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Phosphorus release and accumulation in the sediments of Fish and Pike Lake, Scott County, MN

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Objectives and background

Fish and Pike lakes are within the Prior/Spring Lake Watershed and have been classified as impaired waters with respect to nutrients by the Minnesota Pollution Control Agency. As a result, a Total Maximum Daily Load (TMDL) study is planned for these two lakes. The goals of this project were to: 1) quantify the amount of total and releasable phosphorus in the surface sediments of Fish Lake and Pike Lake; 2) estimate lake-wide phosphorus release rates for each lake using sediment-P concentrations and intact sediment core incubations; and 3) examine phosphorus accumulation since European settlement in Fish Lake. Lake sediments were collected on July 19, 2013 using gravity-type and piston-type corer to preserve the sediment-water interface.

Fish Lake P Fractions

Nine short sediment cores (20-30cm) were collected from Fish Lake and analyzed for phosphorus fractions in the upper six centimeters of sediment (Figure 1). Using a sequential digestion technique that dissolves bound phosphorus from the sediment (Hieltjes and Lijklema, 1980; Triplett et al., 2009), we quantified the amount of phosphorus extracted from a known mass of sediment. We calculated total P, calcium bound P, iron/aluminum bound P (Fe/Al bound P), loosely bound P, and organic P (Table 1). Together, the Fe/Al bound P and loosely bound P fractions constitute releasable phosphorus (Table 2). The majority of the releasable P is located near the deeper central parts of the basin, whereas the shallower sediments tend to have higher amounts of tightly bound phosphorus. Using the relationship established by Pilgrim et al. (2007) for Minneapolis – Saint Paul lakes, we estimated the P release rate for each site and then averaged the values across the lake basin to get an estimated potential rate of internal P release from the sediments (with standard deviation) (Table 2). We find that the sediments of Fish Lake have the potential to release 4.26 ± 2.74 mgP/m^2/day under anoxic conditions.

Pike Lake P Fractions

Pike Lake is a much shallower lake, with a maximum depth of 2.7m (Figure 2). At the time of sampling, the dissolved oxygen levels right above the surface sediments were quite low, at less than 1.0 ppm. Six short sediment cores were collected from Pike Lake and analyzed in the same way as the short cores from Fish Lake. Total phosphorus concentrations in these sediments are similar to Fish Lake (Table 3), but the amount of releasable P in the lake overall is nearly three times greater than Fish Lake, and the

potential release rates reflect these observations (Table 4). We find that the sediments of Pike Lake have the potential to release 12.9 ± 4.4 mgP/m^2/day under anoxic conditions.

Intact Sediment Core Incubations

We also carried out detailed measurements of total P released from the sediments to the overlying water from incubated sediment cores. Cores were collected and transported to the University of St. Thomas, where they were incubated at 10 ˚C (similar to the temperature reading in the field) following the methods outlined in Pilgrim et al. (2007). Three cores from Fish and Pike Lake were incubated under anoxic conditions, and three cores from Pike Lake were incubated under oxic conditions. The Fish Lake results were very similar to the values calculated from the sediment-P fractions, however the lake-wide mean is considerably higher (8.2 mgP/m^2/day), due to cores from the deepest locations being incubated (S1, S4, and S7 in Figure 1). We therefore feel that the sediment-P fractions more accurately reflect a whole-basin P-release potential. It is notable that the P-release in the cores occurred mainly within the first 2-3 days of the experiment. In Pike Lake, P-release values of 5.7 and 23.7 mgP/m^2/day were calculated for sites S3 and S5, respectively, while the third incubated core failed (Figure 2). Interestingly, the oxic cores quickly became effective at binding P from the overlying water. Indeed, the rate at which TP was being pulled from the water was 21.4 mgP/m^2/day. Similar to the findings from Fish Lake, we feel the results from the sediment-P fractions more accurately describe the whole-basin P-release potential under anoxic conditions.

Fish Lake piston core

We collected a 95cm sediment core from the central part of the Fish Lake basin (site S1, Figure 1), dated it and calculated the sedimentation rate using lead-210 radioactive decay. The age model allowed us to calculate the accumulation or flux of phosphorus to the lake bottom (mgP/cm^2/yr) over the past 160 years (Figure 3). Between 1910 and 1950, P flux rapidly increases to the highest levels present in the entirety of the collected record. We interpret the increasing P flux to be a result of increased agriculture following settlement of the area in the late 1800s, coupled with the increased usage of fertilizers towards the mid-1900s. Post-1950 the P flux returns to levels close to pre-European settlement. From 1980-1995, P flux rapidly decreases from 0.14 mgP/cm^2/yr to 0.08 mgP/cm^2/yr. In 1995, the P flux rapidly increases to 0.14 mgP/cm^2/yr. Czeck (2010) found a similar trend in phosphorus accumulation rate in Spring Lake, MN, and attributed the reduction to decreased agricultural activity during a period called the Farm Crisis. It follows that Fish Lake was possibly affected in the same way by the farming crisis.

Fish Lake X-ray Fluorescence for major elements

This study also yielded interesting geochemical results for other elements of interest. The biggest change in the lake's deposition started around 1910. Iron was the main element being deposited, but in 1910, calcium deposition starts to become more dominant, as the main element of deposition (Figure 4). Calcium concentration has increased almost 1500% since the late 1800s, and we interpret this to be a shift from erosional sedimentation dominating the system to chemical precipitation dominating the system. Other elements of interest include redox sensitive elements, which are susceptible to changes

in oxygen levels. These include sulfur and manganese, both of which have increased by at least 150% over the last 160 years. Manganese is probably being deposited as part of sulfide compounds, which is common in systems that regularly experience anoxic bottom-waters.

Conclusions

Our study yielded estimates of phosphorus release under anoxic conditions for both Fish Lake (4.26 ± 2.74 mgP/m^2/day) and Pike Lake (12.9 ± 4.4 mgP/m^2/day). Pike Lake has a higher P release potential than Fish Lake, but our incubation experiment also showed the potential for the P to bind to the sediments during oxygenated mixing periods. Historically, Fish Lake has experienced significant changes in TP accumulation over the last 160 years. A large increase in P flux to the sediments following European settlement and an intensification of farming (~ 1900 - 1950), has been nearly reversed in the post-1950 period following decreases in the late 1950s, 1980s and late-1990s.

References

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Figure Captions

Figure 1: Fish Lake bathymetry with overlying graphs showing % abundance of sedimentary-bound phosphorus fractions at each of the nine sampling sites. The green shades represent fractions that constitute releasable P.

Figure 2: Pike Lake with overlying graphs showing % abundance of sedimentary-bound phosphorus fractions at each of the six sampling sites. The green shades represent fractions that constitute releasable P. No bathymetric data is available for this lake.

Figure 3: Total sedimentary P (mg/g; grey line) and P flux (mg P / cm^2 / yr; black line) from the Fish Lake piston core.

Figure 4: XRF elemental analysis results for iron and calcium (left vertical axis) and sulfur and manganese (right vertical axis) from the Fish Lake piston core.

Table 1: Sediment characteristics and phosphorus concentrations for multiple cores within Fish Lake, Scott Co.

Core	interval (cm)	dry bulk density (g/cm3)	%moisture	%organic matter	%carbonate	%mineral	Sediment phosphorous concentrations (mg/g)					Mass per volume of sediment (mg/cm3)				
							Total	Loosely bound	Fe-Al bound	Ca bound	Organic (residual)	Total	Loosely bound	Fe-Al bound	Ca bound	Organic (residual)
S1	0-2	0.050	95.16	25.22	29.61	45.18	1.67	0.071	0.72	0.29	0.59	0.08	0.0035	0.036	0.014	0.029
	2-4	0.071	93.17	22.40	33.19	44.41	1.39	0.056	0.61	0.25	0.47	0.10	0.0040	0.043	0.018	0.034
	4-6	0.083	92.03	21.14	34.39	44.48	1.27	0.033	0.60	0.27	0.37	0.11	0.0027	0.050	0.022	0.031
	mean						*1.44*	*0.05*	*0.64*	*0.27*	*0.48*	*0.10*	*0.0034*	*0.043*	*0.018*	*0.031*
S2	0-2	0.054	94.72	26.45	26.46	47.09	1.31	0.061	0.33	0.26	0.66	0.07	0.0033	0.018	0.014	0.036
	2-4	0.074	92.85	24.61	29.16	46.24	1.36	0.039	0.32	0.26	0.74	0.10	0.0029	0.024	0.019	0.055
	4-6	0.082	92.15	24.31	28.83	46.86	0.99	0.049	0.28	0.30	0.36	0.08	0.0040	0.023	0.024	0.029
	mean						*1.22*	*0.05*	*0.31*	*0.27*	*0.59*	*0.08*	*0.0034*	*0.022*	*0.019*	*0.040*
S3	0-2	0.058	94.37	20.67	59.88	19.45	0.73	0.056	0.11	0.50	0.06	0.04	0.0032	0.006	0.029	0.003
	2-4	0.133	87.63	15.16	67.64	17.21	1.08	0.060	0.09	0.60	0.32	0.14	0.0079	0.012	0.080	0.043
	4-6	0.192	82.75	11.65	72.68	15.66	0.79	0.054	0.07	0.62	0.05	0.15	0.0103	0.013	0.119	0.010
	mean						*0.87*	*0.06*	*0.09*	*0.58*	*0.14*	*0.11*	*0.0072*	*0.011*	*0.076*	*0.019*
S4	0-2	0.059	94.31	22.69	19.78	57.53	1.10	0.043	0.29	0.31	0.45	0.06	0.0025	0.017	0.018	0.027
	2-4	0.115	89.18	20.69	19.98	59.33	1.12	0.038	0.22	0.57	0.29	0.13	0.0044	0.025	0.066	0.033
	4-6	0.129	87.97	20.32	20.17	59.51	1.08	0.031	0.23	0.32	0.49	0.14	0.0040	0.030	0.041	0.063
	mean						*1.10*	*0.04*	*0.25*	*0.40*	*0.41*	*0.11*	*0.0037*	*0.024*	*0.042*	*0.041*
S6	0-2	0.053	94.81	25.10	30.02	44.87	1.94	0.079	1.08	0.27	0.52	0.10	0.0042	0.058	0.014	0.028
	2-4	0.075	92.81	23.47	32.09	44.45	1.75	0.076	1.26	0.28	0.14	0.13	0.0057	0.094	0.021	0.010
	4-6	0.080	92.31	22.51	31.66	45.84	1.53	0.049	0.80	0.31	0.37	0.12	0.0039	0.064	0.025	0.029
	mean						*1.74*	*0.07*	*1.05*	*0.29*	*0.34*	*0.12*	*0.0046*	*0.072*	*0.020*	*0.022*
S7	0-2	0.065	93.76	24.03	29.40	46.57	1.21	0.044	0.31	0.26	0.59	0.08	0.0028	0.020	0.017	0.038
	2-4	0.082	92.18	23.31	30.14	46.56	1.15	0.034	0.30	0.25	0.56	0.09	0.0028	0.025	0.021	0.045
	4-6	0.093	91.19	22.53	30.09	47.38	0.89	0.036	0.26	0.29	0.30	0.08	0.0033	0.024	0.027	0.028
	mean						*1.08*	*0.04*	*0.29*	*0.27*	*0.48*	*0.08*	*0.0030*	*0.023*	*0.021*	*0.037*
S8	0-2	0.072	93.03	25.75	22.09	52.16	1.24	0.052	0.24	0.39	0.56	0.09	0.0038	0.017	0.028	0.040
	2-4	0.103	90.22	24.43	22.59	52.99	0.97	0.061	0.30	0.32	0.30	0.10	0.0063	0.031	0.033	0.031
	4-6	0.107	89.86	25.56	21.83	52.61	0.83	0.049	0.19	0.36	0.23	0.09	0.0052	0.020	0.038	0.025
	mean						*1.01*	*0.05*	*0.24*	*0.35*	*0.36*	*0.09*	*0.0051*	*0.023*	*0.033*	*0.032*
S9	0-2	0.066	93.59	27.00	20.47	52.53	1.06	0.052	0.27	0.24	0.50	0.07	0.0035	0.018	0.016	0.033
	2-4	0.088	91.62	26.28	20.47	53.24	1.20	0.055	0.23	0.19	0.71	0.10	0.0048	0.021	0.017	0.062
	4-6	0.100	90.47	26.48	20.56	52.96	1.30	0.057	0.18	0.25	0.82	0.13	0.0057	0.018	0.025	0.082
	mean						*1.19*	*0.05*	*0.23*	*0.23*	*0.68*	*0.10*	*0.0047*	*0.019*	*0.019*	*0.059*
S10	0-2	0.058	94.37	31.90	17.18	50.92	1.17	0.045	0.31	0.22	0.60	0.07	0.0026	0.018	0.013	0.035
	2-4	0.089	91.51	30.10	16.10	53.80	1.21	0.038	0.30	0.30	0.58	0.11	0.0034	0.026	0.026	0.051
	4-6	0.094	91.05	29.82	17.36	52.82	0.96	0.054	0.21	0.26	0.44	0.09	0.0051	0.020	0.024	0.041
	mean						*1.11*	*0.05*	*0.27*	*0.26*	*0.54*	*0.09*	*0.0037*	*0.021*	*0.021*	*0.042*

Table 2: Summary of P release rates from Fish Lake sediments		
Core	Potential Mobile P ($g/m^2/cm$)	Release Rate ($mgP/m^2/day$)
S1	0.46	6.29
S2	0.25	3.08
S3	0.18	1.99
S4	0.28	3.49
S6	0.77	10.87
S7	0.26	3.23
S8	0.28	3.50
S9	0.23	2.85
S10	0.25	3.07
Lakewide mean	**0.33**	**4.26**
Lakewide variability (sd)	0.18	2.74
Note: release rate is calculated using the linear relationship of Pilgrim et al. (2007) for phosphorus release against mobile P concentrations in sediment.		

Table 3: Sediment characteristics and phosphorus concentrations for multiple cores within Pike Lake, Scott Co.

Core	interval (cm)	dry bulk density (g/cm3)	%moisture	%organic matter	%carbonate	%mineral	Sediment phosphorous concentrations (mg/g)					Mass per volume of sediment (mg/cm3)				
							Total	Loosely bound	Fe-Al bound	Ca bound	Organic (residual)	Total	Loosely bound	Fe-Al bound	Ca bound	Organic (residual)
S1	0-2	0.1055	0.9004	16.6621	11.3982	71.9397	1.56	0.015	0.76	0.23	0.55	0.16	0.0016	0.080	0.025	0.058
	2-4	0.1522	0.8599	14.4538	11.9569	73.5893	1.18	0.015	0.50	0.23	0.43	0.18	0.0023	0.077	0.035	0.066
	4-6	0.1750	0.8409	14.2903	11.9188	73.7909	1.01	0.017	0.47	0.24	0.29	0.18	0.0030	0.082	0.042	0.051
	mean						*1.25*	*0.02*	*0.58*	*0.23*	*0.42*	*0.17*	*0.0023*	*0.079*	*0.034*	*0.058*
S2	0-2	0.1042	0.9016	16.0899	11.4597	72.4504	1.45	0.023	0.78	0.41	0.24	0.15	0.0024	0.081	0.043	0.025
	2-4	0.1558	0.8569	14.8285	11.9885	73.1831	1.41	0.010	0.78	0.28	0.33	0.22	0.0015	0.122	0.044	0.052
	4-6	0.1881	0.8301	14.2475	11.9797	73.7728	1.12	0.018	0.44	0.25	0.41	0.21	0.0034	0.084	0.047	0.077
	mean						*1.33*	*0.02*	*0.67*	*0.31*	*0.33*	*0.19*	*0.0024*	*0.095*	*0.045*	*0.051*
S3	0-2	0.0713	0.9313	22.0176	10.4672	67.5152	1.76	0.021	0.64	0.23	0.87	0.13	0.0015	0.046	0.016	0.062
	2-4	0.1146	0.8922	19.8632	9.6262	70.5106	1.35	0.010	0.47	0.23	0.64	0.16	0.0011	0.054	0.026	0.074
	4-6	0.1282	0.8803	18.5468	11.7061	69.7471	1.37	0.023	0.42	0.23	0.70	0.18	0.0030	0.053	0.030	0.090
	mean						*1.49*	*0.02*	*0.51*	*0.23*	*0.74*	*0.15*	*0.0018*	*0.051*	*0.024*	*0.075*
S4	0-2	0.1245	0.8838	13.8769	14.2152	71.9080	1.33	0.013	0.71	0.20	0.41	0.17	0.0017	0.088	0.025	0.051
	2-4	0.2176	0.8068	11.9969	16.5945	71.4085	1.03	0.011	0.39	0.28	0.36	0.22	0.0024	0.084	0.060	0.077
	4-6	0.2509	0.7809	11.8379	17.6494	70.5127	0.76	0.023	0.44	0.29	0.01	0.19	0.0059	0.110	0.072	0.002
	mean						*1.04*	*0.02*	*0.51*	*0.25*	*0.26*	*0.19*	*0.0033*	*0.094*	*0.053*	*0.043*
S5	0-2	0.2768	0.7619	8.9111	9.2397	81.8492	0.91	0.021	0.49	0.29	0.10	0.25	0.0059	0.136	0.081	0.029
	2-4	0.3553	0.7062	8.6022	9.8235	81.5743	0.81	0.016	0.37	0.23	0.19	0.29	0.0056	0.132	0.082	0.067
	4-6	0.4137	0.6675	8.0875	10.4394	81.4731	0.67	0.021	0.31	0.25	0.09	0.28	0.0086	0.127	0.104	0.039
	mean						*0.80*	*0.02*	*0.39*	*0.26*	*0.13*	*0.27*	*0.0067*	*0.132*	*0.089*	*0.045*
S6	0-2	0.1119	0.8948	14.3606	22.6371	63.0023	1.23	0.015	0.56	0.30	0.35	0.14	0.0017	0.063	0.034	0.040
	2-4	0.1840	0.8336	13.0858	14.6730	72.2412	0.96	0.013	0.41	0.23	0.31	0.18	0.0023	0.075	0.042	0.057
	4-6	0.2114	0.8116	12.5840	14.2090	73.2070	0.77	0.019	0.35	0.27	0.13	0.16	0.0039	0.073	0.058	0.028
	mean						*0.99*	*0.02*	*0.44*	*0.27*	*0.27*	*0.16*	*0.0027*	*0.071*	*0.045*	*0.042*

Table 4: Summary of P release rates from Pike Lake sediments		
Core	Potential Mobile P ($g/m^2/cm$)	Release Rate ($mgP/m^2/day$)
S1	0.82	11.65
S2	0.98	14.09
S3	0.53	7.29
S4	0.97	13.99
S5	1.38	20.19
S6	0.73	10.36
Lakewide mean	**0.90**	**12.93**
Lakewide variability (sd)	0.29	4.36
Note: release rate is calculated using the linear relationship of Pilgrim et al. (2007) for phosphorus release against mobile P concentrations in sediment.		

Figure 1: Fish Lake Phosphorus Fractions

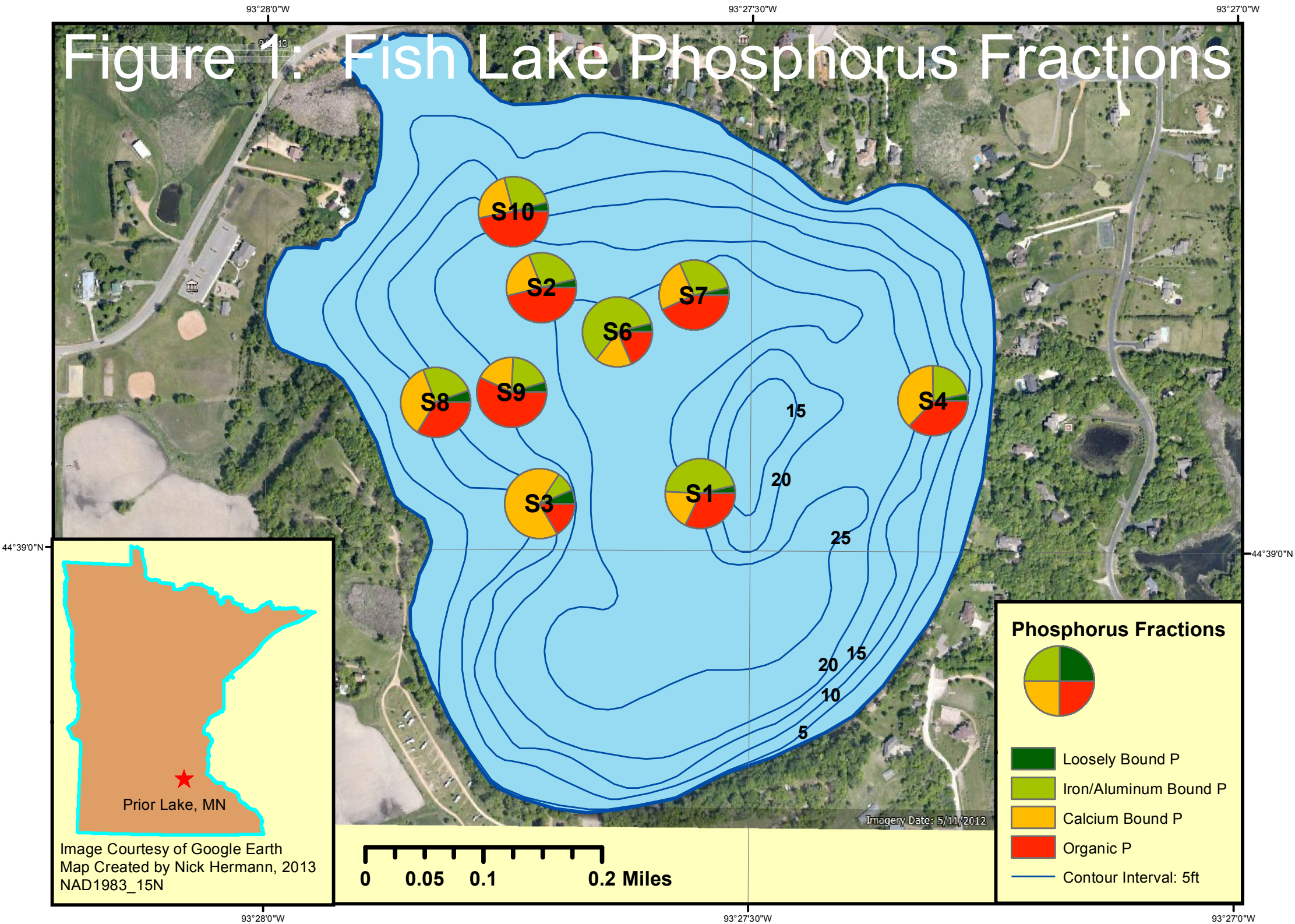

Figure 2: Pike Lake Phosphorus Fractions

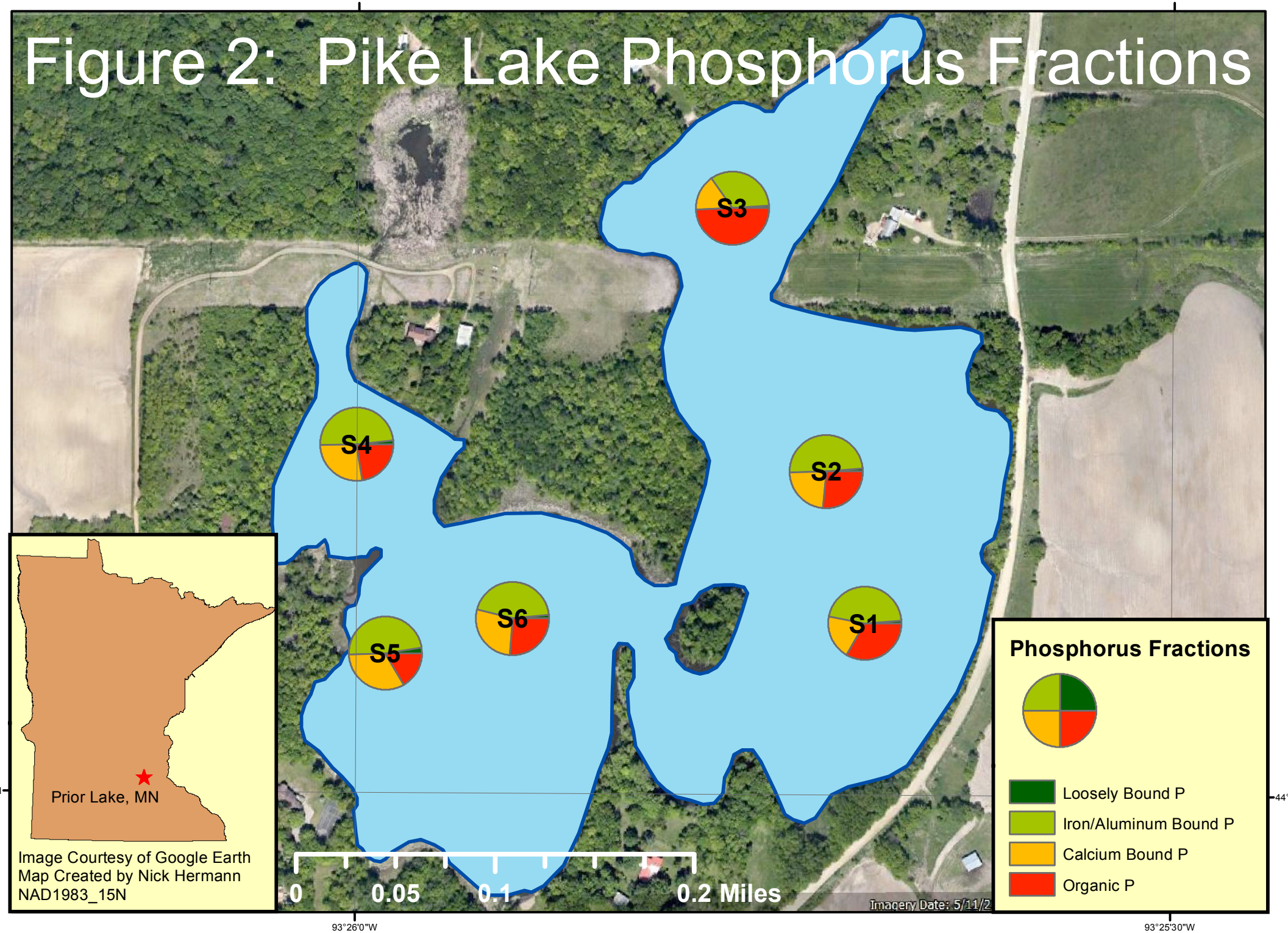

Figure 3: Sedimentary total phosphorus and phosphorus flux

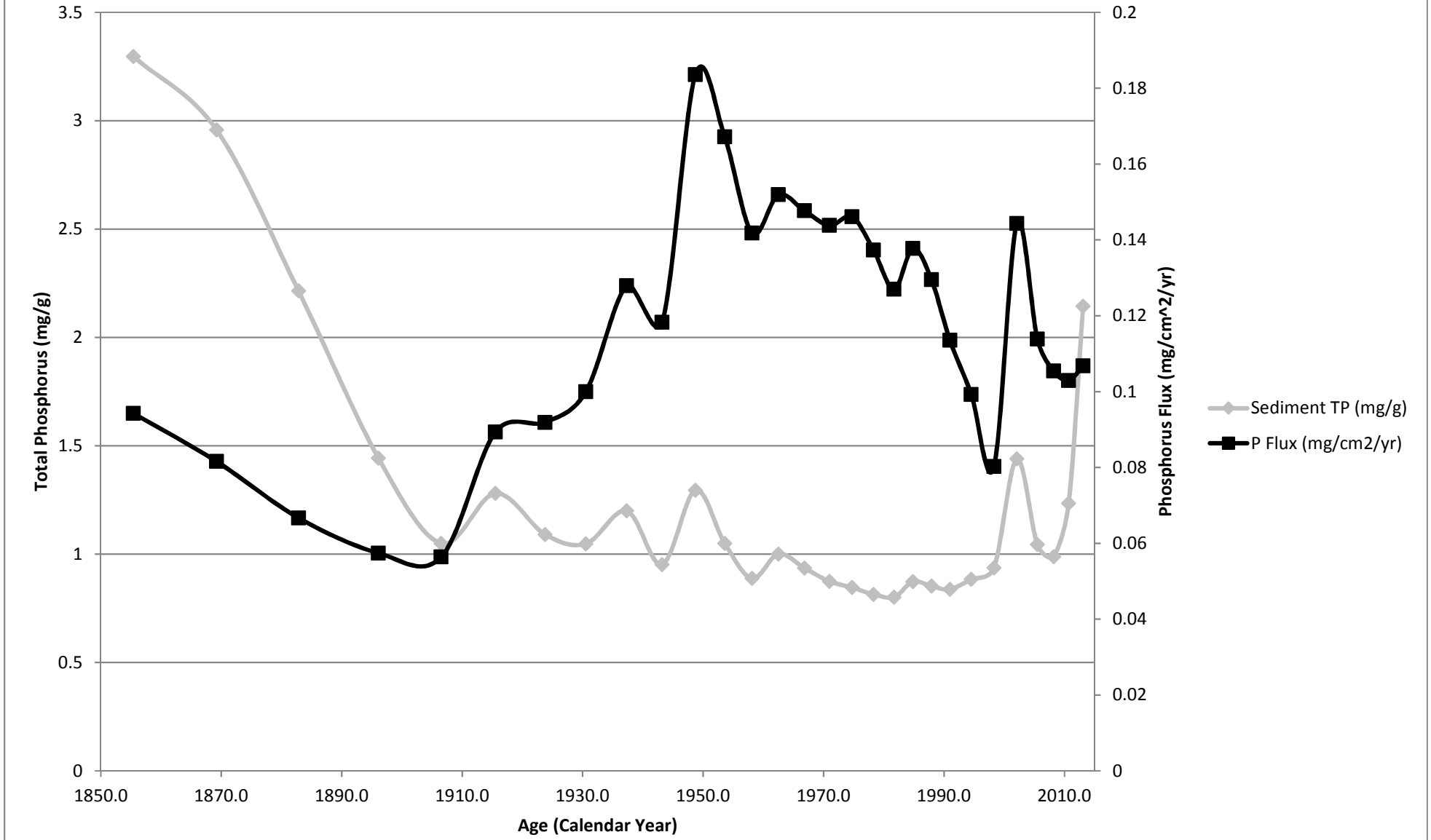

Figure 4: X-ray fluorescence elemental analysis results for Fish Lake