References

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James, W. F. Barko, J. W., and Eakin, H. L. 1995. Internal phosphorus loading in Lake Pepin, Upper Mississippi River. *J. Freshwater Ecology*. 10: 269-276

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depth averaged aerobic internal phosphorus load estimation (180 kg/growing season) is a reasonable estimate for the phosphorus budget analysis and modeling.

Three approaches were used to determine a summer growing season (May 1- September 30) internal phosphorus load for Upper St. Croix Lake. These approaches were:

1) Separately calculate the average aerobic and anaerobic phosphorus release rates and then apply them throughout the lake without accounting for location or depth variations.
2) Use an average phosphorus release rates for different water depth ranges. GIS and WDNR bathymetric maps were used to assign an area to these depth ranges.
3) Distribute the depth averaged release rates between aerobic and anaerobic based on an average stratification depth of 4.6 meters.

Table 2 summarizes the growing season phosphorus release using these estimation approaches.

Table 2. Growing Season Internal Phosphorus Loading Estimates for Upper St. Croix Lake

Estimation Approach	Growing Season P (kg)
Average Aerobic Rate	252
Average Anaerobic Rate	491
Depth-Variable Aerobic Rate	115
Depth-Variable Anaerobic Rate	500
Aerobic Rate except for 90 days with depth greater than 4.6 meters where Anaerobic Rate Assumed	180

Discussion

A review of the oxygen and temperature profiles for Upper St. Croix Lake over the last seven years suggests little thermal stratification that could lead to an anaerobic environment above the sediment. As a result, the applying the anaerobic release rates lake-wide would most likely overestimate the total internal load. The range between the two aerobic rate calculations and the mixed aerobic/anaerobic rate would be between 115 and 252 kg/year. Further monitoring of Upper St. Croix Lake is needed to determine which approach and internal phosphorus load to use. At this time it is believed that the

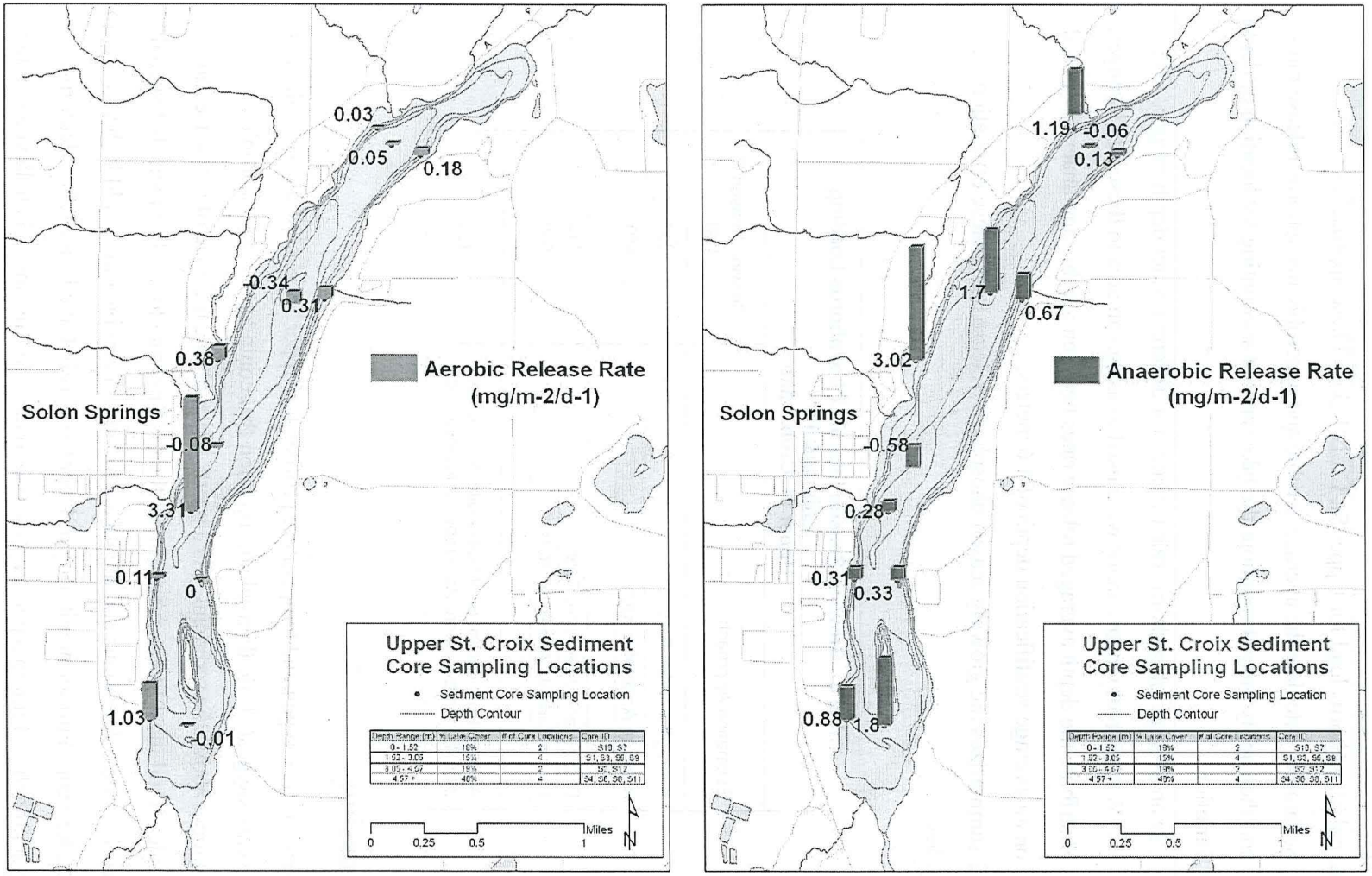

Figure 5 Spatial variations of laboratory derived aerobic and anaerobic phosphorus release rates.

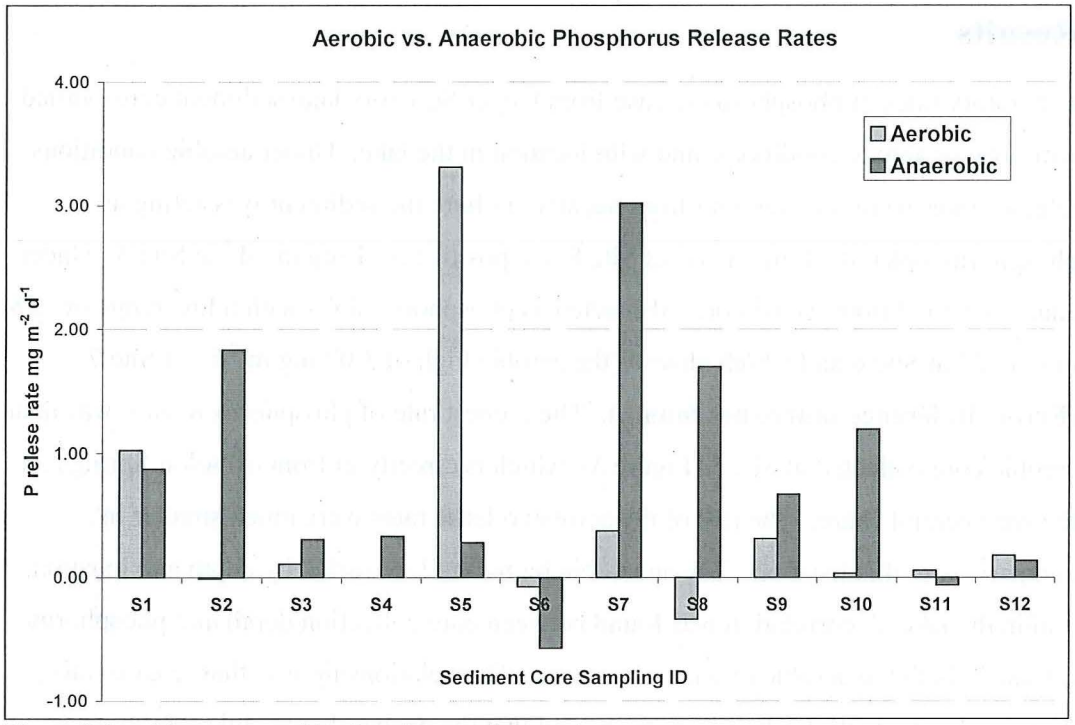

Figure 3 Aerobic vs. anaerobic phosphorus release rates.

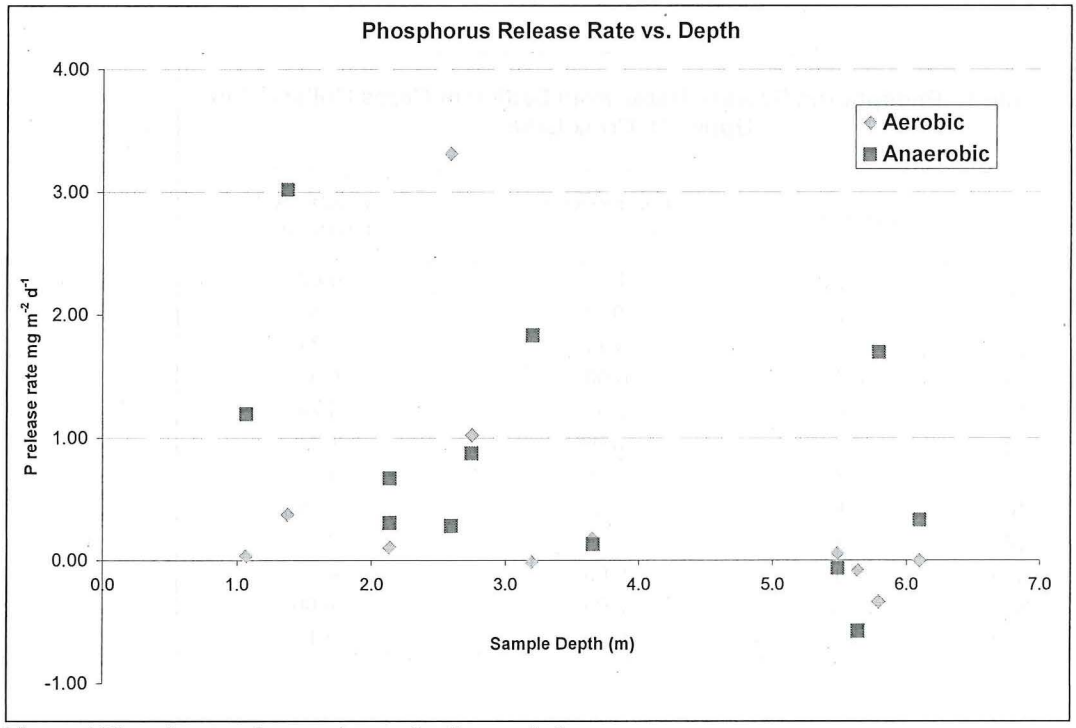

Figure 4 Phosphorus release rates vs. depth sampled.

Results

Laboratory rates of phosphorus release from Upper St. Croix lake sediment cores varied with oxic or anoxic conditions, and with location in the lake. Under aerobic conditions, releases rates were low, ranging from negative (where the sediment was acting as a phosphorus sink) -0.34 mg m^{-2} d^{-1} at Site 8 to a positive 3.31 mg m^{-2} d^{-1} at Site 5. Under anaerobic conditions, some cores also acted as phosphorus sinks with a low range of -.58 mg m^{-2} d^{-1} at Site 6 and a high close to the aerobic high of 3.02 mg m^{-2} d^{-1} at Site 7 (**Error! Reference source not found.**). The highest rate of phosphorus release was in an aerobic core collected at Site 5 (Figure 3), which is directly in front of Solon Springs on the west central shore. The rest of the aerobic release rates were much smaller in comparison to this location. The anaerobic highs and low varied by depth and location within the lake. A correlation was found between core collection depth and phosphorus release in both the aerobic or anaerobic cores. This relationship was that release rates decreased with depth for both conditions and that the deeper depths did seem to have some of the lowest release rates (Figure 4).

Table 1. Phosphorus Release Rates from Sediment Cores Collected in Upper St. Croix Lake

Site ID	Depth (m)	Aerobic Rate mg m^{-2} d^{-1}	Anaerobic Rate mg m^{-2} d^{-1}
S1	2.7	1.03	0.88
S2	3.2	-0.01	1.83
S3	2.1	0.11	0.31
S4	6.1	0.00	0.33
S5	2.6	3.31	0.28
S6	5.6	-0.08	-0.58
S7	1.4	0.38	3.02
S8	5.8	-0.34	1.70
S9	2.1	0.31	0.67
S10	1.1	0.03	1.20
S11	5.5	0.05	-0.06
S12	3.7	0.18	0.13

Samples were collected daily and monitored for pH. They were filtered through a 0.45 µm filter and analyzed for SRP using a Lachat auto-analyzer at the UWSP Watershed and Environmental Analysis Laboratory. The water that was removed by the sample was replaced with lake water that was kept under the same conditions of the cores. Rates of SRP exchange from the sediment (mg m^{-2} d^{-1}) were calculated as a change in concentration in the overlying water divided by time and the area of the core.

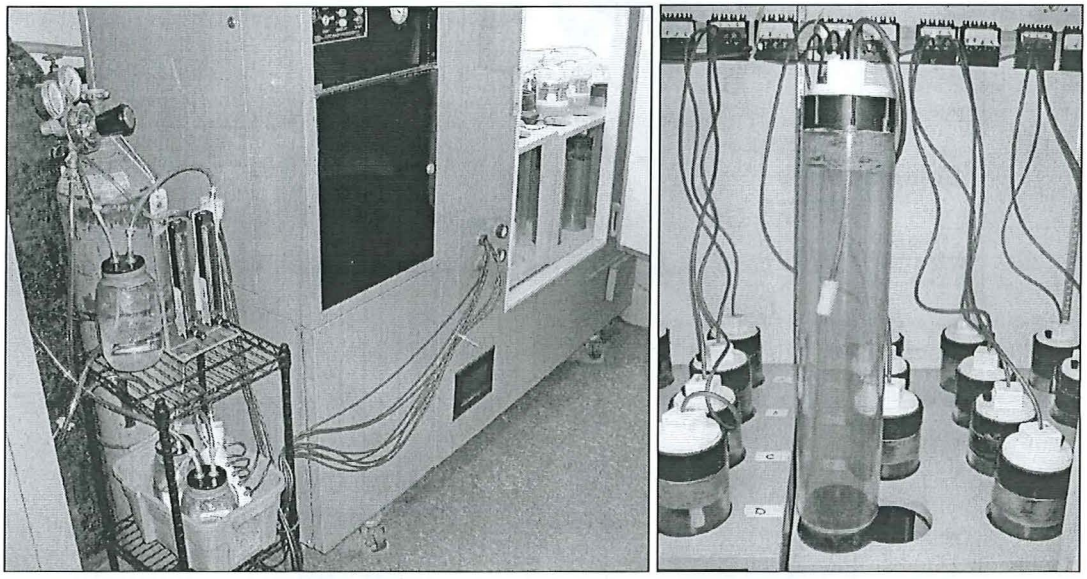

Figure 2 Environmental chamber housing sediment core incubation system.

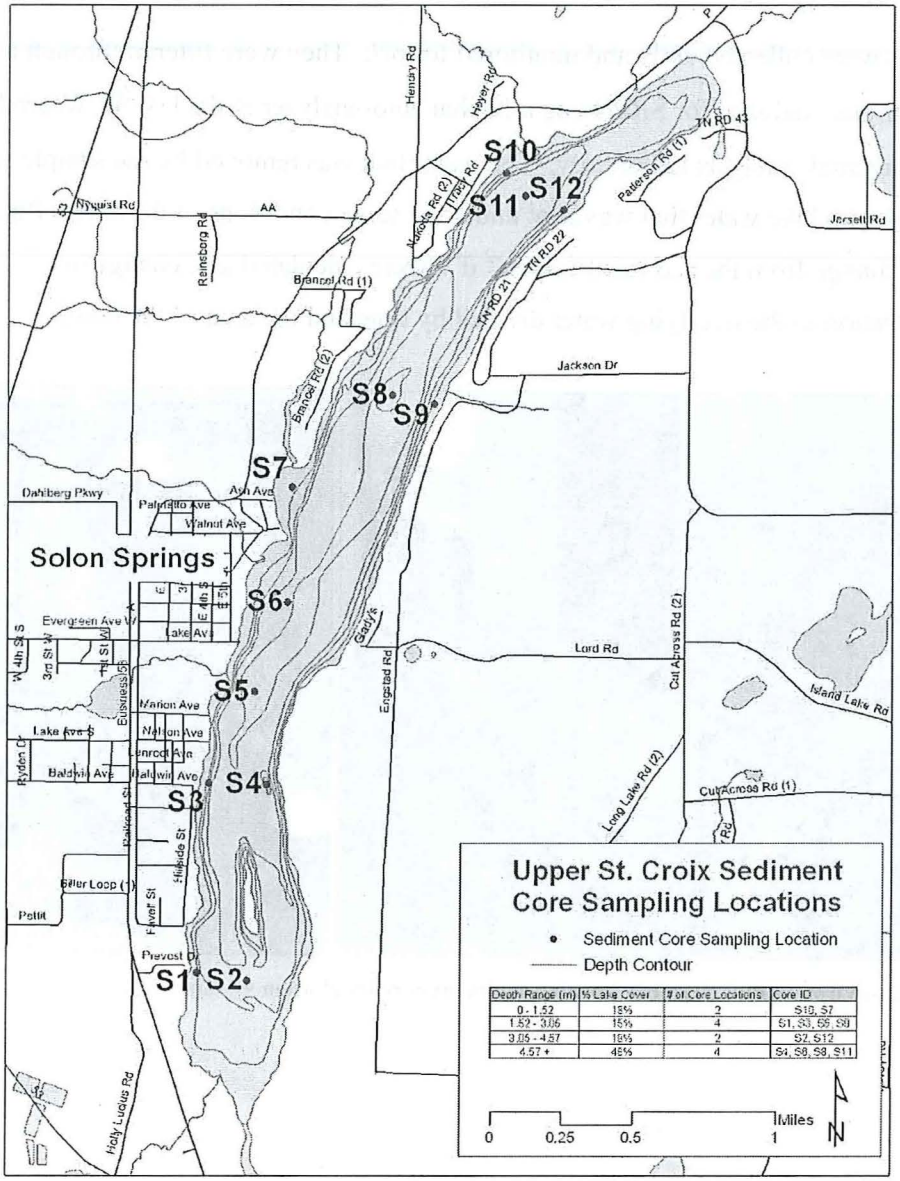

Figure 1 Sediment core sampling locations within Upper St. Croix Lake.

Overlying core water was decanted and replaced with filtered lake water from the location at which they were sampled. Care was taken not to resuspend sediment. The cores were randomly assigned one of two treatments and maintained for a 9 day incubation period. Rates of soluble reactive phosphorus (SRP) exchange at the sediment/water interface was calculated from a change in SRP concentration in the overlying water during the incubation period.

The source of eutrophication is not clear at this time. In the fall of 2005 algae samples were collected in the Upper St. Croix for identification of blue-green algae species. Aphanizomenon sp. (at 119,400 filaments/mL) and Anabaena sp. (at 45,800 filaments/mL) were identified in the sample. These concentrations are above the World Health Organization standards.

Methods

Phosphorus release from Upper St. Croix Lake sediments were measured using the approach of James and Barko (1991). This is a laboratory method that measures phosphorus release over time from sediment cores that were collected from the lake. Sediment cores were collected from twelve locations on March 3rd and 4th of 2007 by UWSP staff and students using a sediment corer equipped with an acrylic or clear PVC core liner (3.5 inch ID, 4.0 inch OD, and 18 inch length). This method created little disturbance at the sediment/water interface during sampling. Figure 1 shows the sample locations. Additional lake water was collected at the sampling location for use in incubation and replacement water. The cores were sealed with rubber caps and placed in a protective box for transport.

An environmental chamber housed a sediment core incubation system constructed according to James, et al. 1995 (Figure 2). The environmental chamber was maintained at 20° Celsius under zero light for 9 days to replicate conditions at the sediment surface during the summer. Phosphorus release was measured under both aerobic (oxidizing) and anaerobic (reducing) conditions. An aerobic environment in the bulk water was maintained by bubbling atmospheric air from an air compressor through an air stone just above the sediment surface. A reductive environment was controlled by bubbling nitrogen gas (N_2) from a compressed air tank. The amount of air was regulated to ensure full mixing of the water but without resuspending the sediment. Prior to entering the environmental chamber, the air was run through a hydration system of deionized water as to limit evaporation of the overlying core water. To control pH in the cores, either CO_2 or N_2 gas was mixed and regulated using a 65 and 150 mm air flowmeter to mimic normal lake pH. A mini-pH electrode (Orion Ross) was used to monitor pH.

Introduction

Sediment plays an important role in phosphorus cycling in a lake by acting as both a sink and source for phosphorus. Phosphorus is deposited on the lake bottom in particulate form within or attached to sediment particles and as dead plant and animal debris. As a result, lake sediment tends to accumulate phosphorus. An increase in external loading of phosphorus to lakes from tributaries, near shore runoff, and the atmosphere has been linked to increases in algae productivity and an accelerated rate of eutrophication. While these external nutrient contributions can contribute directly to algal productivity, they can also contribute indirectly through an increased accumulation and ultimately a release of phosphorus from the sediment. This study examined the importance of phosphorus release from the sediment of Upper St. Croix Lake as source of phosphorus during the summer growing season. Phosphorus release rates were measured in the laboratory from sediment cores taken at various depth and locations within the lake. This release rate can be included in a phosphorus budget analysis to determine its importance as a sink or source of phosphorus to the water.

Study Location

Upper St. Croix Lake is an 855 acre, naturally impounded lake that is the headwaters of the St. Croix River. It has a maximum depth of 22 feet. The lake receives water from groundwater, seven tributaries, surface runoff, and precipitation. There is significant residential development around much of the lake, with approximately two-thirds of the 9.5 mile shoreline developed (DNR, 1997).

Upper St. Croix Lake is a soft water lake with an average hardness value of 44 mg/L and alkalinity of 39 mg/L as CaCO3. The total nitrogen to total phosphorus ratios ranges from 12-50 and averages 22. During summer the growing season phosphorus concentrations have ranged from 12 ug/L in June to 48 ug/L in late August with chlorophyll *a* concentrations increasing similarly from 2 ug/L to 31 ug/L. Secchi depth declines during this time from more than 3.5 meters to less than 1.5 meters. Water quality monitoring and identification of blue green algae indicate that the Upper St Croix Lake is eutrophic.

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