Phosphorus budget for Gull Lake, Michigan

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Background and previous studies

Gull Lake is one of the largest inland lakes in Michigan, with an area of 822 ha and a maximum depth of 33 m (Fig. 1). The Kellogg Biological station (KBS) campus is situated along its shore. This lake is unusual in southern Michigan because it supports a diverse fishery, including both warm- and cold-water species, and serves as an important recreational site for the region. Residential development lines the lakeshore; unlike most local lakes, there is no wetland along its shores and vascular plant growth in the littoral zone is sparse along most of the lakeshore.

The realization by the 1970s that Gull Lake was becoming increasingly eutrophic prompted studies of the linkage between nutrient loading and phytoplankton blooms, and those studies established that phosphorus (P) was the principal limiting nutrient for algal growth (Moss 1972, Moss et al. 1980, Tessier and Lauff 1992). Changes in P availability over time are therefore of particular interest with regard to water quality, including transparency, the risk of harmful algal blooms, and support of aquatic food webs leading to healthy fish populations.

Figure 1. Locations of the main inflows into and outflow from Gull Lake, Kalamazoo County, Michigan. Base map from Google Maps.

The P budget for Gull Lake needs to include P inputs via tributaries, groundwater emerging directly into the lake, precipitation, fertilizer use along the lakeshore, and excretion by migratory waterfowl that have fed elsewhere. Loss of P via the outflow stream (Gull Creek) also needs to be factored in. A hydrologic budget provides estimates of water volumes entering and leaving the lake, and P concentrations in inputs and outputs multiplied by rates of water flux yield total transport of P via tributary inflows, groundwater, precipitation, and the outflow. Estimates of water and P transport via inflows and the outflow must be interpolated between measurement dates; whereas precipitation sampling includes all events (i.e., rain and snow) throughout the year.

The hydrologic budget for Gull Lake for 1974 estimated that the lake receives 40% of its water from groundwater inflow, 25% from direct precipitation, and 35% from stream inflows (Tague 1977; Fig. 2). Evaporation was estimated from measurements at a meteorological station in South Haven, MI. Gross groundwater inflow was estimated by modeling. Tague's thesis included a phosphorus (P) budget for the lake for 1974, and concluded that septic systems and lawn fertilization comprised 76% of the annual P inputs, and that most of the P input was ultimately retained within the lake by sedimentation. Tague's budget showed that the sum of P sources to the lake considerably exceeded export via the outflow stream, which he attributed to net P retention by sedimentation. In the early 1980s lakeside homes were put on a sewer system to reduce septic inputs, which apparently led to reductions in summer algal blooms and improvements in water clarity in later years (Tessier and Lauff 1992).

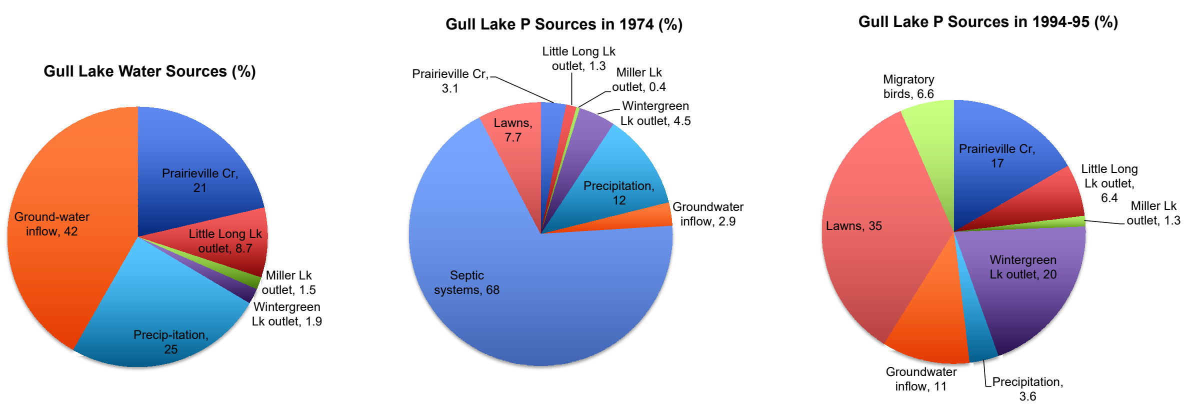

Figure 2. Gull Lake hydrologic budget and P sources for 1974 from Tague (1977) and P sources for 1994–95 estimated by Tessier (1995). P inputs from lawn fertilizer were unchanged from Tague's estimates. Fertilizer inputs as well as surface and groundwater P inflows became proportionately more important in Tessier's update mainly because septic system P inputs were assumed to have been eliminated. Tessier also estimated inputs from migratory birds, which were not included in Tague's budget.

Tessier (1995) put together a comparable hydrologic and P budget for Gull Lake for a year spanning Sep 1994–Nov 1995. As in Tague's (1977) budget, Tessier measured discharge and P concentrations in tributary inflows and the outflow. He used Tague's (1977) estimates of lawn fertilizer use, net groundwater inflow, and the inflow from the Wintergreen Lake outlet, and assumed that septic inputs had ceased because of diversion into the sewer system. Groundwater P concentrations were based on sampling of 31 domestic water supply wells in the vicinity of the lake. As with Tague's (1977) budget, Tessier (1995) found that the sum of estimated sources of P to the lake was higher than the outflow, suggesting net retention in the lake. Other water quality data in Tessier's report included vertical profiles of temperature and dissolved oxygen; oxygen drawdown in deep waters over the summer stratification period are an indicator of total lake productivity.

More recent research on Gull Lake has included observations and experiments to investigate the effects of the zebra mussel (*Dreissena polymorpha*), an invasive species that appeared in Gull Lake in the early 1990s, on phytoplankton composition. Studies were initiated in the late 1990s after visible scums of the harmful bloom-forming cyanobacterium *Microcystis aeruginosa* were observed in late summer in Gull Lake, which was surprising given the lake's low P concentrations. A series of publications eventually established that zebra mussels enhance the abundance of *Microcystis* in P-limited, oligotrophic to mesotrophic lakes such as Gull Lake (summarized in Bahlai et al. 2021). The critical role of P as the most limiting nutrient for phytoplankton growth in Gull Lake has been reconfirmed more recently (Hamilton et al. 2007). Other recent research in Gull Lake has included bacterial transformations of nitrogen (nitrification and denitrification) by Bruesewitz et al. (2012), and lake mixing processes simulated with hydrodynamic modeling by Safaie et al. (2017). Study of the lake has continued, with limnological measurements conducted by both the Hamilton and Litchman labs at KBS, as well as sampling of the lake by the Gull Lake Quality Organization as part of the state's Cooperative Lakes Monitoring Program, which measures total P among other water quality variables.

Objectives

In this report, we summarize measurements of the P budget of Gull Lake, comparing a recent year of measurements (2013–14) of tributary inflows and the outflow with similar measurements made for the P budgets compiled by Tague (1977) and Tessier (unpublished). Tessier's unpublished data are included as Appendix B. The 2013–14 data do not represent as complete a budget as the two previous ones, but are useful to consider whether watershed inputs of P via tributary inflows are changing. Watershed inputs are a particular concern for the Gull Lake Quality Organization because of new confined animal feeding operations and the applications of manure on croplands within the Gull Lake watershed.

Methods for the 2013–14 P budget

The 2013–14 update only included tributary inflows and the outflow. Calculations of the annual P transport in tributary inflows and the outflow span 15 Oct 2013–14 Oct 2014. Water samples were collected on 17 dates throughout the year at the main inflows (Prairieville Creek at M43, Little Long Lake outflow at M43, and the Wintergreen Lake outflow) and at the Gull Creek outflow just below the Gull Lake dam (Fig. 1).

On each sampling date, discharge measurements were taken using a Marsh-McBirney flow meter at Prairieville Creek and the Little Long Lake outflow. Prairieville Creek is split into two channels downstream of highway M43, so sampling was always conducted just above M43. For the Wintergreen Lake outflow, water level measurements in a Parshall flume at the KBS Bird

Sanctuary allowed estimation of discharge using the relationship provided by the manufacturer. Discharge at the Gull Lake dam needed to account for the changes in outflow configuration that were recorded based on emails from the operators (Roger Turner and Bill English), changes in lake level measured at the dam, and the relationship between outflow configuration and flow measured on 3 Apr 2014. (That dam has since been rebuilt.)

We also monitored water levels continuously in the inflows and outflow using Solinst water level loggers corrected for barometric pressure variation. We had planned to construct stage-discharge relationships to estimate daily discharge, but the observed relationships were poor, so we used the mean of all sampling dates as the mean annual discharge for Prairieville Creek and the Little Long Lake outflow, and the Parshall flume rating equation for the Wintergreen Lake outflow. These shallow channels—even inside the flume—were evidently subject to variable damming by organic debris that interfered with the expected stage-discharge relationships.

Results and Discussion

The hydrologic budgets for the three years consistently indicated that precipitation and Prairieville Creek were the largest water sources to Gull Lake (Fig. 3). Based on the analysis by Tague (1977), groundwater inflow is likely higher than either of the aforementioned inflows; neither Tessier (1995) nor the current study estimated groundwater inflows.

The sum of precipitation and tributary inflows was smaller than the outflow discharge in each of the three years. The higher outflow of water can mostly be accounted for by net groundwater inflow directly into the lake. The absolute groundwater inflow is undoubtedly higher than the difference between inflows and the outflow in Fig. 3 because evaporative water loss is also an important term in the lake's hydrologic budget, as noted earlier (but evaporation does not remove P from lake water).

Concentrations of total P were far higher in the Wintergreen Lake outflow than in other water sources to the lake, although they were lower in the 2013–14 budget than in the two previous budgets (Fig. 4). Plotting the same data without the high Wintergreen Lake outflow concentrations shows greater variation among the three budgets than was apparent in the hydrologic budgets (Fig. 5).

The P budgets for the three annual periods, summarized as transport of total P into and out of Gull Lake, are shown in Figure 6. Precipitation inputs show large variability and were far lower in Tessier's (1995) study, suggesting issues with P contamination of samples in the collectors deployed in the other two annual periods because only Tessier collected precipitation from a special sampler that opens when liquid precipitation is detected, and was located in an open area away from vegetation canopies.

Tributary inflows of total P were lower in the 2013–14 budget at all three locations (Fig. 6). The sum of inflows was not much lower than in the 1994–95 budget because of the higher precipitation estimate for 1994–95, which however may be inaccurate as discussed in the previous paragraph. The Gull Lake outflow carried considerably less total P in 2013–14 than in the other two budgets, reflecting the lower concentrations as shown in Figure 5.

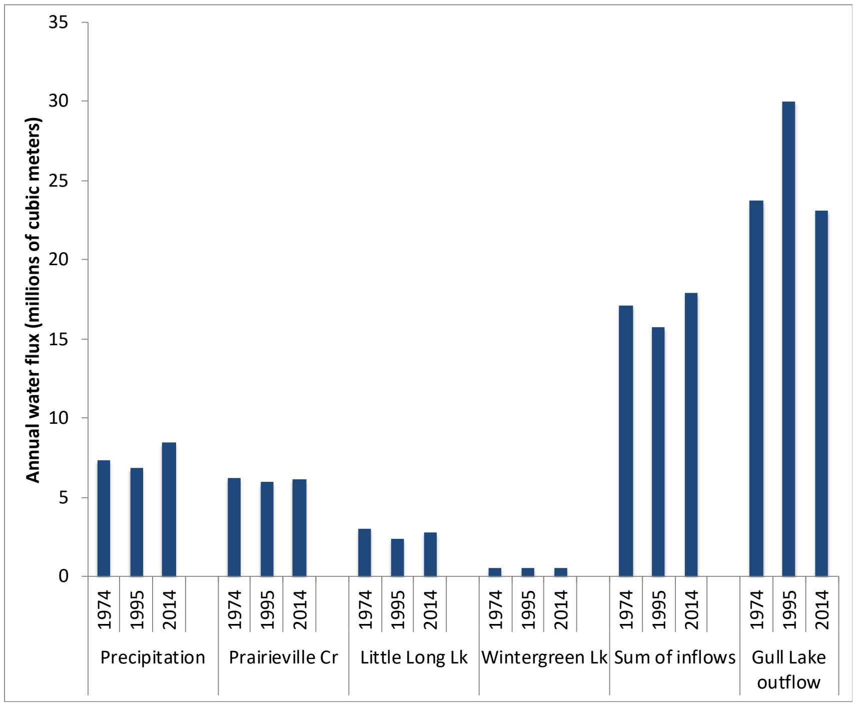

Figure 3. Annual water inputs and drainage via the outflow at Gull Lake.

The greatest uncertainties in the three total P budgets for Gull Lake include the concentrations in precipitation, although Tessier's (1995) measurements are probably the most accurate, and the volume and P concentrations in groundwater inputs. Lawn fertilizer (Tague 1977) and migratory bird inputs (Tessier 1995) are only approximate estimates. Campaigns by the Gull Lake Quality Organization to encourage residents to avoid fertilizers containing P, as well as a statewide ban since 2012 on P in fertilizer for routine lawn applications, have presumably reduced P fertilizer use. However, soils in lakeshore lawns probably still contain legacy P from decades of over-application and would be expected to leach P for years after inputs cease.

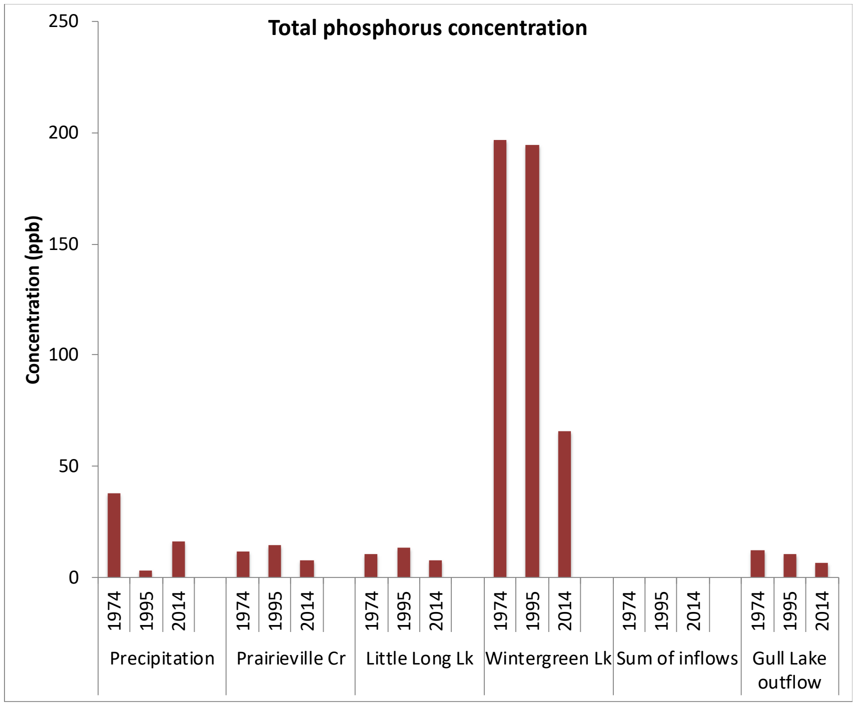

Figure 4. Total P concentrations in precipitation, tributary inflows, and the outflow of Gull Lake.

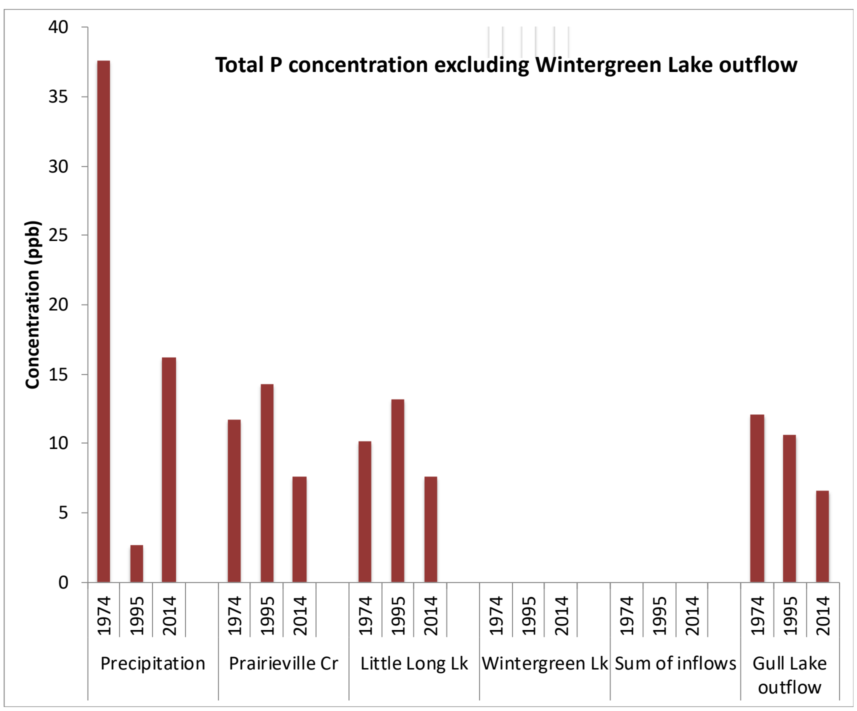

Figure 5. Total P concentrations in precipitation, tributary inflows, and the outflow of Gull Lake, but excluding the Wintergreen Lake outflow to better show interannual variation at the other sites.

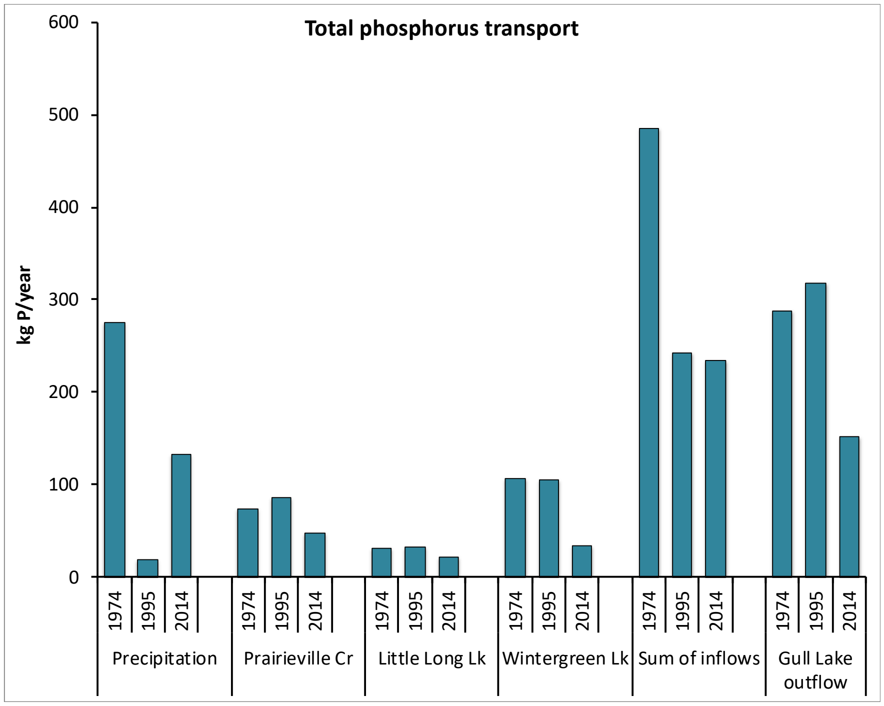

Figure 6. Total P transport into Gull Lake via precipitation and tributary inflows and out of the lake via the Gull Creek outflow.

Total P concentrations in the surface water (epilimnion) of Gull Lake do not appear to have changed greatly over the years spanned by the three P budgets (Appendix A). Tessier and Lauff (1992) presented evidence for a substantial decline in total P after installation of the sewer system in the early 1980s (Fig. A.1), but since that time concentrations have been fairly stable, generally falling in the range of 2–10 ppb in recent years, characteristic of oligotrophic conditions (Figs. A.2 and A.3). Concentrations of chlorophyll-a, an indicator of total phytoplankton biomass, have also been fairly stable over the past two decades, falling in the oligotrophic range most of the time.

In conclusion, P budgets for Gull Lake over three annual periods spanning 40 years show the main sources of P to the lake, with the earliest budget by Tague (1977) being the most comprehensive, and latest one (2013–14) presented in this report focused on surface-water inflows and outflow. The latest budget indicates lower total P concentrations in tributary inflows, and therefore suggests that watershed P inputs have not increased, even though livestock operations and associated manure applications to croplands have grown in the watershed over the past couple of decades.

Acknowledgements

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Kellogg Biological Station and by Michigan State University AgBioResearch. The earlier P budgets were supported in part by the Gull Lake Quality Organization.

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Appendix A. Total phosphorus measurements in Gull Lake.

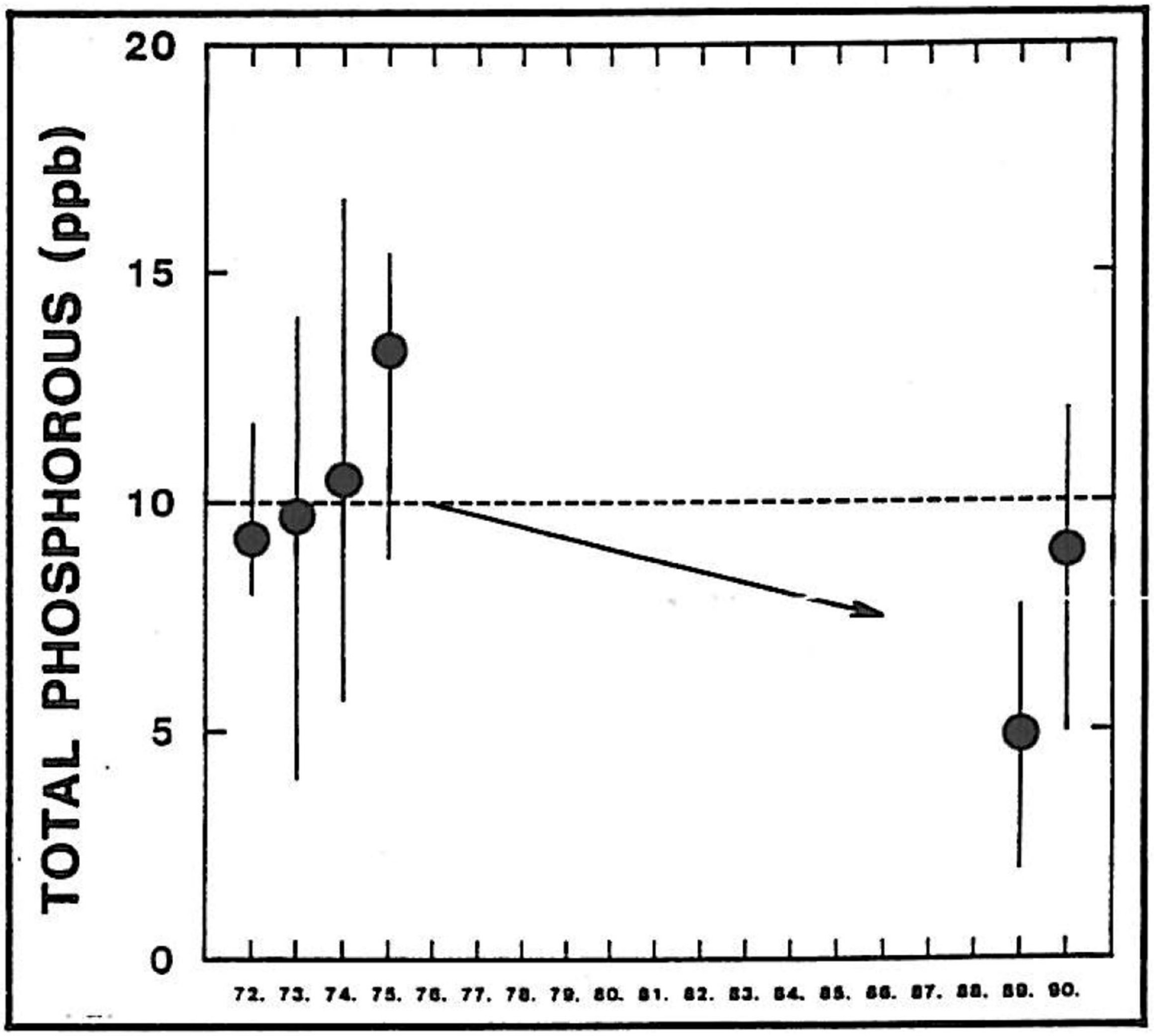


Figure A.1. Total P in the upper mixed layer (epilimnion) of Gull Lake, excerpted from Tessier and Lauff (1992). The years on the x axis range from 1972–1990.

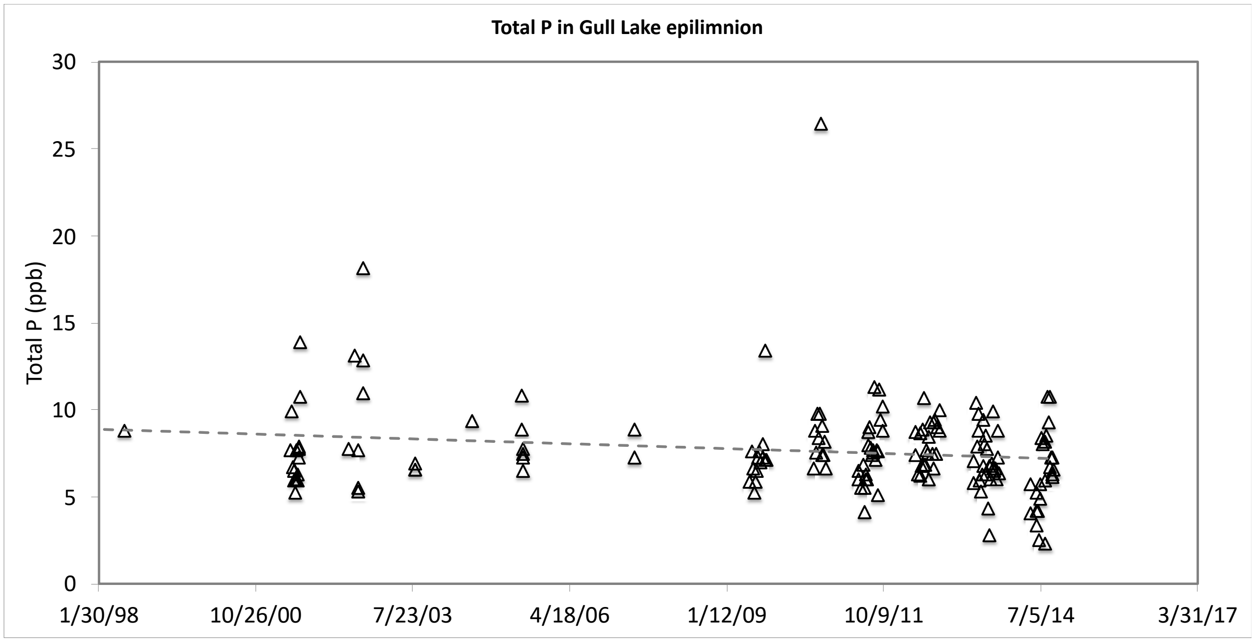
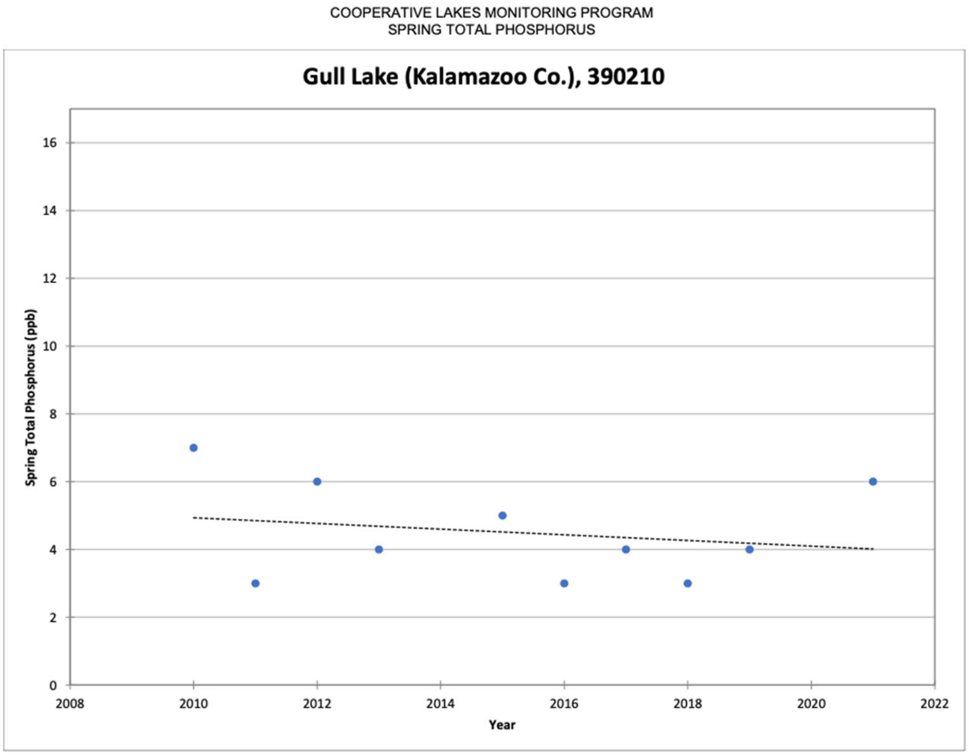


Figure A.2. Hamilton lab measurements of total P in the center of Gull Lake over summers when zebra mussel research was being conducted. The statistical significance of the trendline is difficult to evaluate in light of the unbalanced sampling effort over time.



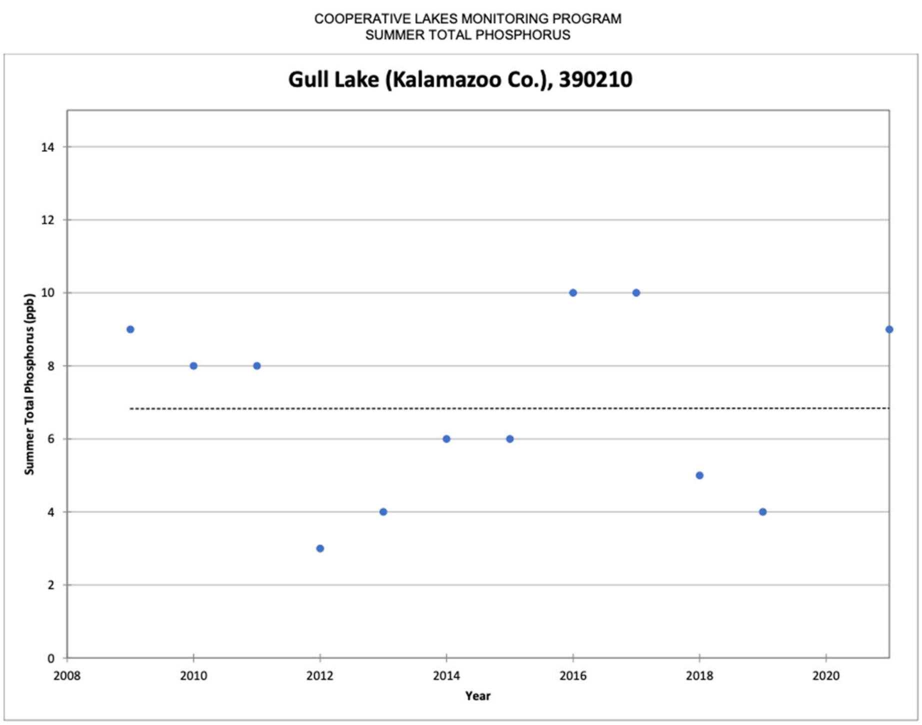


Figure A.3. Total P measurements made on samples collected by Gull Lake Quality Organization volunteers through the Cooperative Lakes Management Program. Statistical details on the trendlines were not provided and their slopes may not be significantly different from zero. Accessed 12 Oct 2022 from https://micorps.net/wp-content/uploads/2022/03/CLMP-Gull-Kalamazoo-390210.pdf

Appendix B (all following pages). Phosphorus budget information for Gull Lake from Tessier (1995).

GULL LAKE PHOSPHORUS BUDGET 1995

Alan Tessier

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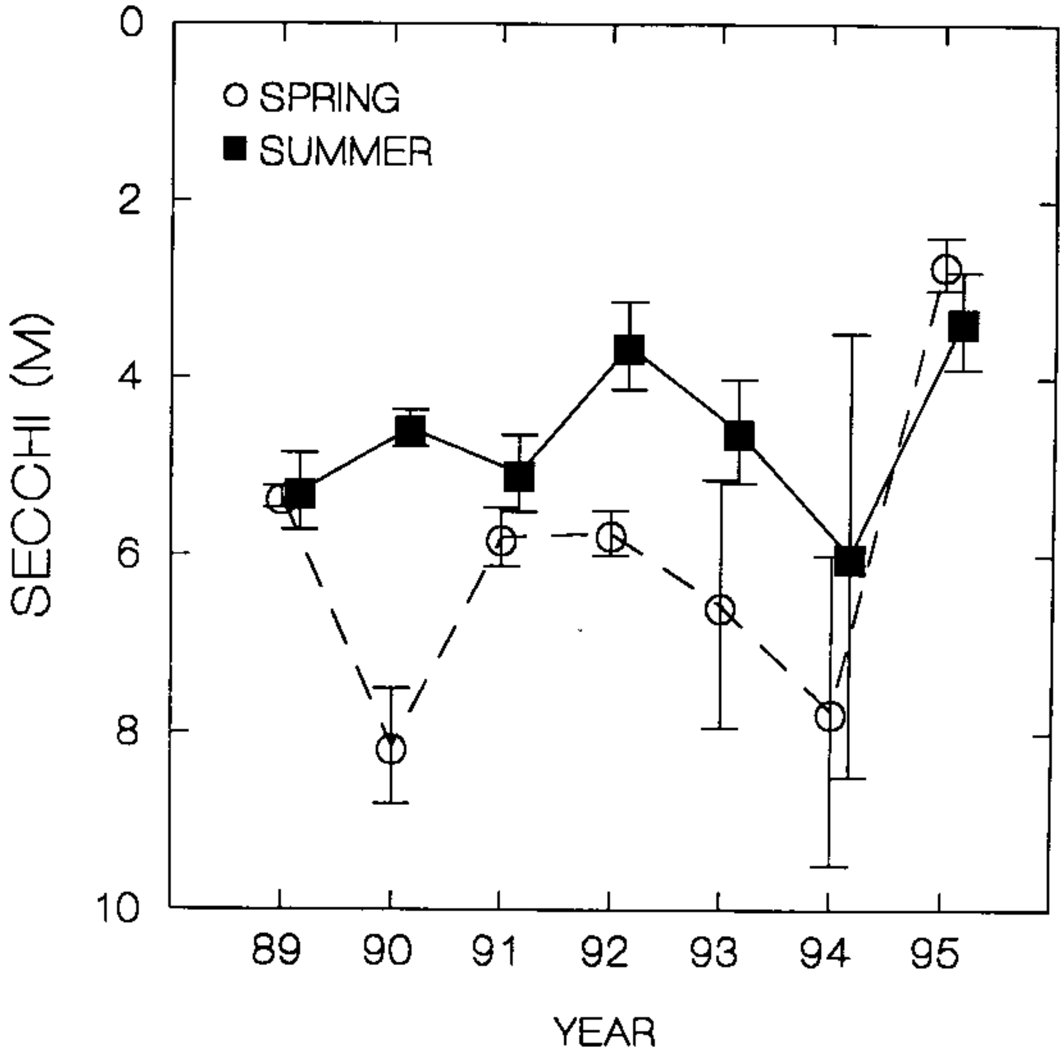

SPRING
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95
YEAR

Summary of the hydrologic budget for Gull Lake for 1994-1995.

	Annual Supply (%)	Annual Volume ($10^6 m^3/yr$)
Tributary inflow		
Prairieville	21.37	5.94
Little Long Lake outlet	8.67	2.41
Miller Lake outlet	0.07	0.02
Miller Lake boathouse	1.47	0.41
Wintergreen	1.94	0.54
Total tributary inflow	33.53	9.32
Precipitation	24.75	6.88
Ground water inflow (net)	41.73	11.6
Total supply	100	27.80
Gull Creek outflow		30.03
Evaporation		?
Storage Change		?

(Table 9, pg. 42 Tague's thesis.)

(Note: Wintergreen value is from Tague's thesis. Our value was 0.31 for the annual volume.)

(Note: The groundwater value is from Tague's thesis. The difference between the total inflow and outflow may due to an increase in groundwater inflow.)

Summary of the total phosphorus budget for Gull Lake for 1994-1995. Symbols used represent: mean concentration (C); annual supply (J); percentage of supply from each source; and areal loading rate (L).

	C (mg/m^3)	J (kg/yr)	%	L ($mg\ m^{-2}\ yr^{-1}$)
Natural supply				
Prairieville Creek	14.3	86.2	16.7	10.4
Little Long Lake outlet	13.2	32.9	6.4	4.0
Miller Lake outlet	29.3	0.3	0.1	0.04
Miller Boathouse	14.6	6.1	1.2	0.74
Wintergreen Lake outlet	194.5	104.6	20.2	12.6
Total from tributaries		230.1	44.4	27.8
Precipitation	2.7	18.5	3.6	2.2
Ground water	4.9	55.8	10.8	6.9
Total natural supply		304.4	58.8	36.9
Artificial Supply				
Fertilizer		179	34.6	21.6
Migratory birds		34.3	6.6	4.1
Total Supply		517.7	100	62.6
Losses				
Gull Creek outflow	11.5	318.3		
Sedimentation	?	?		
Total loss	?	?		
Loss to sediments exceeding inputs		?		

(Table 19, pg. 82 Tague's thesis.)

(Note: Wintergreen J and L is based on Tague's annual flow data.)

(Note: Fertilizer estimate from Tague.)

Table 9. Summary of the hydrologic budget for Gull Lake for 1974.

	Annual Supply (%)	Annual Volume ($10^6 m^3/yr$)
Tributary inflow		
Prairieville Creek	21.2	6.21
Long Lake outlet	10.3	3.03
Miller Lake outlet	2.2	0.648
Wintergreen Lake outlet	1.8	0.538
Total tributary inflow	35.5	10.4
Precipitation	25.0	7.32
Ground water inflow (net)	39.5	11.6
Total supply in 1974	100	29.3
Gull Creek outflow		23.7
Evaporation		6.26
Storage change		- 0.64

Table 19. Summary of the total phosphorus budget for Gull Lake for 1974. Symbols used represent: mean concentration (C); annual supply (J); percentage of supply from each source; and areal loading rate (L).

	C (mg/m^3)	J (kg/yr)	%	L ($mg\ m^{-2}yr^{-1}$)
Natural supply				
Prairieville Creek	11.7	72.7	3.1	8.8
Long Lake outlet	10.2	31.1	1.3	3.8
Miller Lake outlet	14.6	9.46	0.41	1.1
Wintergreen Lake outlet	197	106	4.5	12.8
Total from tributaries		219	9.4	26.5
Precipitation	37.6	275	11.8	33.3
Ground water	5.86	68.0	2.9	8.2
Total natural supply		562	24.1	68.0
Artificial supply				
Disposal (septic) systems				
Residences		1503	64.5	182
Institutions		87.0	3.7	1.1
Lawn fertilization		179	7.7	21.6
Total artificial supply		1769	75.9	214
Total supply		2331	100	282
Losses				
Gull Creek outflow	12.1	287	11.4	
Sedimentation		2225	88.6	
Total loss		2512	100	
Loss to sediments exceeding inputs		181		

Mean daily discharge and monthly flow volumes for Prairieville Creek and Little Long Lake outlet during 1994-1995.

Month	Prairieville Creek			Little Long Outlet		
	Mean Daily Discharge m^3sec^{-1}	Mean Daily Discharge $10^3m^3day^{-1}$	Monthly Flow Volume $10^3m^3mon^{-1}$	Mean Daily Discharge m^3sec^{-1}	Mean Daily Discharge $10^3m^3day^{-1}$	Monthly Flow Volume $10^3m^3mon^{-1}$
Sep	0.214	18.5	555	0.065	5.6	168
Oct	0.213	18.4	570	0.052	4.5	139
Nov	0.185	16.0	480	0.120	10.4	311
Dec	0.197	17.0	528	0.112	9.7	301
Jan	-------	------	-----	-------	----	----
Feb	0.172	14.9	416	0.056	4.9	136
Mar	0.208	17.9	556	0.089	7.7	239
Apr	0.229	19.8	593	0.074	6.4	192
May	0.170	14.7	456	0.129	11.2	346
Jun	0.169	14.6	439	0.041	3.5	106
Jul	0.162	14.0	433	0.038	3.2	101
Aug	0.258	22.3	690	0.082	7.1	220
Sep	0.156	13.5	404	0.059	5.1	153
Oct	0.169	14.6	453	0.030	2.6	80
Nov	0.139	12.0	360	0.125	10.8	324
Annual Total			5943			2414
Mean	0.184			0.076		

(Table 3, Pg. 18 in Tague's thesis)

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Mean daily discharge and monthly flow volumes for Wintergreen Lake, Miller Lake, and Miller Boathouse outlets during 1994-1995.

	Wintergreen Lake			Miller Lake			Miller Boathouse		
Month	Mean Daily Discharge m^3sec^{-1}	Mean Daily Discharge $10^3m^3day^{-1}$	Monthly Flow Volume $10^3m^3mon^{-1}$	Mean Daily Discharge m^3sec^{-1}	Mean Daily Discharge $10^3m^3day^{-1}$	Monthly Flow Volume $10^3m^3mon^{-1}$	Mean Daily Discharge m^3sec^{-1}	Mean Daily Discharge $10^3m^3day^{-1}$	Monthly Flow Volume $10^3m^3mon^{-1}$
Sep	-------	----	---	0.000	0.0	0	0.009	0.8	24
Oct	-------	----	---	0.000	0.0	0	0.009	0.8	23
Nov	-------	----	---	0.002	0.2	5	0.019	1.7	50
Dec	0.012	1.1	33	0.001	0.1	2	0.017	1.5	47
Jan	0.018	1.6	49	-------	----	--	-------	----	---
Feb	0.012	1.0	29	0.000	0.0	0.4	0.024	2.1	57
Mar	0.011	0.9	29	0.000	0.0	1	0.016	1.3	42
Apr	0.036	3.1	24	0.002	0.1	4	0.012	1.0	30
May	0.022	1.9	59	0.002	0.2	5	0.025	2.2	68
Jun	0.007	0.6	18	0.000	0.0	0	0.013	1.2	35
Jul	0.000	0.0	0	0.000	0.0	0	0.008	0.7	20
Aug	0.014	12.1	37	0.000	0.0	0	0.009	0.8	25
Sep	0.001	0.1	3	0.000	0.0	0	0.010	0.9	26
Oct	0.002	0.2	5	0.000	0.0	0	0.004	0.3	11
Nov	0.008	0.7	21	0.000	0.0	0	0.008	0.7	21
Annual Total			307			15			409
Mean	0.011			0.000			0.012		

(No similar table in Tague's thesis. Only for comparative purposes to Prairieville and Little Long.)

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Mean daily discharge and monthly flow volumes for Gull Lake outlet during 1994-1995.

Gull Lake Outlet

Month	Mean Daily Discharge $m^3 sec^{-1}$	Mean Daily Discharge $10^3 m^3 day^{-1}$	Monthly Flow Volume $10^3 m^3 mon^{-1}$
Sep	0.433	37.5	1124
Oct	0.854	73.8	2286
Nov	1.422	122.8	3685
Dec	1.525	131.8	4084
Jan	-------	-------	-------
Feb	0.990	85.5	2395
Mar	0.798	68.9	2137
Apr	0.361	31.2	936
May	1.151	99.4	3082
Jun	0.731	63.2	1895
Jul	0.803	69.3	2150
Aug	0.853	73.7	2285
Sep	0.485	41.9	1257
Oct	0.794	68.6	2127
Nov	0.887	76.6	2299
Annual Total			30025
Mean	0.873		

(No similar table in Tague's thesis. Only for comparative purposes to Prairieville and Little Long.)

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Monthly precipitation at Gull Lake Michigan during 1994-1995.

Month	Precipitation inches mon^{-1}	Precipitation $10^6 m^3$ mon^{-1}	Total Phosphorus mg m^{-3}	Phosphorus loading kg mon^{-1}
August	3.82	0.802	2.86	2.3
September	0.42	0.088	3.25	0.3
October	4.04	0.849	3.17	2.7
November	3.27	0.687	2.79	1.9
December	1.71	0.359	1.66	0.6
January	1.35	0.284	4.53	1.3
February	0.54	0.113	2.32	0.3
March	1.42	0.298	2.53	0.8
April	2.65	0.557	3.43	1.9
May	5.60	1.176	3.00	3.5
June	2.16	0.454	3.55	1.6
July	3.83	0.805	1.22	1.0
August	4.63	0.973	2.31	2.2
September	0.06	0.487	2.11	1.0
October	0.06	0.531	2.23	1.2
November	0.09	0.712	2.80	2.0
Annual Totals	32.76	6.881		18.5
Mean			2.73	

(Table 5, pg. 24 and Table 14, pg. 60 in Tague's thesis.)

tables.wpd
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Summary of the hydrologic budget for Gull Lake for 1994-1995.

	Annual Supply (%)	Annual Volume ($10^6 m^3/yr$)
Tributary inflow		
Prairieville	21.37	5.94
Little Long Lake outlet	8.67	2.41
Miller Lake outlet	0.07	0.02
Miller Lake boathouse	1.47	0.41
Wintergreen	1.94	0.54
Total tributary inflow	33.53	9.32
Precipitation	24.75	6.88
Ground water inflow (net)	41.73	11.6
Total supply	100	27.80
Gull Creek outflow		30.03
Evaporation		?
Storage Change		?

(Table 9, pg. 42 Tague's thesis.)

(Note: Wintergreen value is from Tague's thesis. Our value was 0.31 for the annual volume.)

(Note: The groundwater value is from Tague's thesis. The difference between the total inflow and outflow may due to an increase in groundwater inflow.)

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Monthly and annual loading from Prairieville Creek during 1994-1995.

Month	Monthly flow volume $10^3 m^3 mon^{-1}$	Monthly phosphorus loading Kg mon^{-1}	Mean Total phosphorus concentration mg m^{-3}
Aug	-----	-----	15.2
Sep	555	6.53	11.8
Oct	570	5.31	9.3
Nov	480	3.12	7.1
Dec	528	4.51	8.5
Jan	-----	-----	15.3
Feb	416	11.08	26.6
Mar	556	12.67	22.8
Apr	593	7.72	13.0
May	456	7.05	15.5
Jun	439	5.72	13.1
Jul	433	5.06	11.7
Aug	690	23.17	33.6
Sep	404	3.51	8.7
Oct	453	2.43	5.4
Nov	360	2.34	6.5
Annual Totals	5943	86.16	
Mean			14.3

(Table 11, pg. 56 Tague's thesis.)

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Monthly and annual loading from Little Long Lake outlet during 1994-1995.

Month	Monthly flow volume $10^3 m^3 mon^{-1}$	Monthly phosphorus loading Kg mon^{-1}	Mean Total phosphorus concentration mg m^{-3}
Aug	-----	------	11.4
Sep	168	2.26	13.4
Oct	139	1.96	14.1
Nov	311	4.43	14.3
Dec	301	8.82	29.3
Jan	-----	------	17.1
Feb	136	1.53	11.2
Mar	239	2.57	10.8
Apr	192	2.19	11.4
May	346	3.46	10.0
Jun	106	0.88	8.3
Jul	101	0.97	9.6
Aug	220	3.12	14.2
Sep	153	2.04	13.3
Oct	80	1.11	13.8
Nov	324	3.01	9.3
Annual Totals	2414	32.85	
Mean			13.2

(Table 12, pg.57 Tague's thesis.)

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Monthly and annual loading from Wintergreen Lake outlet during 1994-1995.

Month	Monthly flow volume $10^3 m^3 mon^{-1}$	Monthly phosphorus loading Kg mon^{-1}	Mean Total phosphorus concentration mg m^{-3}
Aug	---	-------	108.9
Sep	---	-------	145.3
Oct	---	-------	219.0
Nov	---	-------	259.2
Dec	33	10.61	325.1
Jan	49	12.94	262.8
Feb	29	4.00	136.9
Mar	29	4.99	171.5
Apr	24	3.27	135.7
May	59	11.27	191.2
Jun	18	3.98	219.2
Jul	0	0.00	-------
Aug	37	3.87	103.1
Sep	3	0.18	68.8
Oct	5	0.75	140.6
Nov	21	6.61	318.6
Annual Totals	307	62.45	
Annual Estimate	538	104.64	
Mean			194.5

(Not in Tague's thesis. For comparison with Prairieville and Little Long.)

(Note: Annual estimate uses Tague's Wintergreen annual flow and our mean concentration.)

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Monthly and annual loading from Miller Lake outlet during 1994-1995.

Month	Monthly flow volume $10^3 m^3 mon^{-1}$	Monthly phosphorus loading Kg mon^{-1}	Mean Total phosphorus concentration mg m^{-3}
Aug	---	-----	25.1
Sep	0	0.00	52.1
Oct	0	0.00	68.3
Nov	5	0.15	32.8
Dec	2	0.02	9.3
Jan	---	-----	19.1
Feb	0.4	0.02	44.7
Mar	1	0.04	33.4
Apr	4	0.07	18.0
May	5	0.09	19.0
Jun	0	0.00	-----
Jul	0	0.00	-----
Aug	0	0.00	-----
Sep	0	0.00	-----
Oct	0	0.00	-----
Nov	0	0.00	14.7
Annual Totals	15	0.33	
Mean			29.3

(Not in Tague's thesis. For comparison with Prairieville and Little Long.)

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Monthly and annual loading from Miller Boathouse outlet during 1994-1995.

Month	Monthly flow volume $10^3 m^3 mon^{-1}$	Monthly phosphorus loading Kg mon^{-1}	Mean Total phosphorus concentration mg m^{-3}
Aug	---	-----	17.8
Sep	24	0.59	24.6
Oct	23	0.63	27.1
Nov	50	0.66	13.1
Dec	47	0.40	8.6
Jan	---	-----	6.9
Feb	57	0.44	7.7
Mar	42	0.45	10.9
Apr	30	0.47	15.4
May	68	1.44	21.3
Jun	35	0.55	15.8
Jul	20	0.33	16.3
Aug	25	0.42	17.1
Sep	26	0.38	14.5
Oct	11	0.13	11.7
Nov	21	0.22	10.8
Annual Totals	409	6.08	
Mean			14.6

(Not in Tague's thesis. For comparison with Prairieville and Little Long.)

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Monthly and annual loading from Gull Lake outlet during 1994-1995.

Month	Monthly flow volume $10^3 m^3 mon^{-1}$	Monthly phosphorus loading Kg mon^{-1}	Mean Total phosphorus concentration mg m^{-3}
Aug	------	------	10.7
Sep	1124	12.66	11.3
Oct	2286	27.37	12.0
Nov	3685	44.64	12.1
Dec	4084	53.37	13.1
Jan	------	------	11.9
Feb	2395	24.76	10.3
Mar	2137	23.65	11.1
Apr	936	16.95	18.1
May	3082	39.03	12.7
Jun	1895	22.21	11.7
Jul	2150	23.25	10.8
Aug	2285	22.37	9.8
Sep	1257	10.30	8.2
Oct	2127	14.78	7.0
Nov	2299	36.07	15.7
Totals	30025	318.34	
Mean			11.5

(Not in Tague's thesis. For comparison with Prairieville and Little Long.)

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Concentration of total phosphorus (mg m^{-3}) in samples from 31 domestic water supply wells located near the periphery of Gull Lake, 1995.

Eastern shore of Gull Lake (n = 9)
Mean = 5.14
St. Error = 1.69

Northern shore of Gull Lake (n = 8)
Mean = 4.28
St. Error = 1.75

Western shore of Gull Lake (n = 6)
Mean = 7.82
St. Error = 2.57

Southern shore of Gull Lake (n = 8)
Mean = 3.18
St. Error = 0.87

Mean of all samples = 4.93 (n = 31)
St. Error = 0.86

(Table 15, pg. 65 Tague's thesis)

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Summary of the total phosphorus budget for Gull Lake for 1994-1995. Symbols used represent: mean concentration (C); annual supply (J); percentage of supply from each source; and areal loading rate (L).

	C (mg/m^3)	J (kg/yr)	%	L ($mg\ m^{-2}\ yr^{-1}$)
<u>Natural supply</u>				
Prairieville Creek	14.3	86.2	16.7	10.4
Little Long Lake outlet	13.2	32.9	6.4	4.0
Miller Lake outlet	29.3	0.3	0.1	0.04
Miller Boathouse	14.6	6.1	1.2	0.74
Wintergreen Lake outlet	194.5	104.6	20.2	12.6
Total from tributaries		230.1	44.4	27.8
Precipitation	2.7	18.5	3.6	2.2
Ground water	4.9	55.8	10.8	6.9
<u>Total natural supply</u>		304.4	58.8	36.9
<u>Artificial Supply</u>				
Fertilizer		179	34.6	21.6
Migratory birds		34.3	6.6	4.1
<u>Total Supply</u>		517.7	100	62.6
<u>Losses</u>				
Gull Creek outflow	11.5	318.3		
Sedimentation	?	?		
Total loss	?	?		
Loss to sediments exceeding inputs		?		

(Table 19, pg. 82 Tague's thesis.)

(Note: Wintergreen J and L is based on Tague's annual flow data.)

(Note: Fertilizer estimate from Tague.)