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Phosphorus Flux from Bottom Sediments in New Spiro Lake, Oklahoma

An Undergraduate Honors College Thesis

in the


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College of Engineering
University of Arkansas
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by

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This thesis is approved.

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Phosphorus Flux from Bottom Sediments in New Spiro Lake, Oklahoma

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Spring 2015

Abstract

Phosphorus loads to water bodies consist of external flux from the watershed and internal flux from the bottom sediments. In this study, the specific objectives were to measure the internal phosphorus flux from bottom sediments under aerobic and anaerobic conditions and determine the effectiveness of various rates of alum treatment on sediment phosphorus release. Eight intact sediment cores from New Spiro Lake were incubated under aerobic and anaerobic conditions for 41 days at room temperature. The cores were treated in the middle of incubation with alum (aluminum sulfate) and sodium aluminate at a ratio of 2:1, ranging from 0.05 to 0.40 mL of liquid alum. SRP concentrations of overlying water in all cores ranged from 0.51 to 0.076 mg L⁻¹ initially and increased to concentrations ranging from 0.122 to 0.161 mg L⁻¹ in cores under anaerobic conditions and from 0.088 to 0.110 mg L⁻¹ under aerobic conditions during the first 19 days of incubation. Average phosphorus flux was 2.56 mg m⁻² d⁻¹ into the water column under anaerobic conditions and 0.61 mg m⁻² d⁻¹ under aerobic conditions. After chemical treatment the SRP concentrations in the overlying water of the cores decreased to < 0.01 mg L⁻¹ in both anaerobic and aerobic cores, but subsequently increased to concentrations similar to that before treatment. The alum treatment was not successful at mitigating sediment phosphorus flux in this experiment, but this experiment should be repeated again.

1. Introduction

Phosphorus loads to lakes and reservoirs include that from the watershed (external flux) and that from within the water body (internal flux). An important internal source of phosphorus loading to overlying water is the sediment accumulating at the bottom, which is composed of clastic materials, organic matter, and microorganisms. The sediment deposited in lakes and reservoirs also scavenges phosphorus and other constituents from the water column as it settles to the bottom (Sognozi et al., 1982).

There are two mechanisms that allow for the release of phosphorus from the sediments into the water column. Under aerobic conditions, phosphorus is desorbed from sediments and mineralized from organic matter in a gradient driven process until an equilibrium phosphorus concentration is achieved. Bottom sediments can be a source or a sink for phosphorus depending on the phosphorus concentrations of the overlying water (Haggard et al., 1999; Lucci et al., 2009). If soluble reactive phosphorus in overlying water is greater than that in sediments, the sediment will

remove phosphorus from water. If soluble reactive phosphorus in overlying water is less than that in sediments, the sediments will release phosphorus.

Under anaerobic conditions, the overlying water becomes anoxic and reductive dissolution of minerals such as iron (Fe) and manganese (Mn) occurs. Bacteria in the sediments reduce Fe and Mn and use them as electron receptors in the absence of oxygen. Phosphorus bound to the minerals is released to the overlying water when conditions become reducing at the sediment-water interface (Mortimer, 1941). In either mechanism, internal phosphorus flux into water bodies can be enough to sustain anthropogenic eutrophication.

Chemical treatment is one method used to reduce internal phosphorus release in lakes and reservoirs. Aluminum sulfate (alum) and sodium aluminate are common chemicals used to mitigate phosphorus release from sediments. The chemicals are applied in liquid form to lakes and reservoirs in order to create an aluminum hydroxide floc that settles to the bottom of the lake. As the floc settles, it adsorbs phosphorus and flocculates sediment particles to the bottom of the lake, decreasing phosphorus concentrations in the water column and making the lake visibly more clear. The floc remains on the top of the sediments and creates a barrier between the sediment and overlying water, which reduces sediment phosphorus flux (Smeltzer, 1990).

This study aimed to analyze the internal phosphorus flux from bottom sediments at New Spiro Lake. The specific study objectives are: (1) measure internal phosphorus flux under aerobic and anaerobic conditions using intact bottom sediment cores and (2) determine effect of various rates of chemical treatment on sediment phosphorus release. The end goal is to understand how much phosphorus is released by bottom sediments relative to that entering from the watershed and whether chemical treatment is a viable option.

2. Methods and Materials

2.1 Site Description

New Spiro Lake provides drinking water to the residents of Spiro, Oklahoma, approximately 2,200 people. The reservoir was constructed in 1963 and covers 250 acres near the eastern Oklahoma border with Arkansas. Its volume is approximately 2,500,000 m³, with a maximum depth of approximately 7 m. The lake has recently experienced large summer algal blooms due to high levels of nitrogen and phosphorus in the water, making it a poor fish habitat and causing visual changes in the quality of the water. It is estimated that 15% of the nutrients come from lake bottom sediments and 85% come from external runoff (Source Water Collaborative, 2010). The flux from sediments, however, has not been quantified to date. This study focused on internal phosphorus sources from one sampling site, 35.196195, -94.617653, near the drinking water intake on the southeast side of the lake.



Figure 1. Map showing location of New Spiro Lake.

2.2 Experiment Procedure

Sediment Sampling

Eight intact sediment-water columns (cores) were collected at the sampling site using clear polyvinyl tubes (7.5 cm inside diameter), which were pushed into the sediment approximately 0.5 m with a hand-corer consisting of a one-way rubber valve on top of the tube and a 17 foot PVC pipe. A properly collected core has an intact sediment column and relatively clear overlying water. Cores were sealed with #14 stoppers, electrical tape, and duct tape for transport to the lab. A carboy of lake water was also collected at the sample site from the surface.

Core Preparation and Incubation

Once cores safely arrived at the lab, each core was adjusted with regard to sediment depth and volume of overlying water. Sediments were let out of the bottom of each core until 20 cm remained and the water levels were topped off to a total volume of 1 L of overlying water using the lake water collected during sampling. The cores were resealed on the bottom with #14 stoppers, duct tape, and electrical tape. Each core was wrapped in aluminum foil to keep light out, limiting the growth of algae in the cores. Four cores were incubated under anaerobic conditions by bubbling dinitrogen gas (N_2) into the water above the sediments (Cores 1-4). The other four cores were incubated under aerobic conditions by bubbling air into the water above the sediments (Cores 5-8). All eight cores were

incubated at room temperature for 41 days. After 19 days, the cores were treated with liquid alum and sodium aluminate at a ratio of 2:1. The four alum doses (0.05 mL, 0.1 mL, 0.2 mL, and 0.4 mL) and sodium aluminate doses (0.025 mL, 0.05 mL, 0.1 mL, 0.2 mL) were each applied to two cores (one aerobic, one anaerobic).

Sampling Procedure

Core water was sampled three times a week throughout the incubation in the lab. For each sample, 60 mL was removed from the water column using a large syringe with a segment of plastic tubing attached. The water was collected from the center of the overlying water in the core, several inches above the sediments so as to not disturb them. The water was filtered through a 0.45 μm filter into two 20 mL plastic vials. One was acidified with HCl to a pH of less than 2 for preservation and the other was frozen for future anion analysis. The acidified sample was used to determine concentrations of phosphorus and nitrogen in the forms of total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), nitrate plus nitrite nitrogen (NN), ammonia nitrogen (NH_3), and total dissolved nitrogen (TDN). This report, however, will focus solely on SRP measured in the water samples.

Data Analysis

Using the SRP concentration data collected from the overlying water in the cores, a phosphorus mass balance was created and corrected for water removed during sampling and water replaced after sampling. During each sampling event, 60 mL of core water is removed and replaced with 60 mL of lake water from the carboy. The concentration of the water removed is known, as well as the replacement water because it was also sampled every time the cores were sampled. An average phosphorus concentration, however, of the carboy is used in the mass balance. This mass balance allows the calculation of mass accumulated over time. The linear portion of mass accumulated over time in the overlying water was used in linear regression to estimate the slope (mg d^{-1}), which can be divided by the core area to estimate flux ($\text{mg m}^{-2} \text{d}^{-1}$). Based upon visual observation, the first 12 days represented the time period when concentrations increased linearly and these were the data used in linear regression to estimate flux under aerobic and anaerobic conditions.

3. Results and Discussion

Phosphorus Concentrations in Overlying Water

Initial SRP concentrations of overlying water in all cores ranged from 0.51 to 0.076 mg L^{-1} on the first day of sampling. In general, SRP concentrations increased in all cores to levels ranging from 0.122 to 0.161 mg L^{-1} in overlying water under anaerobic conditions and from 0.088 to 0.110 mg L^{-1} under aerobic conditions during the first 19 days of incubation. The increase was rather monotonic for the first 12 days, and then several of the concentrations leveled off and became variable.

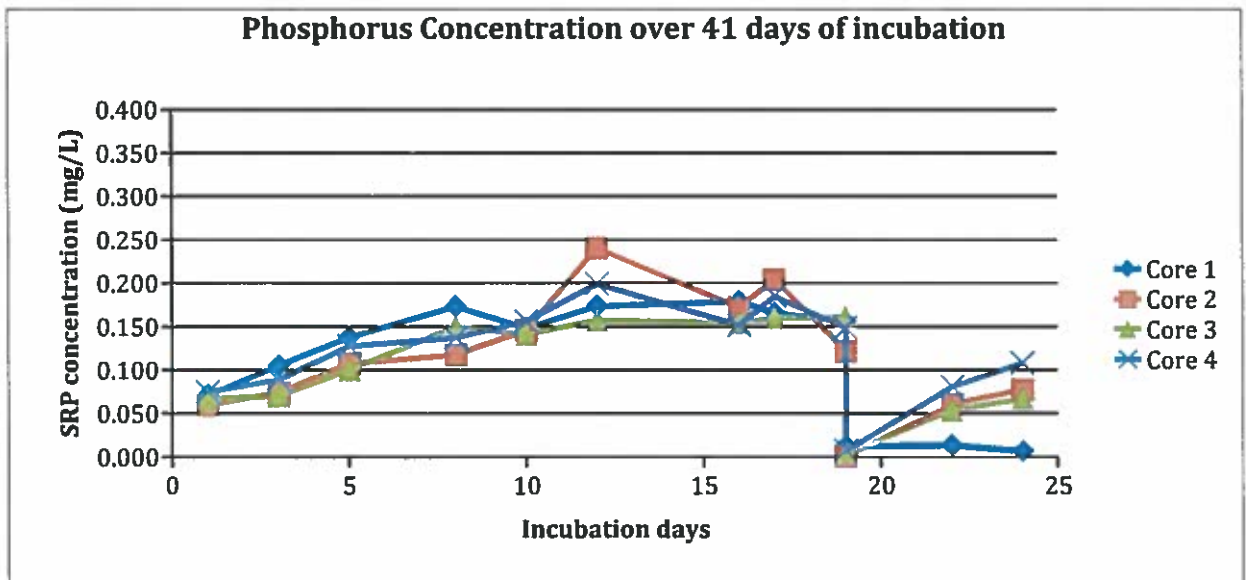


Figure 2. SRP concentrations in overlying water of anaerobic cores over 41-day incubation period.

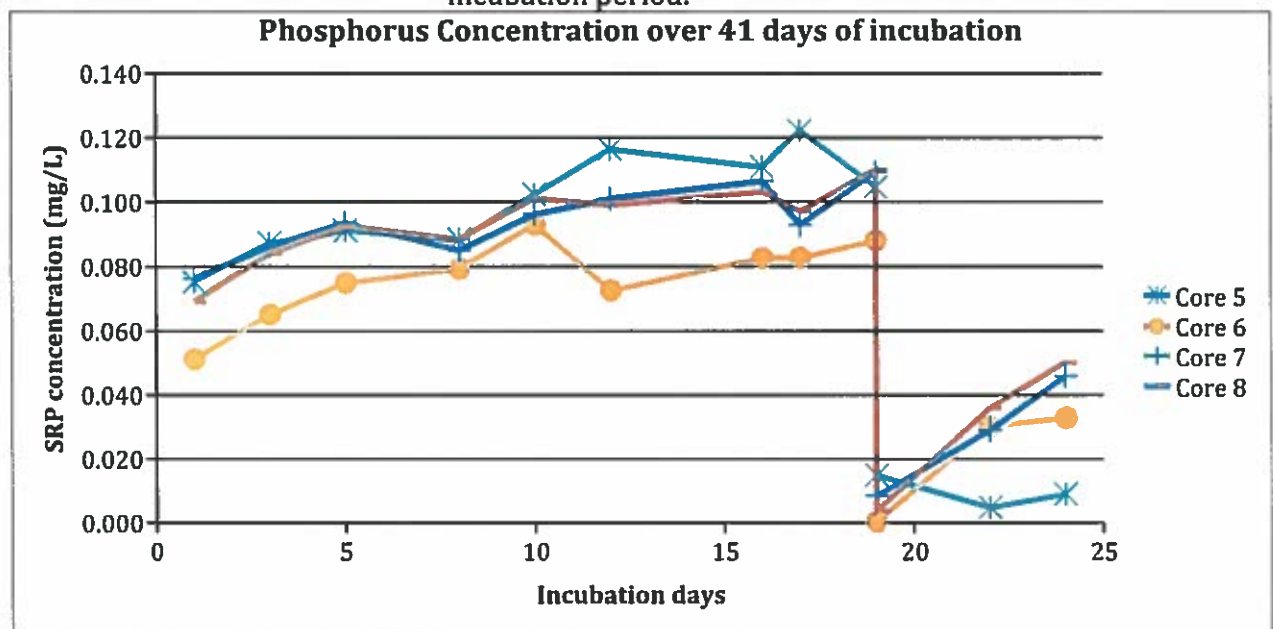


Figure 3. SRP concentrations in overlying water of aerobic cores over 41-day incubation period.

Phosphorus Flux from Bottom Sediments

The corrected mass data in the overlying water generally followed a linear pattern, where time explained more than 60% of the variability in phosphorus mass accumulating. The slopes from linear regressions of SRP mass over time were significant ($P < 0.05$). Based on these slopes and unit areas, the average phosphorus flux was $2.56 \text{ mg m}^{-2} \text{ d}^{-1}$ to the overlying water under anaerobic conditions and 0.61

mg m⁻² d⁻¹ under aerobic conditions. The fluxes measured in New Spiro Lake were within the range reported for other Oklahoma reservoirs in this region. For example, internal phosphorus flux in sediment cores from two other lakes in Oklahoma, Lake Eucha (Haggard, 2005) and Lake Wister (Haggard, 2012), ranged from 0.0 to 6.05 mg m⁻² d⁻¹ in anaerobic conditions and from 0.75 to 1.14 mg m⁻² d⁻¹ for aerobic conditions, so the flux values calculated are typical of water bodies in the region. As observed in other studies, the phosphorus flux under anaerobic conditions was greater than that observed under aerobic conditions (ANOVA, P < 0.05).

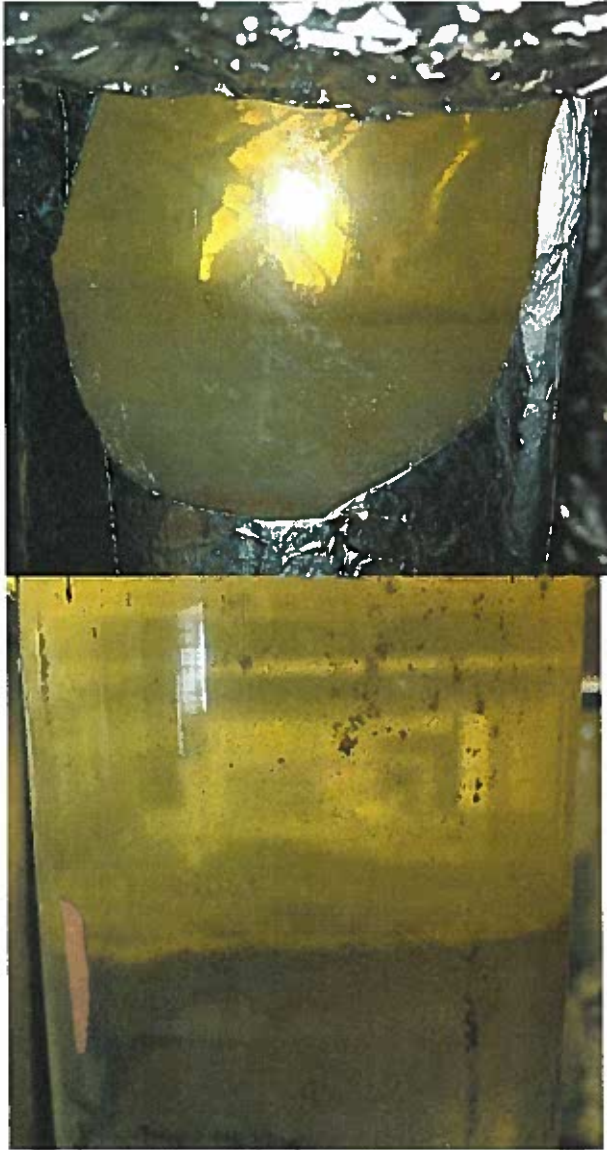
Table 1. Soluble reactive phosphorus flux from intact sediment cores collected on 30 January 2015 from one site in New Spiro Lake, Oklahoma.

	Core	Slope (mg d ⁻¹)	P Flux (mg m ⁻² d ⁻¹)
Anaerobic	1	0.0099	2.24
	2	0.0146	3.30
	3	0.0097	2.20
	4	0.011	2.49
Aerobic	5	0.0033	0.75
	6	0.0027	0.61
	7	0.002	0.45
	8	0.0027	0.61

Effect of Alum Treatment

Directly after chemical treatment with liquid alum and sodium aluminate, a floc was observed in each core. The thickness of floc varied proportionally with the amount of chemicals added. In the cores with the highest doses of alum, the floc was a thick white cloudy material approximately an inch thick. In the cores with the lowest doses of alum, the floc appeared as a cloudy dusting across the sediment-water interface, and the overlying water appeared cloudier than the other cores. After treatment, some cores seemed noticeably easier to filter during sampling.

After the alum treatment, the cores were incubated under the same conditions for an additional 22 days. The SRP concentrations in the overlying water of the cores decreased to < 0.01 mg L⁻¹ in both anaerobic and aerobic cores, representing a decrease of one to two orders of magnitude. The SRP concentrations in cores 1 and 5 (treated with the highest alum doses) continued to decrease for the next three days, however after those three days, SRP concentrations steadily increased to levels similar to that before treatment. Also, at the end of the incubation period, all visible floc had disappeared from the top of the sediments.



Figures 4. Core 1 directly after alum treatment (left) with thick, cloudy floc and core 1 at end of 41-day incubation with no visible floc.

At the end of the incubation period, SRP concentrations in the overlying water of the cores ranged from 0.074 to 0.171 mg L⁻¹ in anaerobic cores and from 0.057 to 0.114 mg L⁻¹ in aerobic cores. The concentrations varied proportionally to the amount of alum and sodium aluminate added.

In this study, the alum treatment was not successful at mitigating the internal phosphorus flux from bottom sediments. The average SRP concentration after incubation under anaerobic conditions decreased from 0.147 to 0.134 mg L⁻¹ and under aerobic conditions the average concentrations decreased from 0.103 to 0.085 mg L⁻¹. This decrease in concentration was not sufficient to determine the alum treatment a success. The reason as to why the alum was not as efficient at reducing sediment phosphorus flux is unclear. Possible explanations are physical or chemical

components of the lake water that were not considered or tested for, or the use of chemicals that had been stored for approximately six months and could have lost potency. Further study is needed to determine whether alum treatment of New Spiro Lake is a potential solution to reduce internal phosphorus loads from the bottom sediments to the water column.

4. References

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