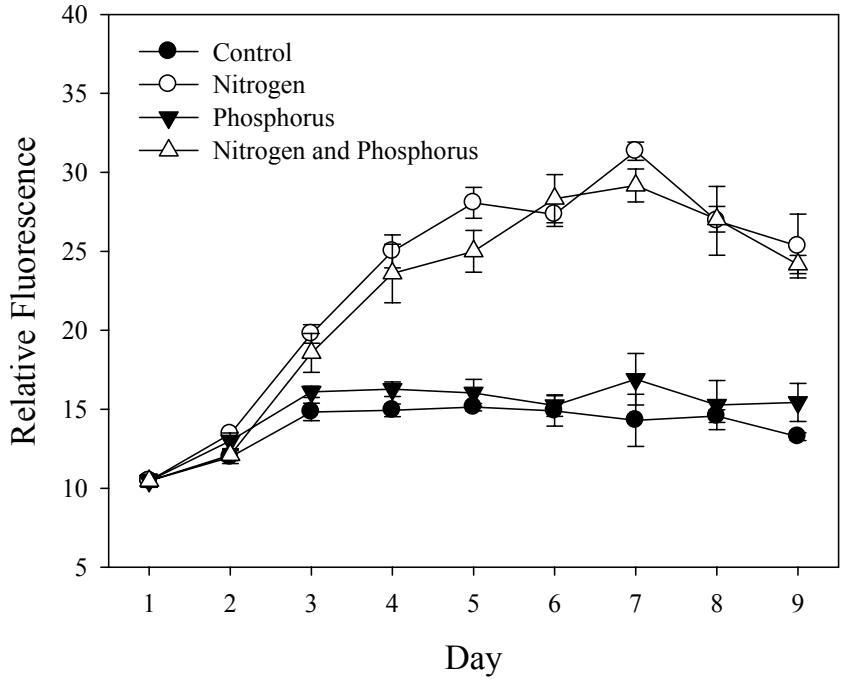

Figure 4. Results from the bioassay experiment to determine nutrient limitation in the reservoir. The reservoir was determined to be N-limited at the time of the bioassay experiment.

Discussion

Historically, the management of eutrophic systems has tended to focus on controlling external nutrient loading. However, it is becoming increasingly clear that internal mechanisms can also contribute to the processes of eutrophication. In the current study, we have shown that large concentrations of P can be released from the sediment under anoxic conditions. The internal nutrient release rates observed for Marion Reservoir are similar to those that we have previously observed in four eutrophic reservoirs in the region (16.1 - 39.8 mg P/m^2/day; Dzialowski *et al*., 2007). As such, our results strongly suggest that internal sources can contribute to the eutrophication of reservoirs in the Central Plains region, and highlight the importance of considering these internal sources in management and restoration efforts.

The results from the bioassay experiment show that the algal community in Marion Reservoir was N-limited, and not P-limited (Figure 4). Dzialowski *et al*. (2005) similarly found in a study of 19 Central Plains reservoirs that P-limitation of algal growth was rare. Instead, reservoirs tended to be co-limited by N and P and to a lesser extent by N alone. Sediment release studies have historically focused on P because it has been considered to be the nutrient most likely limiting algal growth; however, it is important to point out that N can also be released from the sediment (e.g., Nowlin *et al*., 2005). (Nowlin *et al*., 2005). Therefore, our results suggest that internal N release rates should also be measured in eutrophic systems such as those located in the Central Plains that tend to be limited by N or co-limited by N+P. Furthermore, even though P did not limit algal growth in Marion Reservoir, P released from the sediment can still have significant impacts on the reservoir. For example, it is likely that when P concentrations are high in

a particular reservoir, N may limit the actual growth rates of algae, but P helps to determine the overall yield of algae (Dzialowski *et al*., 2005). P-released from the sediment may also affect algal community structure. Increases in P from the sediment may lead to decreases in water column N:P ratios, creating conditions that facilitate blooms of nuisance cyanobacteria (Smith and Bennett, 1999).

In the current study, we have shown that sediment can release relatively high rates of P under anoxic conditions using laboratory incubation experiments. However, it is important to stress that abiotic and biotic processes within the reservoir will help to determine the actual in-reservoir release rates. For example, NO_3 concentrations in the water column can have either a positive or negative effect on release rates depending on bacterial activity (Bostrom *et al*., 1988). Nowlin *et a*l. (2005) reported that when they added NO_3 to sediment cores, there was a substantial decrease in P-release rates relative to control cores. Gachter and Muller (2003) also showed that anoxia is not always a good indicator of release rates. They found that P-release rates from the sediment did not always decrease when the hypolimnion of a eutrophic reservoir was oxygenated (Gachter and Muller, 2003). While the concentrations of P-released in the current study appear to be high, it is important to consider how processes within the individual lakes affect actual release rates. Therefore, additional research is needed to monitor abiotic and biotic factors that influence P-release rates (such as NO_3 concentrations and bacterial activity) during periods of anoxia in order to quantify actual reservoir release rates.

Interestingly, we did not observe anoxic conditions near the sediment surface of the reservoir (Figure 2), suggesting that there is a low potential for internal nutrient release in Marion Reservoir. However, it is important to note that the probe was

positioned roughly 2-m above the sediment surface and may have missed periods of anoxia near the sediment-water interface. Unpublished data from Marion Reservoir shows that it does experience at least brief periods of anoxia during the summer (unpublished dissolved oxygen data is presented in Figure 5). Therefore, we believe that Marion Reservoir has the potential to support internal nutrient recycling.

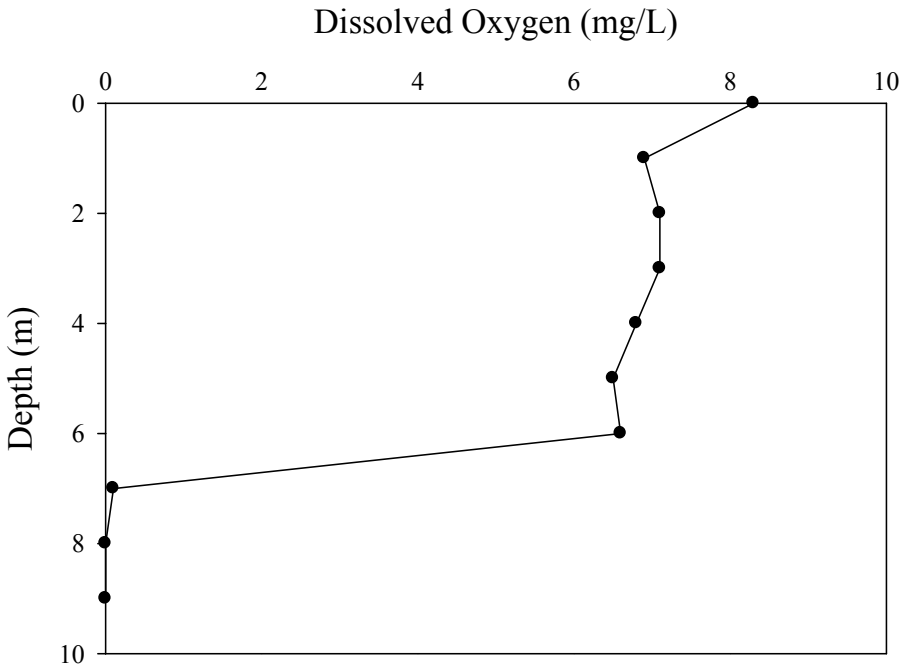

Figure 5. Dissolved oxygen profile collected from the main basin of Marion Reservoir on 7-25-2006 (unpublished data). This profile was included to show that the reservoir does experience at least some periods of anoxia.

A number of pervious studies have concluded that internal P recycling can hinder restoration efforts so that water column P concentrations do not respond to external load reductions (Marsden, 1989). For example, Shagawa Lake, Minnesota remained eutrophic despite reductions of external P-inputs due to sediment release that occurred during periods of anoxia (Larson *et al*., 1981). In contrast, others have shown that internal P-release from the sediment does not always hinder restoration efforts. Reductions in external nutrient loads resulted in lower water column P concentrations in a shallow, eutrophic lake in Florida despite the effects of sediment resuspension and nutrient release under anoxic conditions (Coveney *et al*., 2005). While it is impossible to determine how internal nutrient recycling will affect management efforts in eutrophic Central Plains reservoirs such as Marion Reservoir, our research does show that reservoirs exhibit at least the potential for internal nutrient release. Therefore, internal nutrient sources should be considered when developing management and restoration plans for this important system and other reservoirs in the region.

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