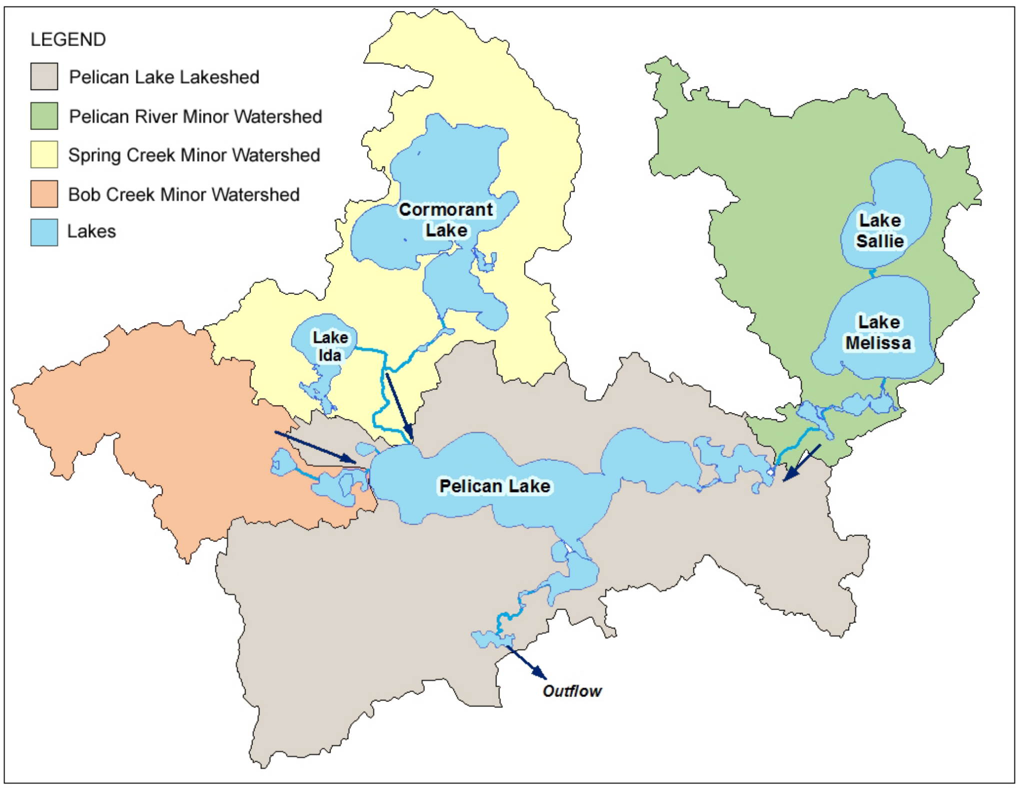
PHOSPHORUS LOADING MODEL



2014

Pelican Group of Lakes Improvement District

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Funded by: Pelican Group of Lakes Improvement District (PGOLID)

Report & Modeling: Moriya Rufer, RMB Environmental Laboratories, Inc

Patrick Sherman, RMB Environmental Laboratories, Inc

Emelia Hauck, RMB Environmental Laboratories, Inc

Data Sources: Pelican Group of Lakes Improvement District (PGOLID)

Minnesota Pollution Control Agency (MPCA)

Minnesota Department of Natural Resources (DNR)

National Land Cover Data Set (NLCD)

National Agricultural Statistics Service (NASS)

Wisconsin Lake Model

US Army Corps of Engineers BATHTUB Model

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

Introduction

PGOLID has an extensive data set from its monitoring programs. The lake monitoring program was started in 1996, and has resulted in consistent data from 1996 to 2014. The stream monitoring program was started in 2001 and has resulted in consistent data from 2001 to 2014. This data was inputted to a BATHTUB computer model (US Army Corps of Engineers) to determine the proportion of phosphorus loading from different sources to the lake. These results can be used to implement programs to improve or maintain the water quality by addressing the phosphorus sources. Potential phosphorus sources include septic systems, shoreline runoff, precipitation, internal loading and inlet loading.

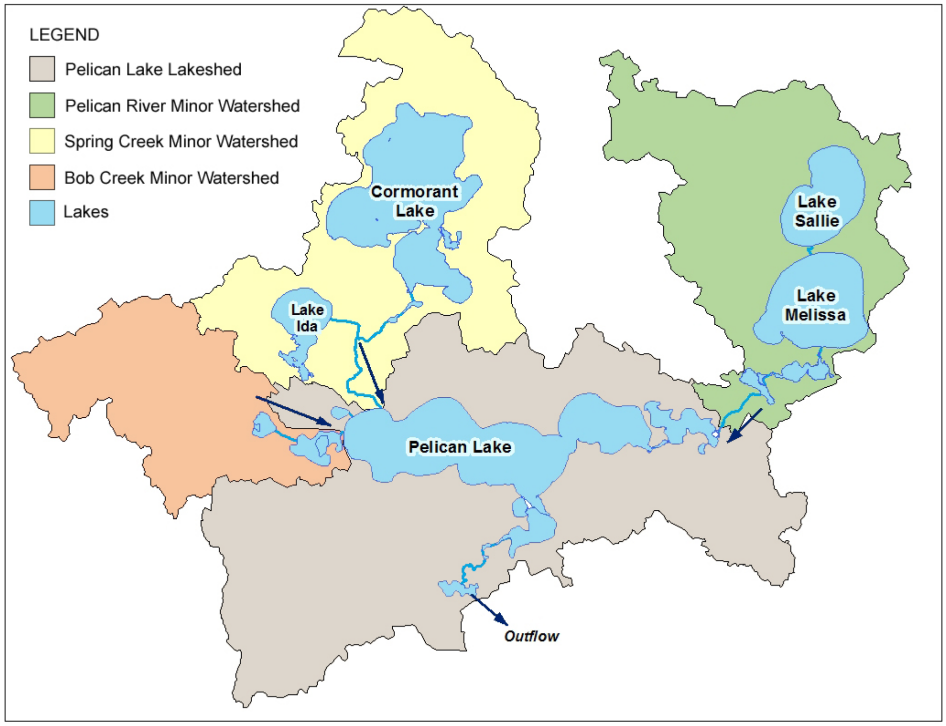

Figure 1. Watersheds contributing water and phosphorus to PGOLID.

Results

The model output for each lake shows the percentage of phosphorus loading from each of the different sources (Figure 2). Little Pelican, Pelican, and Fish Lakes look somewhat similar because they have major inflows from the Pelican River. Overall, the largest source of phosphorus loading to the lakes is the inlets, especially the Pelican River. Septic systems and shoreline runoff are minimal in comparison to the inlets.

Bass Lake looks different from the other lakes because it is fairly isolated, with no major inlets. The connection between Bass and Fish Lakes does not appear to move much water back and forth, but there is undoubtedly some exchange (~11%). Therefore, the septic systems and shoreline runoff have a larger proportional impact in Bass Lake than the other PGOLID lakes (Table 1, Figure 2).

Septic systems and shoreline runoff have a larger proportional impact in Bass Lake than the other PGOLID lakes

Table 1. Model output of phosphorus loading proportions from 2009.

	Little Pelican Lake	Pelican Fairhills Bay	Pelican Main Bay	Fish Lake	Bass Lake
Inlet Loading	94.1%	73.8%	77.0%	96.2%	10.5%
Internal Loading	2.4%	16.6%	7.0%	1.0%	11.1%
Precipitation	1.9%	4.5%	11.5%	1.6%	30.4%
Shoreline Runoff	1.1%	0.9%	2.2%	0.7%	31.0%
Septic Systems	0.6%	1.1%	2.3%	0.5%	17.0%

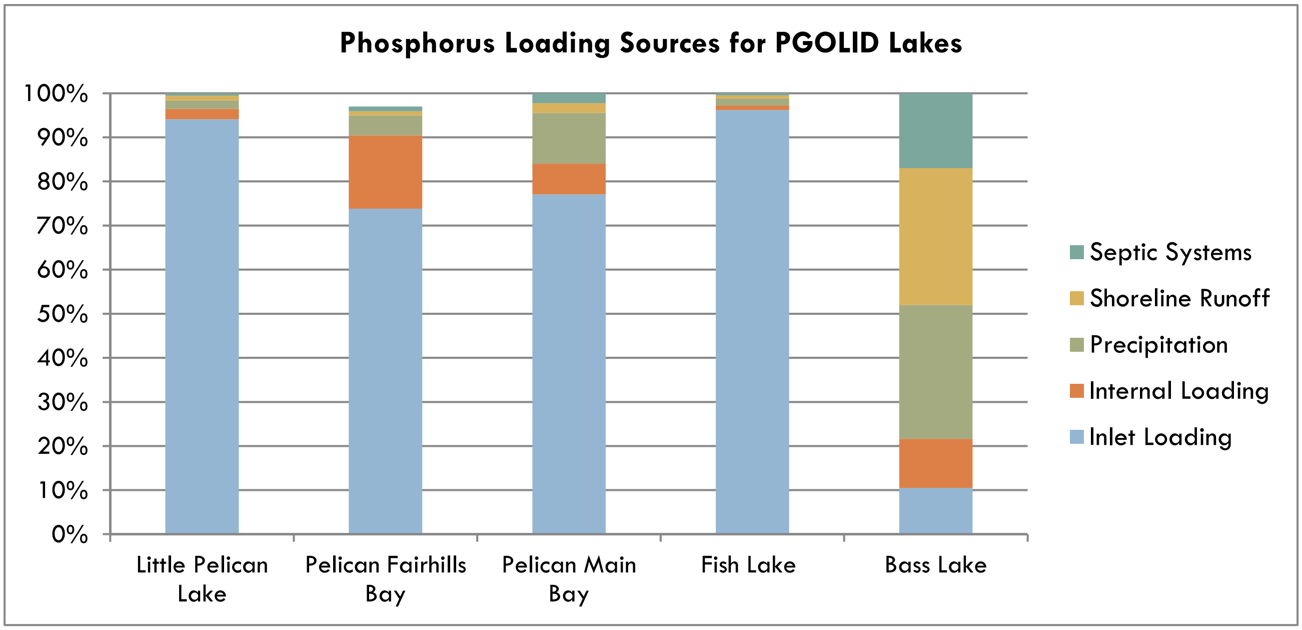

Figure 2. Phosphorus loading sources for PGOLID Lakes.

Implications

Because the Pelican Group of Lakes has so much water flowing through them, they are continually flushed out. This is good, because much of the nutrients coming into the lake go back out of the lake. The nutrients that stay in the lake are taken up by plants and algae and settle down into the sediments.

Septic Systems

Septic systems are a phosphorus source to the lake that can be controlled. Because of the Pelican River flow through the lakes, septic systems do not have much impact on the lake. Bass Lake, however, is different. Because there is not the water exchange occurring in Bass Lake, the septic system nutrients stay in the lake. It is still important to make sure the septic systems in the lake remain in good working order.

Shoreline Runoff

Shoreline runoff is a phosphorus source to the lake that can be controlled. Because of the Pelican River flow through the lakes, shoreline runoff is not a major source of phosphorus to the lake, but it does still affect it, especially in localized areas. When looking at the shoreline area from the water's edge to 250 feet back from the lake, 58-85% of the phosphorus loading from that land area comes from developed lots (impervious surface and turf grass). Shoreline runoff can fuel plant growth in swimming areas near shore. PGOLID has been implementing a Shoreline Restoration Program with a DNR Shoreline Habitat Restoration Grant since 2009. Restoring turf lawns to native grasses, wildflowers, trees and shrubs, and limiting the impervious surface in new development will limit future shoreline runoff. Having a natural shoreline is especially important in Bass Lake because it does not have a major inlet flushing it out.

When looking at the shoreline area from the water's edge to 250 feet back from the lake, 58-85% of the phosphorus loading from that land area comes from developed lots (impervious surface and turf grass).

Precipitation

Precipitation is a phosphorus source to the lake that cannot be controlled. The amount of phosphorus loading from precipitation is determined by the surface area of the lake. The more surface area the lake has, the more rain it receives directly from rainfall. Bass Lake had the highest loading from precipitation, but this is because it has very little inlet loading. Of the other segments, the Main Bay of Pelican Lake had the most phosphorus loading from precipitation because it has the largest surface area. There is nothing that can be done to limit phosphorus loading from precipitation.

Internal Loading

Internal loading is a phosphorus source to the lake that can be somewhat controlled. It is based on the morphometry (size and depth), and biology of the lake, but it is also based on the amount of phosphorus in the lake. Limiting external phosphorus inputs to the lake can help reduce the amount of internal loading in a lake. Internal loading is most prevalent in Fairhills Bay of Pelican Lake. This is because this bay is deep enough to stratify (separate into a warm top layer and cold bottom layer) and it receives nutrients and sediment from the Pelican River. Little Pelican Lake has the highest in-lake phosphorus of all the PGOLID lakes, but because it is shallow it does not fully stratify in the summer. The water column remains fairly mixed, and so the bottom of the lake has oxygen present, which keeps the phosphorus in the sediments from releasing in to the water.

Inlet Loading

Inlet loading is a phosphorus source to the lake that can be somewhat controlled. The best way to manage inlet loading is to maintain good relationships with upstream neighbors, and to monitor for any problems that could arise. If problems are detected they can hopefully be fixed before the impact to the lake is large. PGOLID has been implementing a stream monitoring program since 2001.

The largest source of phosphorus to the PGOLID Lakes is the Pelican River (Figure 2). This means much of the phosphorus comes from upstream in the watershed such as Detroit Lakes (Figure 3).

The largest source of phosphorus to the PGOLID Lakes is the Pelican River. This is mainly due to the large amount of water entering Pelican Lake from upstream.

It is difficult to control phosphorous inputs upstream in the watershed. PGOLID maintains good working relationships with upstream entities such as the Pelican River Watershed District and the City of Detroit Lakes.

Spring Creek also contributes phosphorus loading to Pelican Lake (20%). PGOLID maintains a good working relationship with the Cormorant Lakes Watershed District, and have a signed agreement for how much water can be discharged from Big Cormorant Lake into Spring Creek. Bob Creek is a minor phosphorus source to Pelican Lake (5%). PGOLID has worked with a farmer along the creek to increase stream buffers to better protect the stream's water quality.

Figure 3. The entire watershed for PGOLID Lakes.

Future Scenarios

Once the model was set up and fit the monitoring data set (predicted water quality from the model = observed water quality from monitoring), future scenarios could be run to see what would affect the water quality of PGOLID lakes.

Zebra mussels

Data from 2013 was put into the model to see what effect Zebra mussels have had on the lakes. The phosphorus values were similar to pre-zebra mussel years, but the clarity values were much different. Zebra mussels affect the clarity of the lake, but not the phosphorus loading. This means that in future years when we run this model, we'll have to make a correction for Zebra mussels for the model to fit.

Inlet loading

The model was run and the phosphorus loading from each inlet was increased by 50% to see what effect that would have on the lakes. There was not much change if the Bob Creek inlet phosphorus loading increased by 50%. If the phosphorus loading was increased by 50% from Spring Creek it would add about 2% more phosphorus to Pelican Lake than current rates. If the phosphorus loading was increased by 50% from the Pelican River, Pelican Lake received 6% more phosphorus and Little Pelican Lake received 2% more phosphorus.

Shoreline Runoff

The model was run and the phosphorus loading from shoreline runoff was increased by 50% to see what effect that would have on the lakes. Bass Lake showed the greatest effect with 9% more phosphorus entering the lake. This would contribute to greener water. The other lakes had about 1% increase in phosphorus.

Septic Systems

The model was run and the phosphorus loading from septic systems was increased by 50% to see what effect that would have on the lakes. Bass Lake showed the greatest effect with 6% more phosphorus entering the lake. This would contribute to greener water. The other lakes had about 1% increase in phosphorus.

Next Steps

The overall conclusions from this study result in the following priorities for future projects:

1. Because the Pelican River is the largest source of phosphorus to the PGOLID lakes, better understand the loading coming from upstream by installing a stream flow monitoring gauge in the river before it gets to Little Pelican Lake to get daily flow estimates. Then re-run the model to compare the more specific flow measurements to the monthly measurements in the historical data set.
2. Educate Bass Lake residents about the large proportional effect that shoreline runoff and septic systems have on the lake because there are no inlets flushing it out. Look into volunteers for shoreline restoration projects and make sure septic systems are compliant.

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2. BACKGROUND

Watershed

A basin is the area of land drained by a river or lake and its tributaries. Minnesota has 4 divides. All water in Minnesota eventually flows into 1 of 4 rivers. The divides are made of 8 major drainage basins (Figure 4). Each drainage basin is made up of smaller units called watersheds, which correspond to the drainage of a tributary or lake system.

Watersheds are categorized as major or minor. A minor watershed is the smallest category of watershed. A group of minor watersheds that eventually flows into a common stream, such as the Otter Tail, forms a major watershed. A group of major watersheds that flow into a common river, such as the Red River, form a basin. A group of basins that flow into a common river form a divide.

The Red River of the North Basin stretches from northeastern South Dakota and west-central Minnesota northward through eastern North Dakota and northwestern Minnesota into southern Manitoba. It ends where the Red River empties into the southern end of Lake Winnipeg.

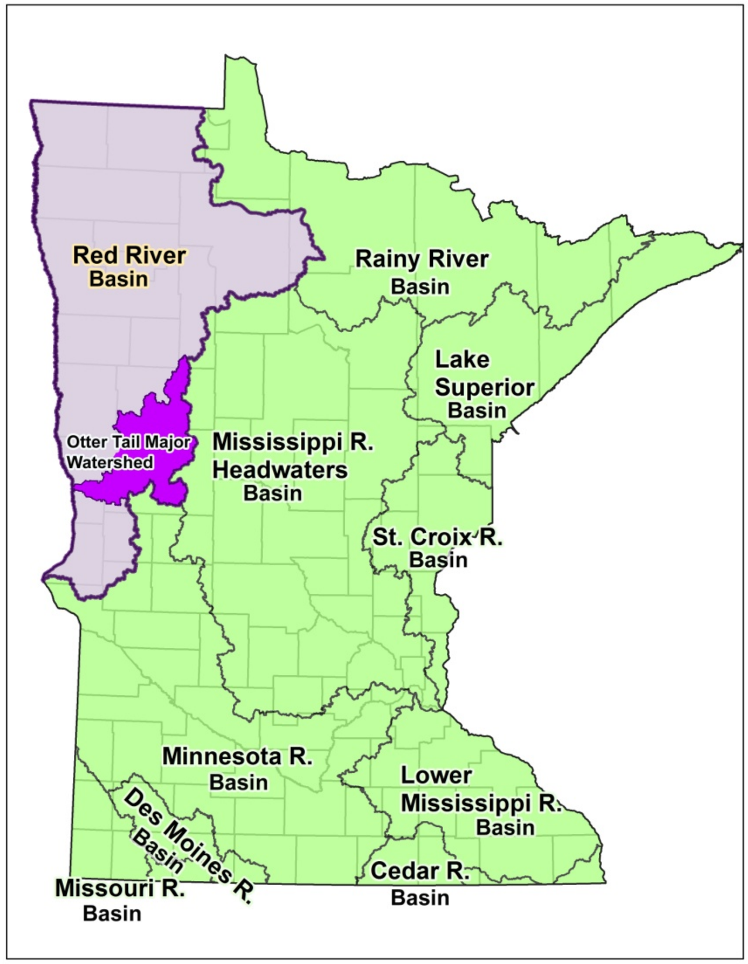

Figure 4. Minnesota showing all major drainage basins, the Red River Basin, and the Otter Tail River Watershed.

The Minnesota portion of the Red River Basin covers about 37,100 square miles in northwestern Minnesota in all or part of 21 counties. It is home to about 17,842 miles of streams and 668,098 acres of lakes.

The terrain of the Red River Basin in Minnesota is very diverse; from the flat, intensively farmed plain just east of the length of the Red River, to the rolling uplands full of trees and lakes in the east-central portion of the basin, to the extensive wetlands in the northeast.

The Otter Tail River Major Watershed represents an area of about 1,920 square miles, including areas of substantial portions of Otter Tail, Becker and Wilkin counties, and very small portions of Clay and Clearwater counties (Figure 5).

The Otter Tail River Watershed is a drainage basin of the Red River and the major tributaries of the watershed are the Ottertail and Pelican Rivers. Where the Otter Tail River joins the Bois de Sioux River is considered to be the headwaters of the Red River. The majority of the lakes in the Red River Basin are found in the Otter Tail River Watershed.

Pelican River Watershed

The Pelican River Watershed is a subset of the Otter Tail River Major Watershed (Figure 5). Its headwaters start north of Floyd Lake in Campbell Creek. From there it flows south through Floyd Lake, through the City of Detroit Lakes to Detroit, Sallie, Melissa, Pelican, Lizzie and Prairie Lakes. From Prairie Lake it flows south and joins the Otter Tail River near Fergus Falls.

There are two taxing entities in the Pelican River Watershed that have jurisdiction over the area. The Pelican River Watershed District encompasses the northern portion of the watershed through Lake Melissa. Pelican Lake has a Lake Improvement District, which encompasses Pelican, Bass, Fish and Little Pelican Lakes and includes all lakeshore properties (Figure 6).

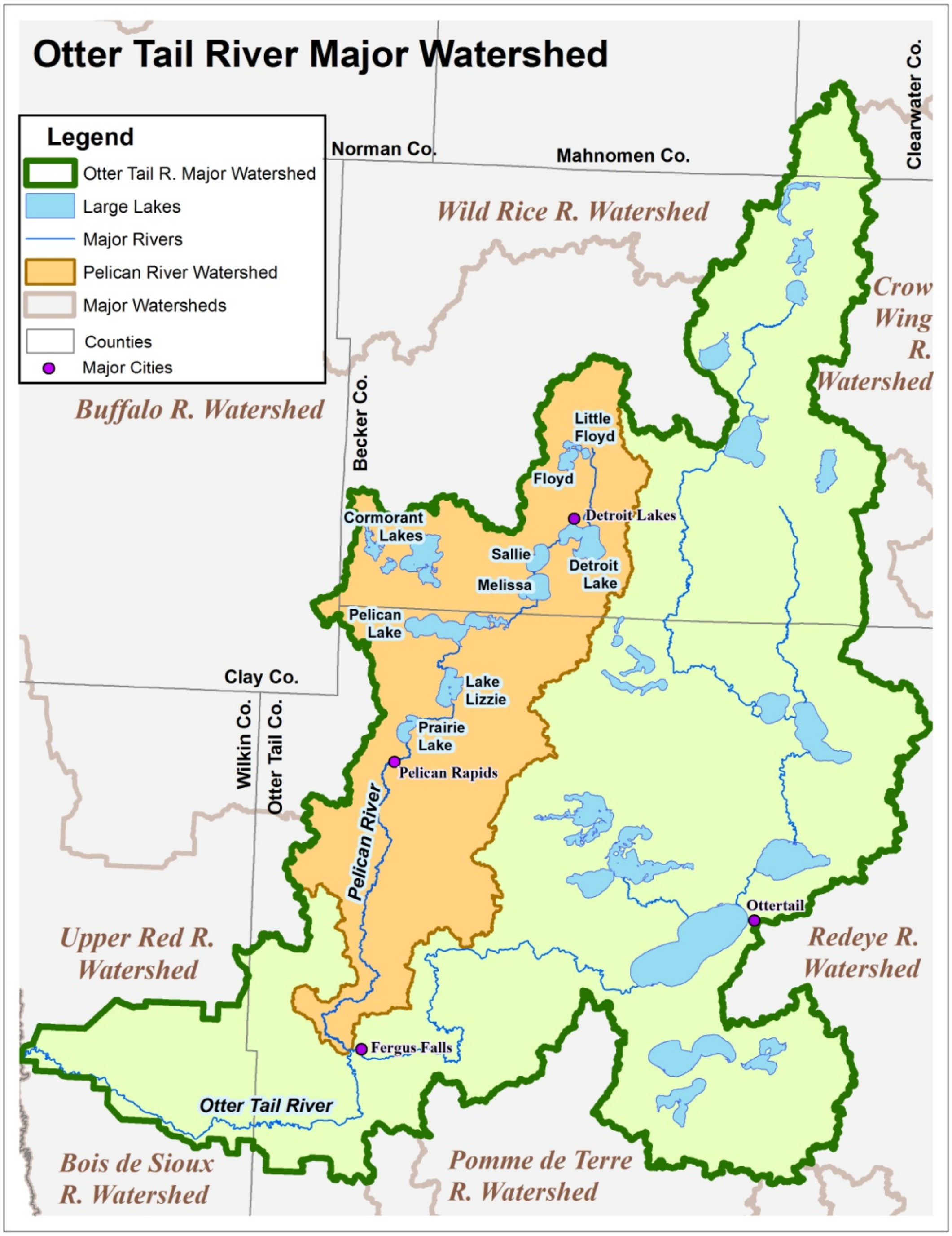

Figure 5. The Otter Tail Major Watershed and Pelican River Subwatershed with its lakes and rivers.

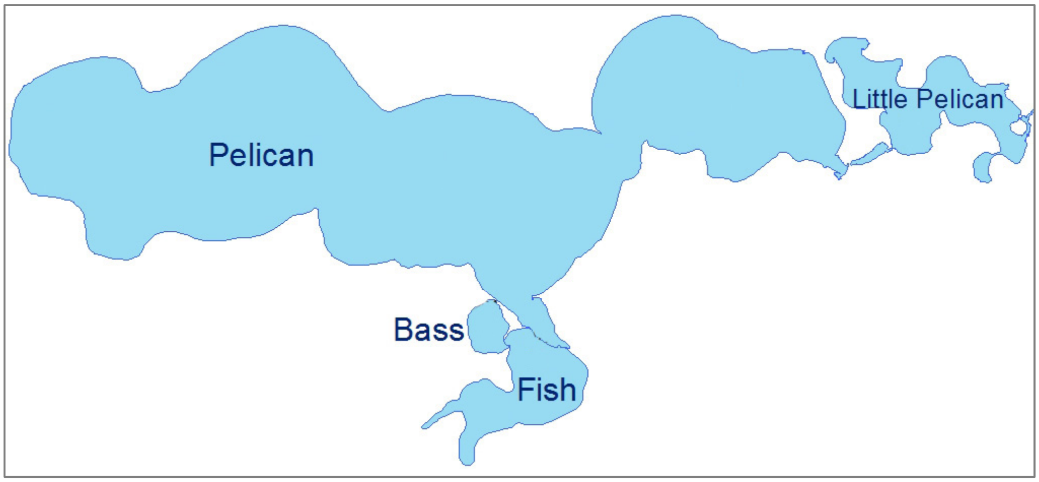

Figure 6. The Pelican Group of Lakes Improvement District, containing Little Pelican, Pelican, Bass, and Fish Lakes.

Pelican Lake's Minor Watersheds

Pelican Lake has three minor watersheds draining into it: the Pelican River, Spring Creek, and Bob Creek (Figure 7). The land area that is touching the lake, but not part of these minor watersheds is the Pelican Group of Lakes lakeshed. The lakeshed is defined as the land area draining towards the lake, and is determined by elevation as all water runs downhill.

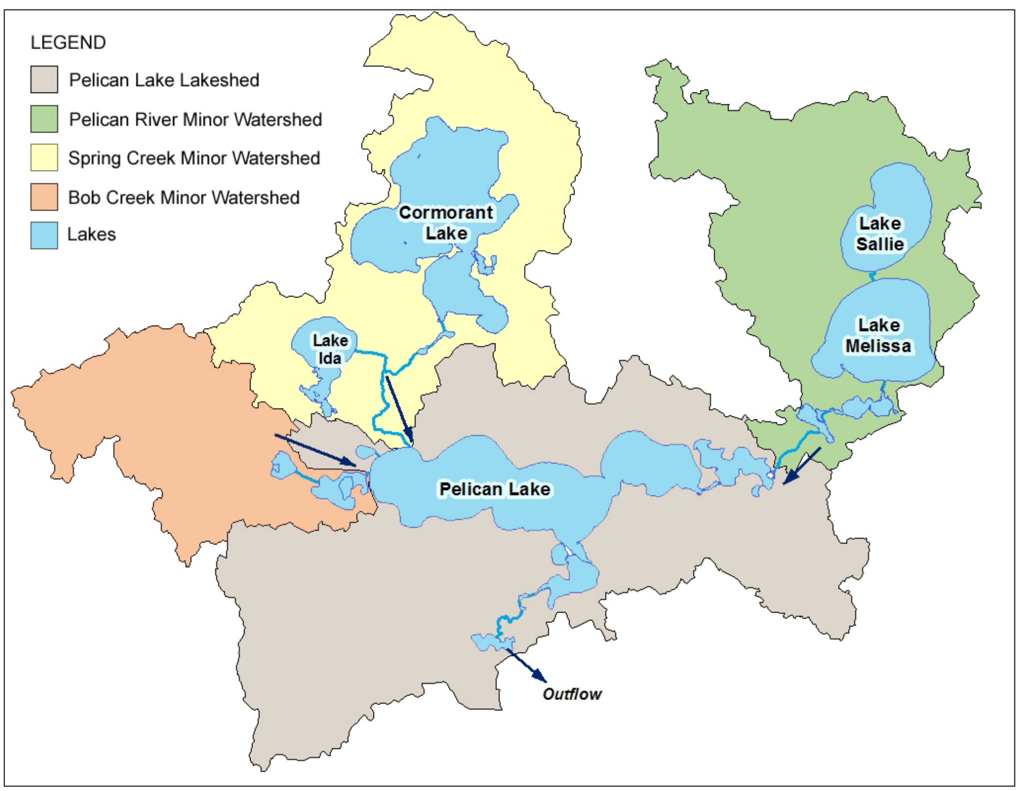

Figure 7. Minor watersheds and lakeshed for the Pelican Group of Lakes.

Land Use

The majority land use in the Pelican Group of Lakes Lakeshed consists of forests, pasture/grassland, and row crops, which is typical for Otter Tail County (Figure 8, Table 1). Row crops and development are of greatest concern for runoff. Most of the row crops occur south of the lake and runoff from those areas are likely not getting to Pelican Lake because of the great distance and the forest buffer around the lake.

The wetlands around Little Pelican Lake are crucial for water storage and water filtration, and absorb a lot of the nutrients coming into the Pelican Group of Lakes from the Pelican River watershed.

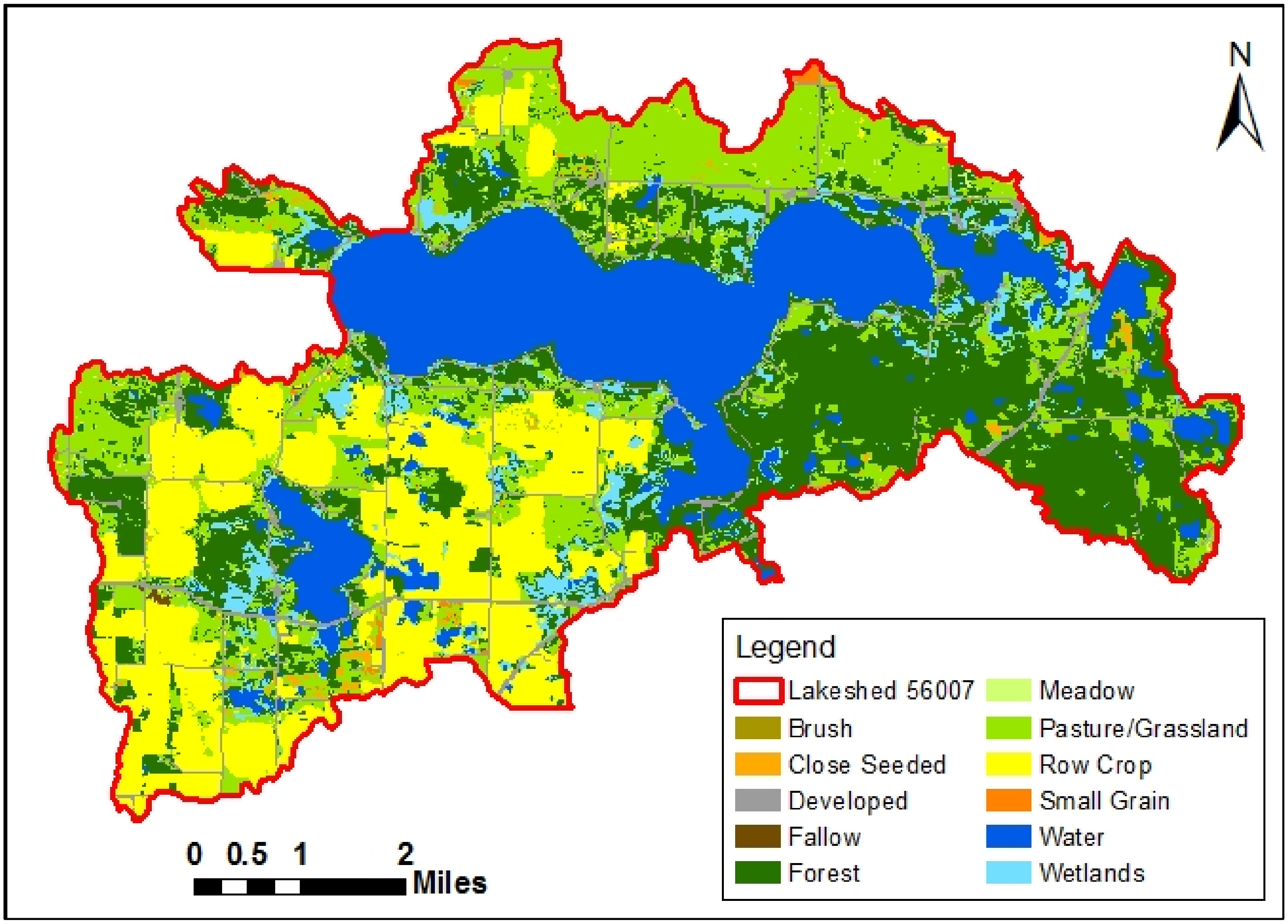

Figure 8. Pelican Lake land cover, 2010.

Table 1. Land cover acreage and percentage in the Pelican, Bass, Fish and Little Pelican lakesheds.

Landcover	Acres	Percent
Forest	7,589	27.8%
Water	5,841	21.4%
Pasture/Grassland	5,635	20.6%
Row Crop	5,239	19.2%
Developed	1,248	4.6%
Wetlands	1,236	4.5%
Close Seeded	195	0.7%
Small Grain	78	0.3%
Fallow	18	0.1%
Brush	5	0.0%
Meadow	216	0
Total	27,300	100%

Land Use Change

Due to the booming economy and housing market from 1990-2000, a lot of additional development occurred around the Pelican Group of Lakes during that time. Cabins were converted to year-round homes, and new homes were built. These practices increase the impervious surface areas around the shoreline of the lake, which increases runoff into the lake. The urban acreage around the lake increased by 57% and the impervious acreage increased by 81% (Table 2).

Table 2. Pelican Lake's lakeshed land cover statsistics and % change from 1990-2000 (http://land.umn.edu).

	1990		2000		% Change
Land Cover	**Acres**	**Percent**	**Acres**	**Percent**	**1990 to 2000**
Urban	592	3.75	929	5.89	56.9% Increase
Total Impervious Area (Percent Impervious Area Excludes Water Area)	136	1.2	246	2.17	80.9% Increase

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3. PHOSPHORUS SOURCES

Phosphorus is the limiting nutrient in lakes. It feeds plants and algae, which make the lake "greener" and reduce water clarity. There are five main phosphorus sources to the Pelican Group of Lakes. Some sources are controllable and some are not (Table 3).

Table 3. Phosphorus sources to Pelican Lake and whether they are controllable or not.

Phosphorus Source	Controllable?
1. Stream inlets	Somewhat
2. Shoreline runoff	Yes
3. Precipitation	No
4. Septic systems	Yes
5. Internal loading	Somewhat

By determining which sources are adding the most phosphorus to the lake, we can make better management decisions to try and reduce phosphorus loading in the areas that are controllable.

Stream Inlets

Major streams are usually the #1 source of nutrient loading to lakes. This is also true for the Pelican Group of Lakes. PGOLID has implemented a stream monitoring program from 2001-2014. All the major inlets to the lake are monitored (Pelican River, Spring Creek, Bob Creek) along with some upper watershed sites as well (Figure 10). Baseline monitoring includes collecting a sample once a month all year round. Event monitoring includes collecting samples during spring runoff and large rain events (>1 inch). Event monitoring shows the worst case scenario for phosphorus loading into the lake.

From PGOLID's long-term stream dataset, it has been determined that the Pelican River supplies the most nutrients of all the inlets (70%), Spring Creek is second (24%) and Bob Creek is third (6%) (Figure 9).

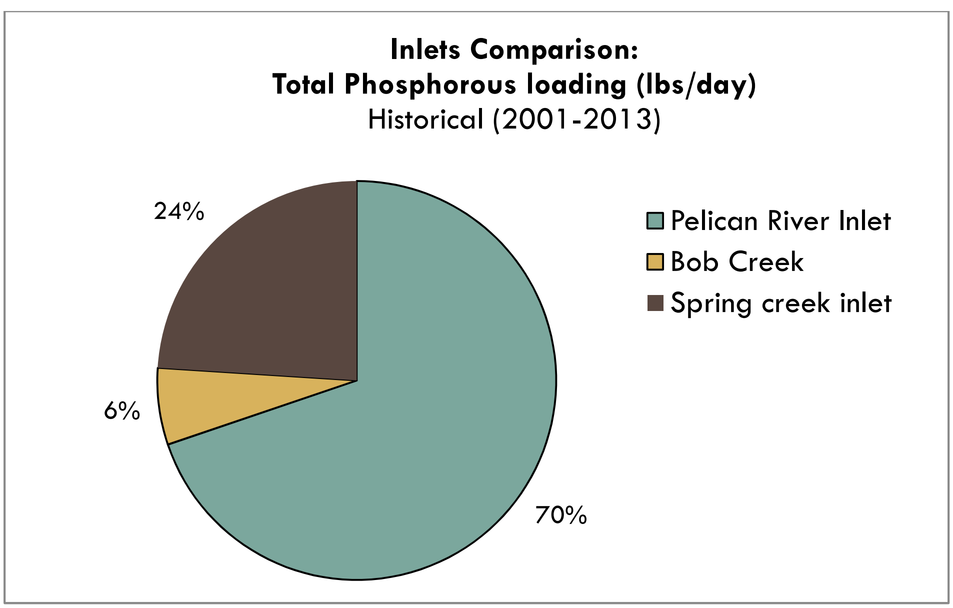

Figure 9. Total phosphorus loading comparison of inlets to Pelican Lake.

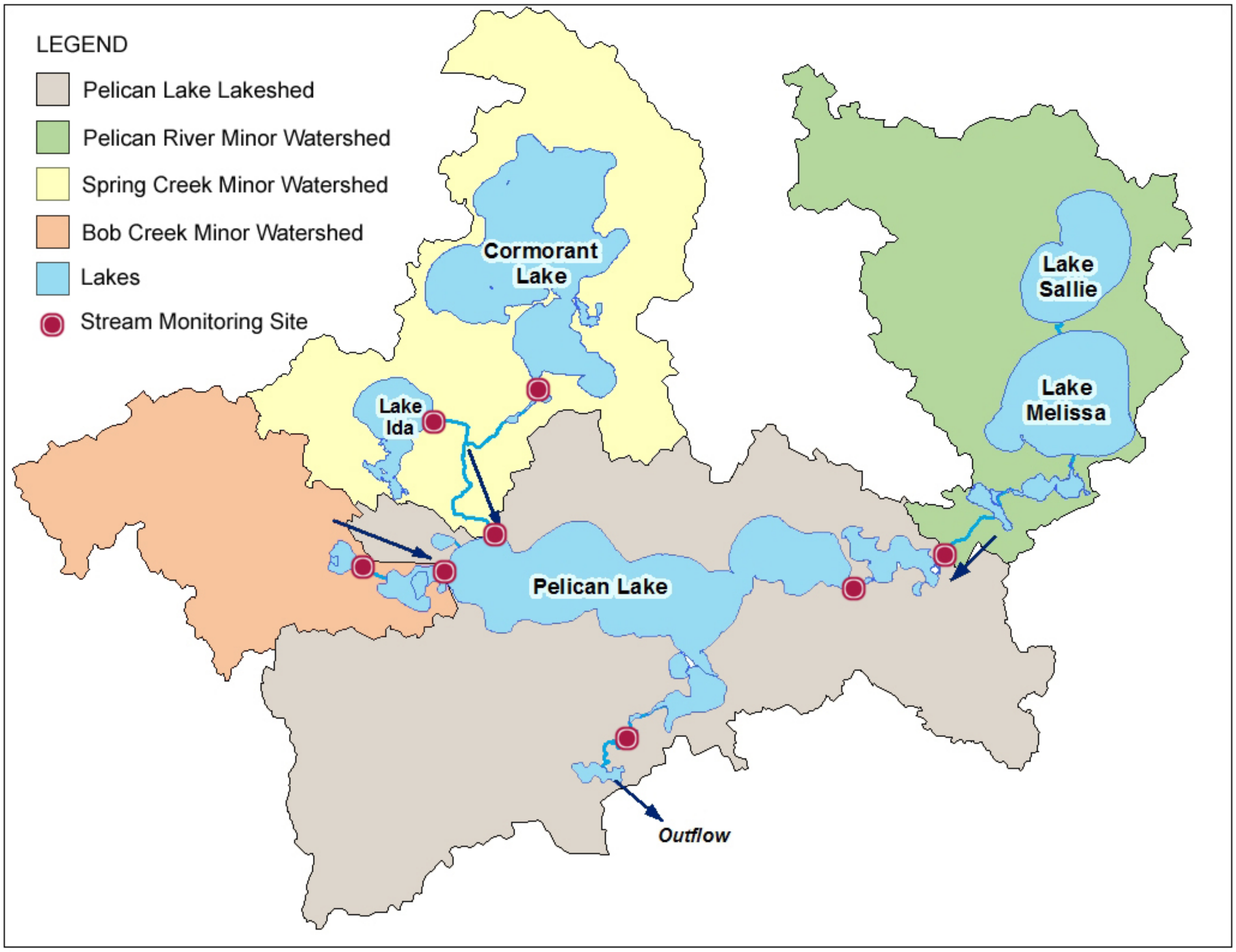

Figure 10. PGOLID stream monitoring sites.

The reason the Pelican River has the highest phosphorus loading to the lake is because it also has the highest flow, or volume of water flowing into the lake (Figure 11). Stream inlets with low phosphorus concentrations and high flow rates can add as much or more phosphorus to a lake than an inlet with high phosphorus concentration that is just a trickle of water.

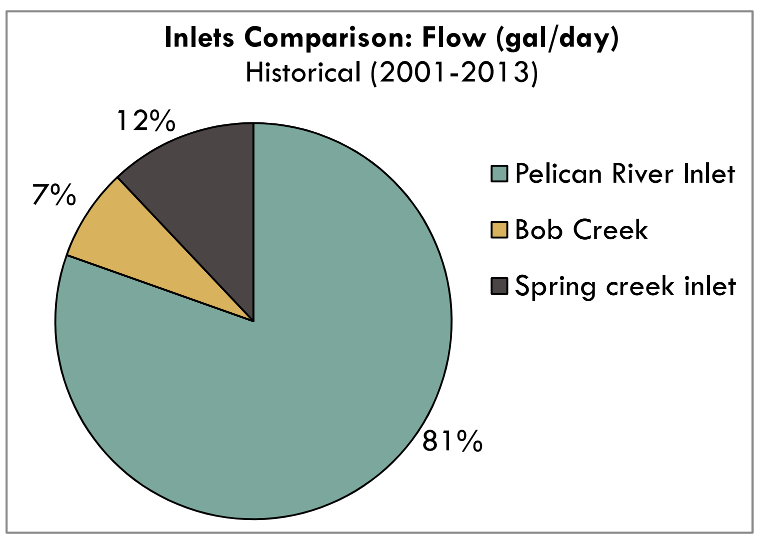

Figure 11. Water flow comparisons for Pelican Lake inlets.

Shoreline Runoff

Shoreline runoff is caused by rain flowing over impervious surface and turf-grass lawns. Impervious surface is any surface on land where rain water cannot infiltrate, for example roofs, driveways, patios and sidewalks. Turf grass has very short roots and when mowed is very flat on top, causing rain water to flow off of it instead of soak into the ground. Native grasses and wildflowers have deep roots, which pull the rainwater down into the ground and filter it (Figure 12).

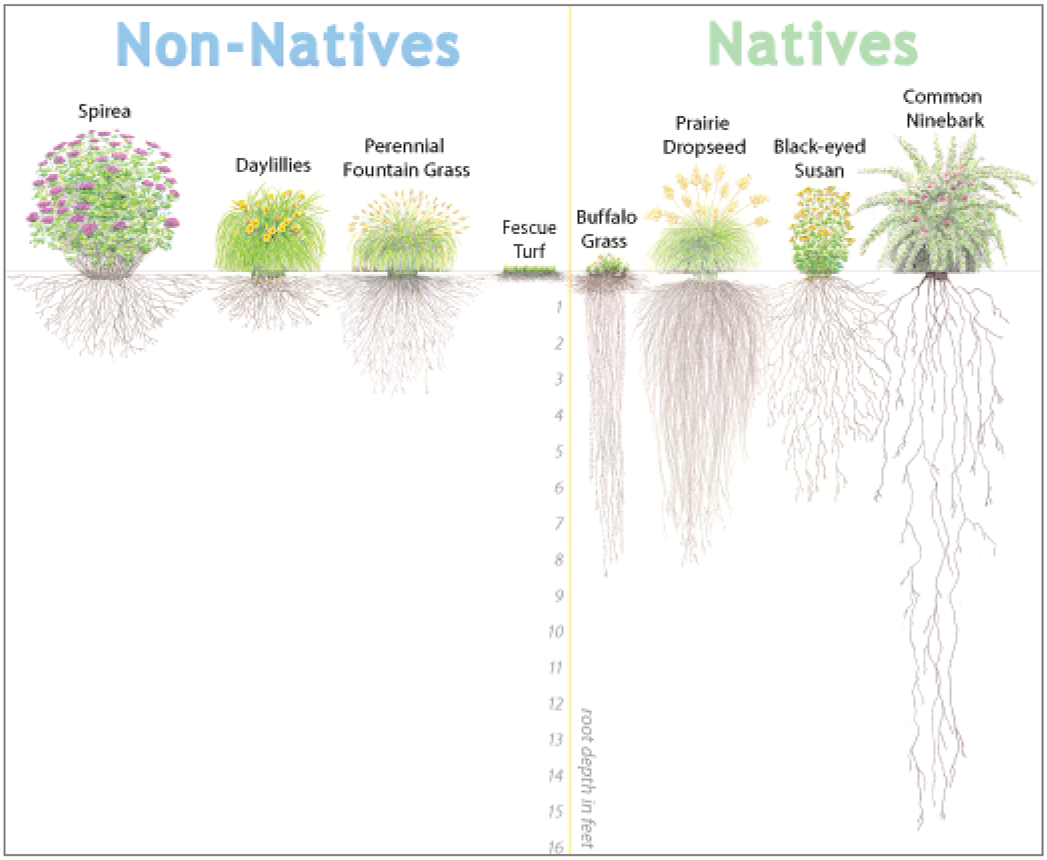

Figure 12. Comparison of root length between native plants and non-native plants.

Each different type of land use has an average phosphorus export coefficient. This is the amount of phosphorus that typically runs off of this land type. Developed land use (impervious surface and turf lawns) has the highest phosphorus export, followed by row crops. Pastures, herbaceous (grassland) and forests have very low phosphorus export (Table 4).

Table 4. Phosphorus runoff coefficients for different land use types.

Land Use	Phosphorus Export Coefficient (kg/acre/year)
developed	125
crops	100
pasture/hay	25
herbaceous	16.9
shrubland	12.9
evergreen forest	12.3
deciduous forest	7.5
open water	0
wetlands	0

For the purposes of this model, the shoreline runoff was defined as the runoff from a 250 foot buffer around each lake. This area is where the first tier development around the lake is located, and was determined to have the most direct runoff during rainfall (Figures 13-17).

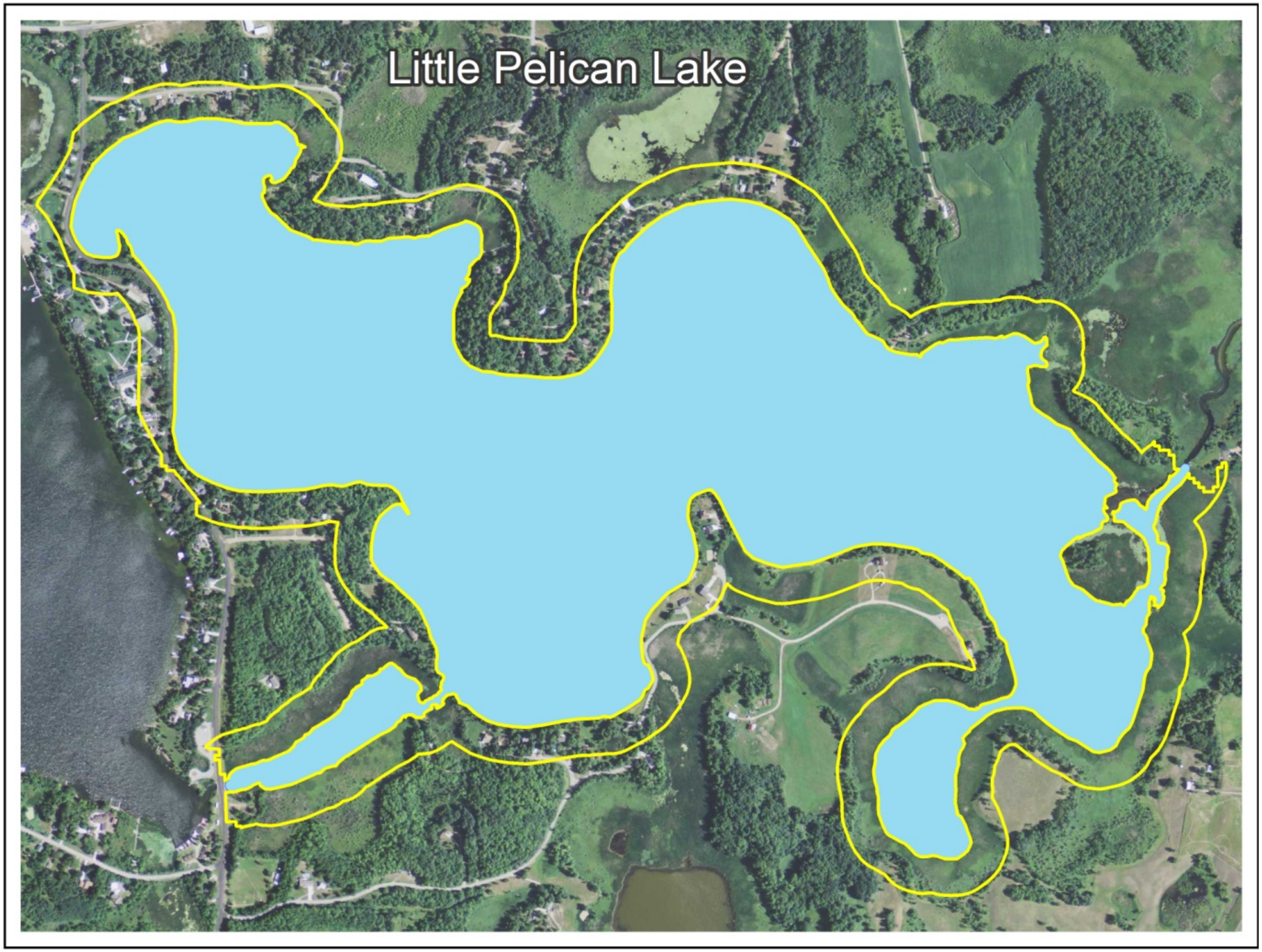

Figure 13. Little Pelican Lake 250 foot shoreline buffer.

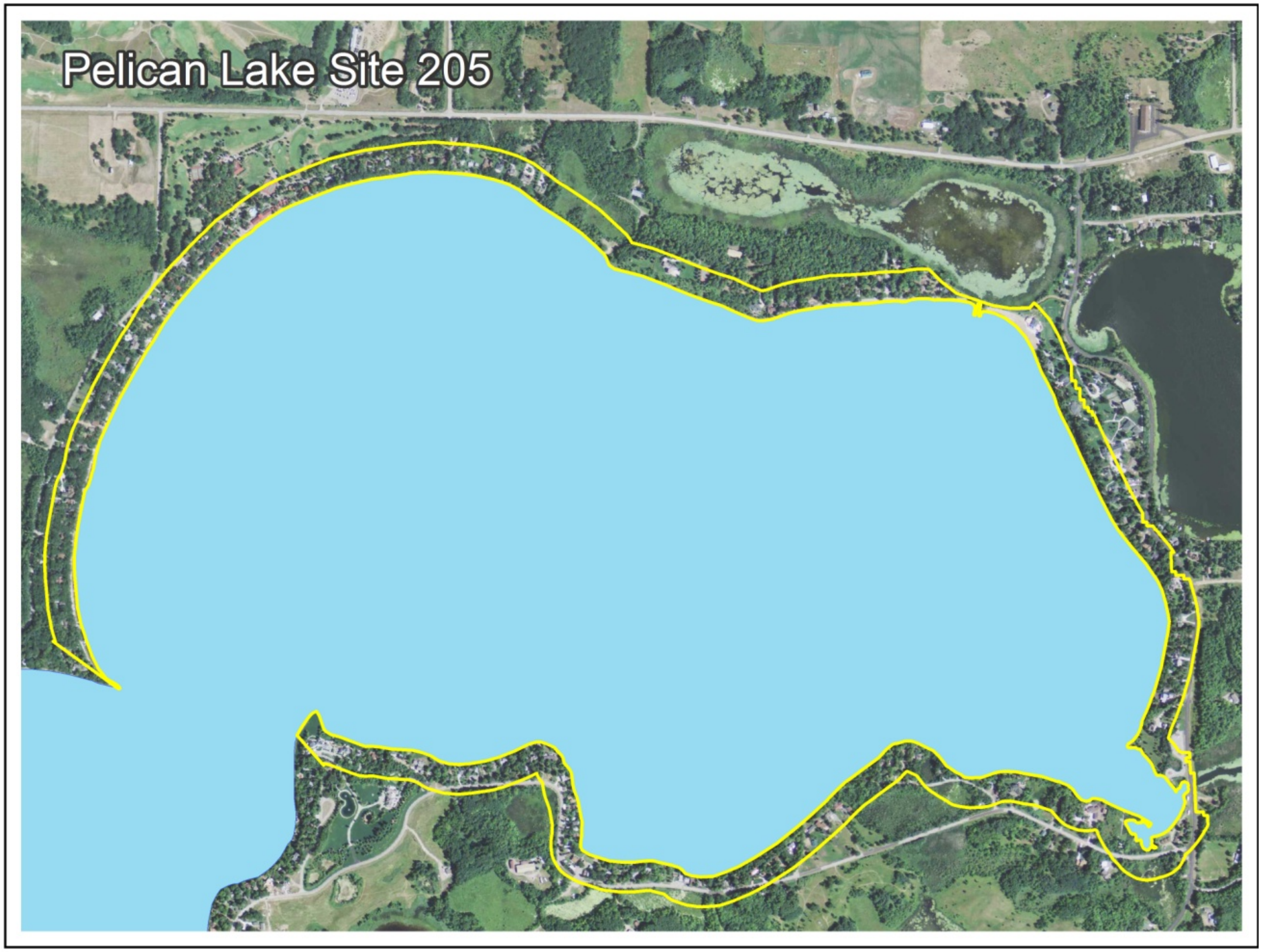

Figure 14. Pelican Lake Fairhills Bay 250 foot shoreline buffer.

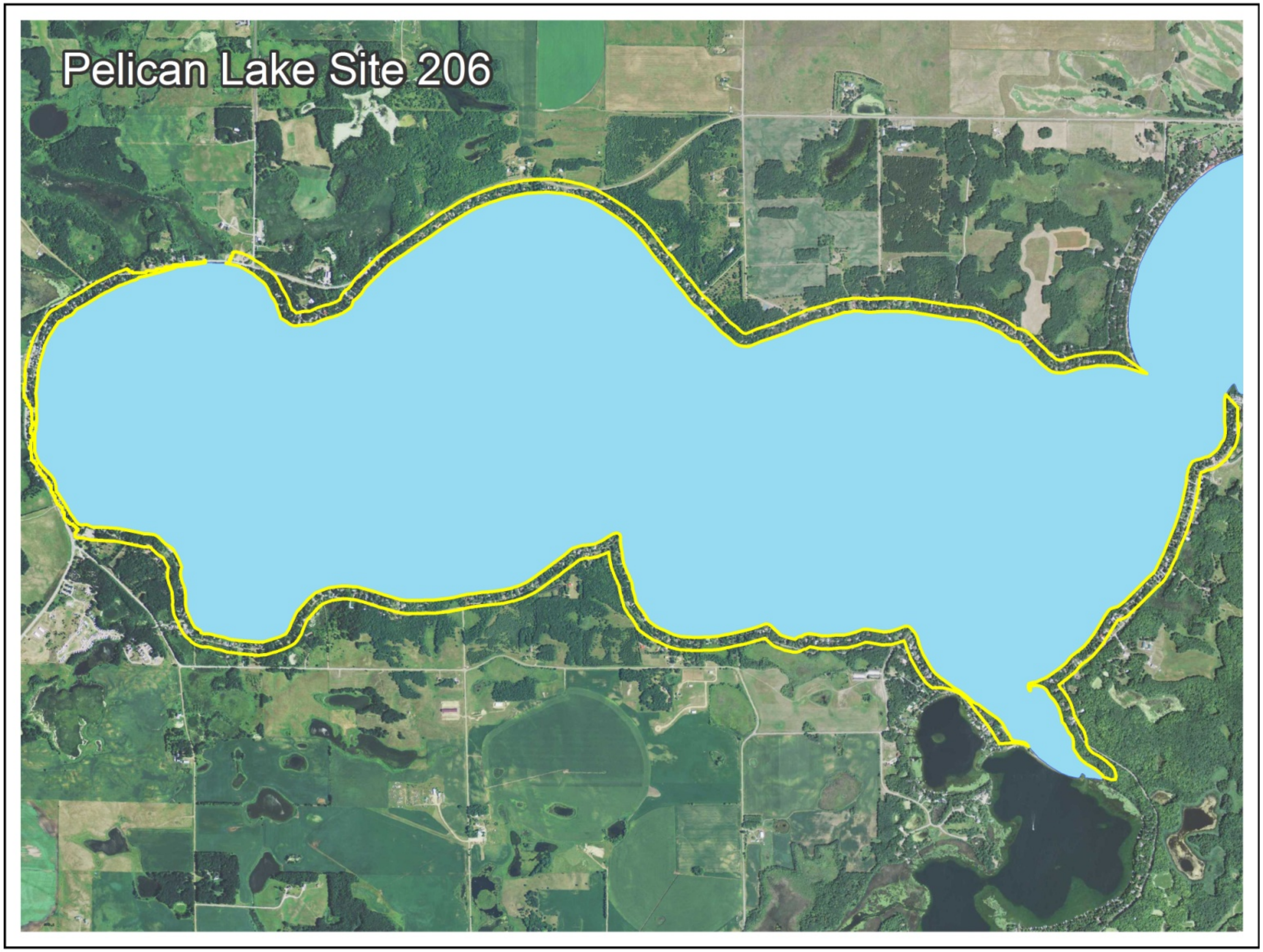

Figure 15. Pelican Lake Main Bay 250 shoreline buffer.

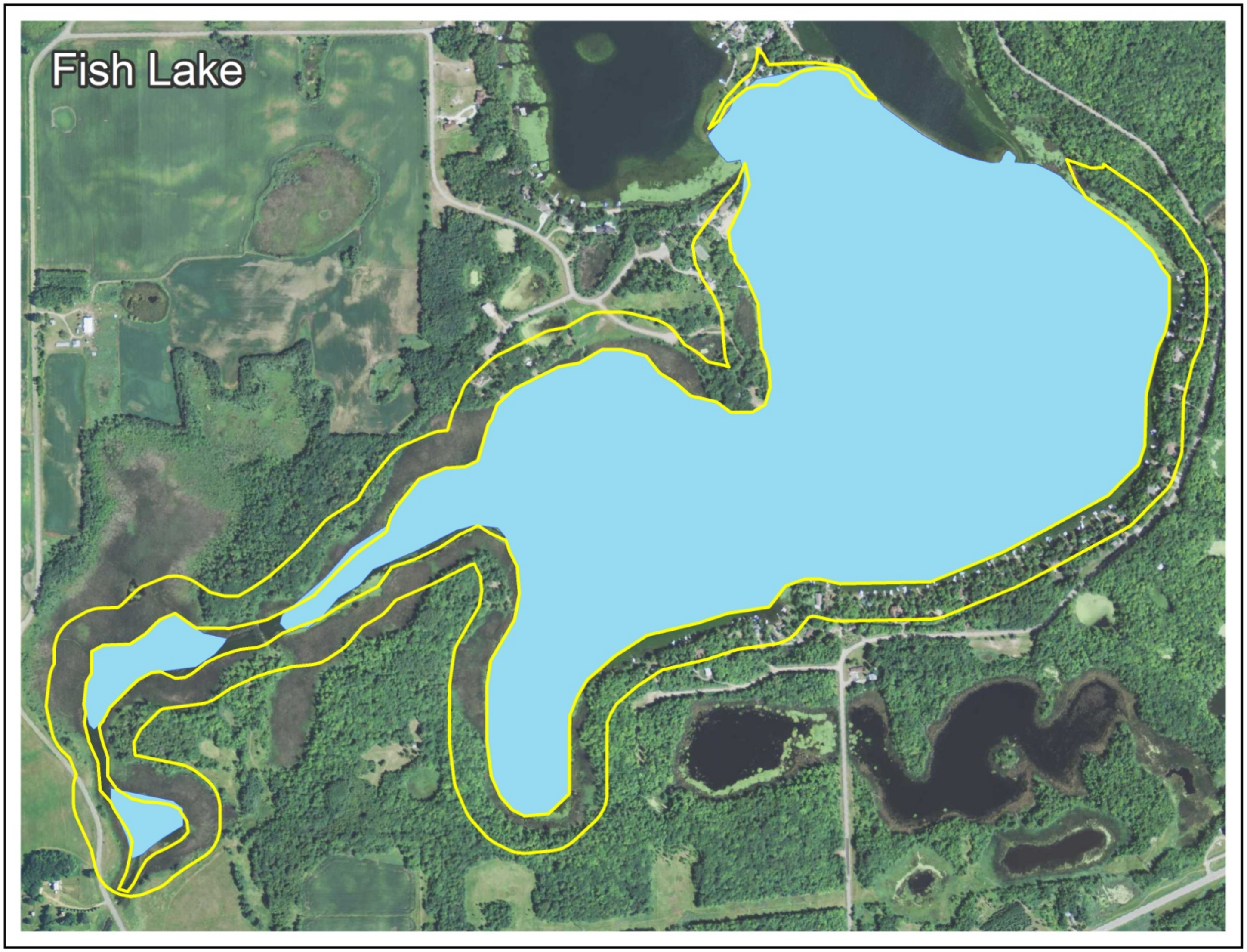

Figure 16. Fish Lake 250 foot shoreline buffer.

Figure 17. Bass Lake 250 foot shoreline buffer.

Little Pelican Lake

The highest land use type in the shoreline buffer around Little Pelican Lake is wetlands and forests (Figure 18). These land uses are generally good for lake water quality. When the area of land use for each type is multiplied by the phosphorus loading coefficient, it is clear that the majority of the phosphorus loading from the shoreline is coming from developed lots (Figure 19).

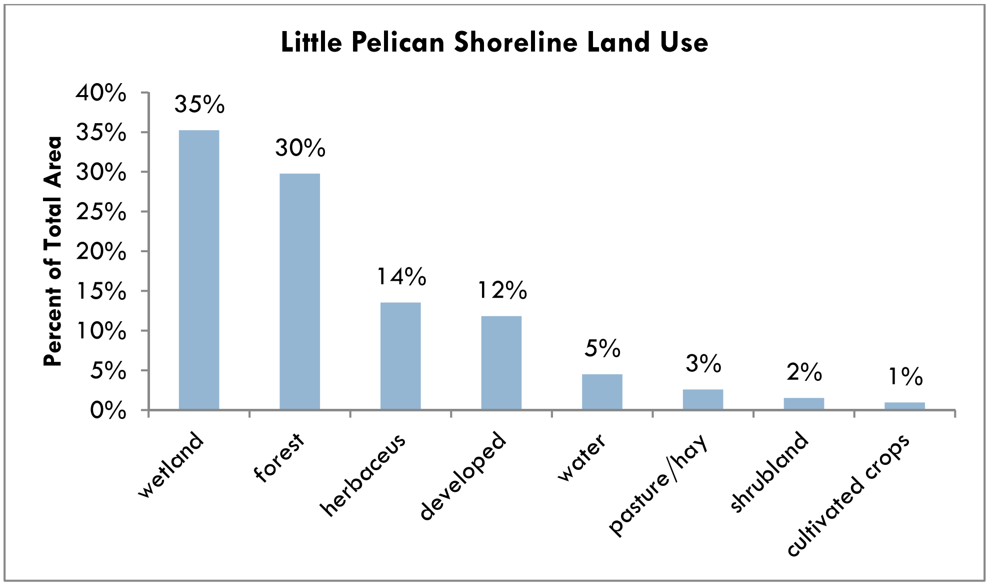

Figure 18. Land Use in the shoreline area around Little Pelican Lake.

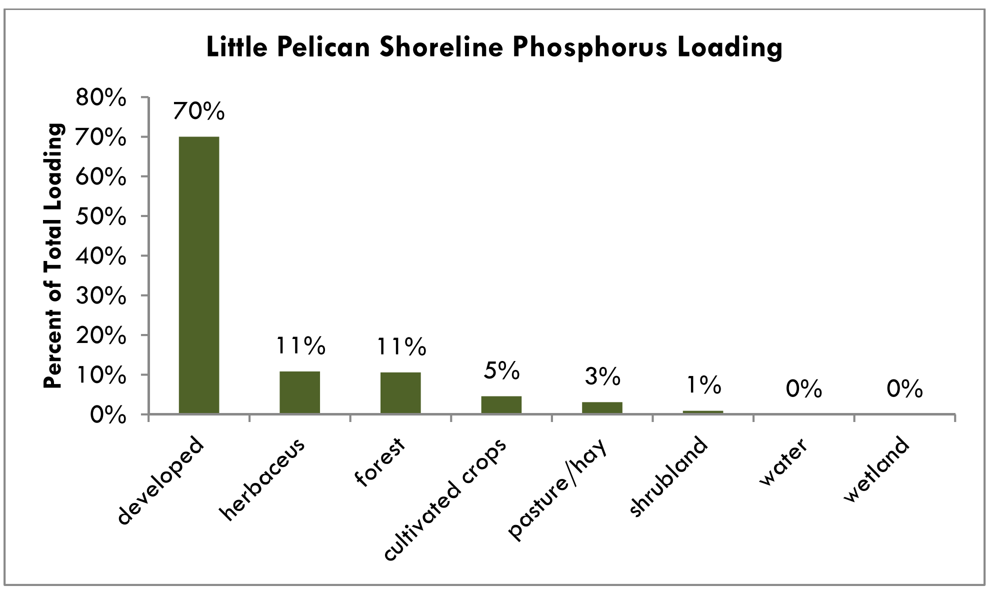

Figure 19. Phosphorus loading in the shoreline area around Little Pelican Lake.

Pelican Lake

The highest land use type in the shoreline buffer around Pelican Lake's Fairhills Bay is deciduous forest (38%) followed by wetlands (20%) (Figure 17). These land uses are generally good for lake water quality. When the area of land use for each type is multiplied by the phosphorus loading coefficient, it is clear that the majority of the phosphorus loading from the shoreline is coming from developed lots (Figure 21).

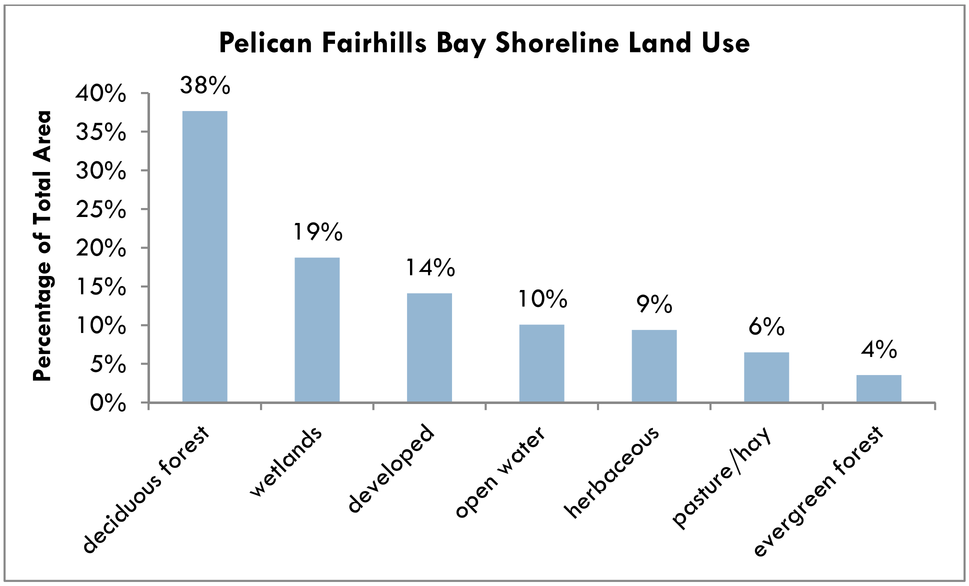

Figure 20. Land use in the shoreline around Pelican Lake's Fairhills Bay.

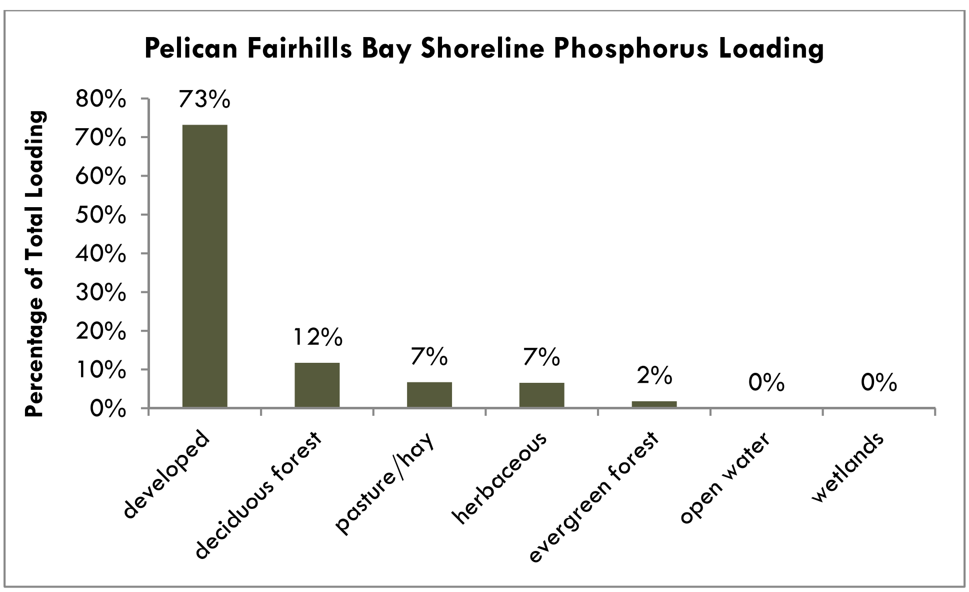

Figure 21. Phosphorus loading in the shoreline area around Pelican Lake Fairhills Bay.

The highest land use type in the shoreline buffer around Pelican Lake's Main Bay is deciduous forest (33%) followed by development (24%) (Figure 22). The high amount of development in the shoreline buffer is somewhat concerning. When the area of land use for each type is multiplied by the phosphorus loading coefficient, it is clear that the majority of the phosphorus loading from the shoreline is coming from developed lots (Figure 23).

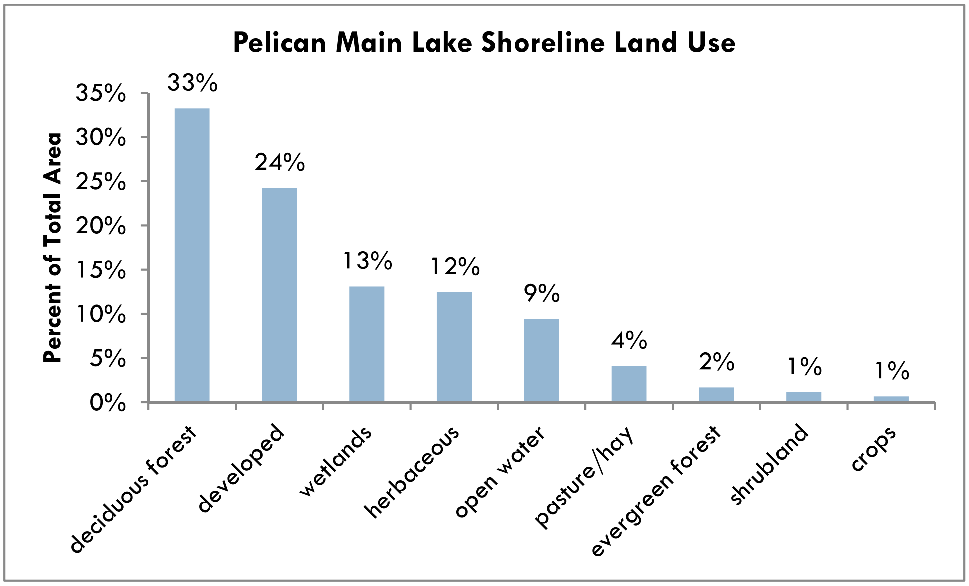

Figure 22. Land use in the shoreline around Pelican Lake's Main Bay.

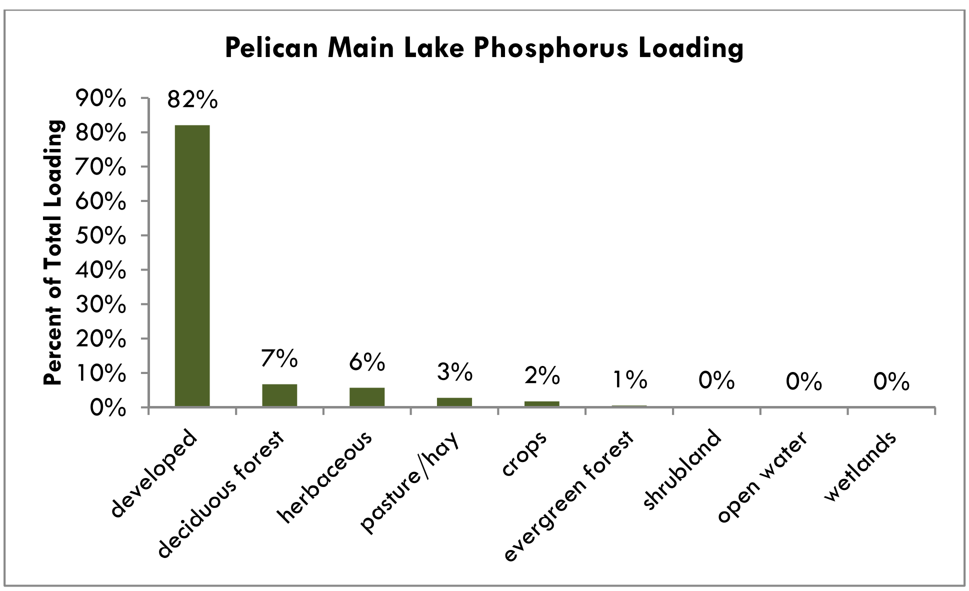

Figure 23. Phosphorus loading in the shoreline area around Pelican Lake Main Bay.

Fish Lake

The highest land use type in the shoreline buffer around Pelican Lake's Fairhills Bay is deciduous forest (40%) followed by wetlands (25%) (Figure 24). These land uses are generally good for lake water quality. There is less developed are in the shoreline buffer around Fish Lake than the other lakes because a lot of the shoreline is undevelopable due to wetlands. When the area of land use for each type is multiplied by the phosphorus loading coefficient, it shows that the majority of the phosphorus loading from the shoreline is coming from developed lots (Figure 25).

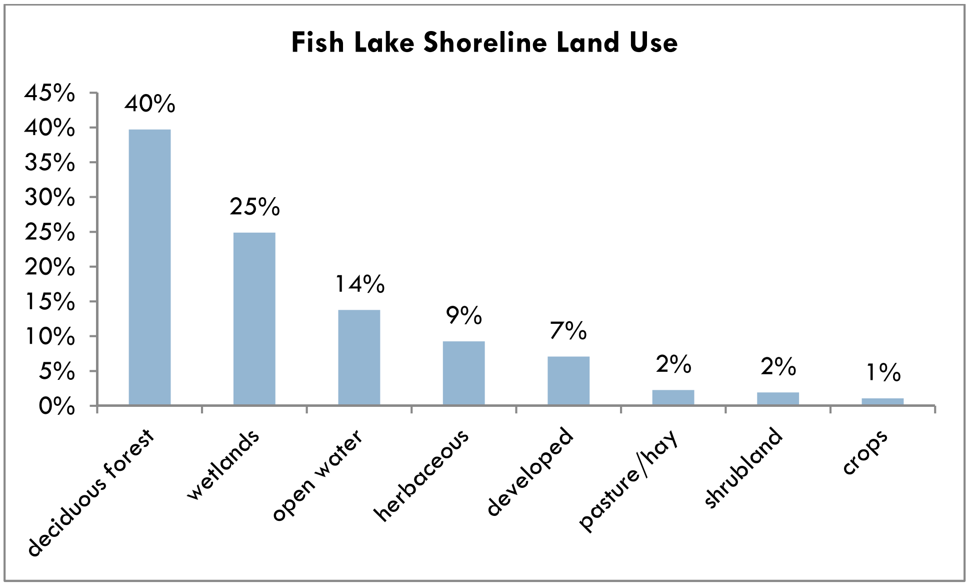

Figure 24. Land use in the shoreline area of Fish Lake.

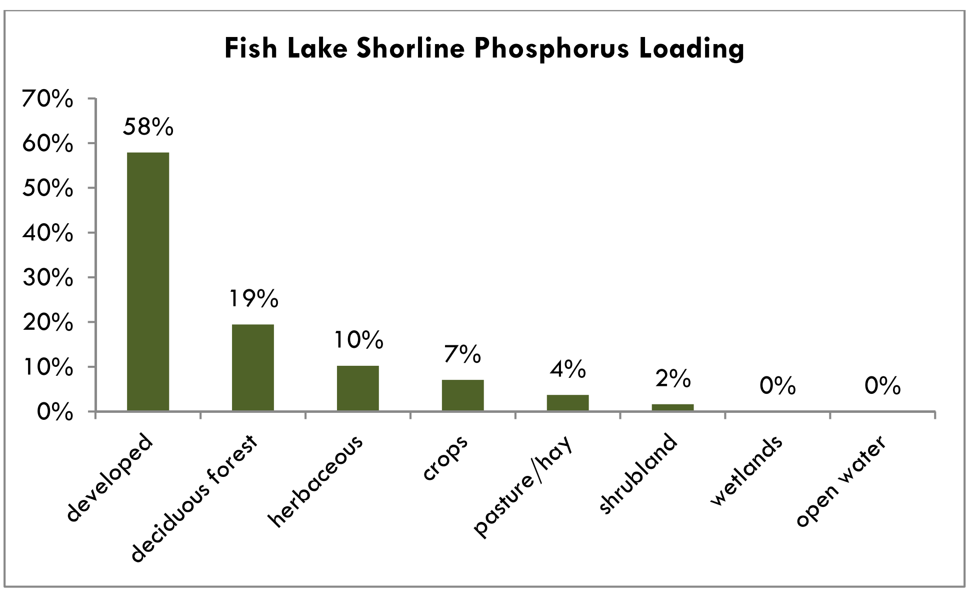

Figure 25. Phosphorus loading in the shoreline area around Fish Lake.

Bass Lake

The highest land use type in the shoreline buffer around Bass Lake is deciduous forest (48%) followed by development (25%) (Figure 26). The high amount of development in the shoreline buffer is somewhat concerning. When the area of land use for each type is multiplied by the phosphorus loading coefficient, it is clear that the majority of the phosphorus loading from the shoreline is coming from developed lots (Figure 27).

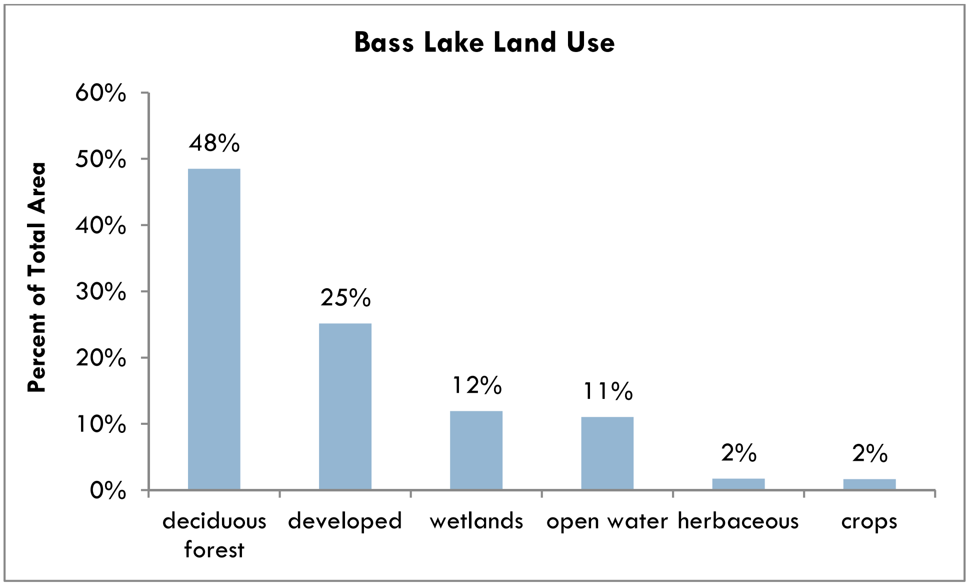

Figure 26. Land use in the shoreline area of Bass Lake.

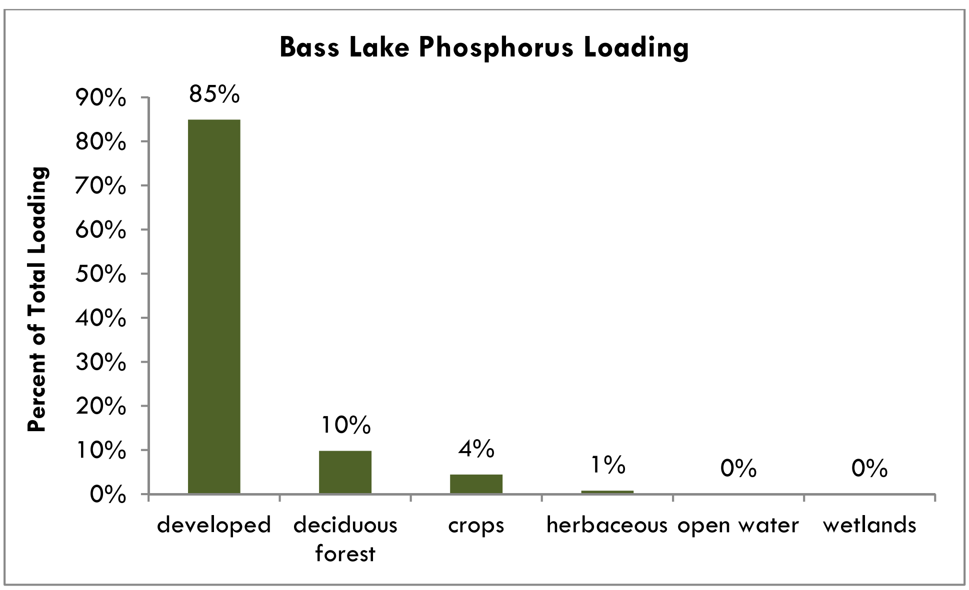

Figure 27. Phosphorus loading in the shoreline area around Bass Lake.

Precipitation

Precipitation is a phosphorus source to the lake because there are dust particles in the rain that contain phosphorus. This phosphorus source is not controllable by humans, so there is nothing we can do about it, but it is still important to include in the model since it is a significant phosphorus source to the lake. The amount of phosphorus loading from precipitation is estimated by the surface area of the lake.

Septic Systems

A septic system treats waste in a drainfield, while a holding tank just holds the waste until it is pumped out. Septic systems are a very good way to treat waste when properly maintained. Holding tanks are common in areas where there is not sufficient surface area or distance from the water table to install a drainfield.

Septic systems are potential phosphorus sources to the lake when they are not working properly. Even a properly working septic system can leach some nutrients into the lake during periods of high water, heavy rains, and high water table. In 2012, 68% of PGOLID waste treatment systems were septic systems, while 31% were holding tanks

Septic impacts are difficult to quantify. Systems that are near lakeshore can be estimated by the equation below; developed by a Wisconsin Lake Model program.

Septic Loading = number of systems x number of residents per system (~2.5)

x amount of phosphorus produced per year per residents (1lb) x soil retention factor (0.9)

For the purposes of this model, the septic systems were assumed to be working 90% of the time (soil retention factor of 0.9). This number is reasonable because PGOLID did a septic systems records study in 2012 that concluded that many of the old septic systems have been replaced and are in working order. The number of systems was determined by the number of parcels around each lake.

Internal Loading

Internal loading is when phosphorus comes back into the water column from the sediments of the lake. All the phosphorus that runs into the lake eventually settles into the bottom sediments and can remain there for decades or more. In addition, all the organic matter in the lake (plants, fish, invertebrates, etc) sinks to the bottom of the lake to decompose after death. This organic matter contains phosphorus as well. Internal loading typically occurs in mid-summer when the oxygen at the bottom of the lake (hypolimnion) is depleted due to the decomposition of organic matter. When there is no oxygen in the hypolimnion, a chemical reaction occurs where phosphorus is released from the lake sediment back into the water. Then in the fall when the lake turns over this phosphorus comes up to the surface (Figure 28).

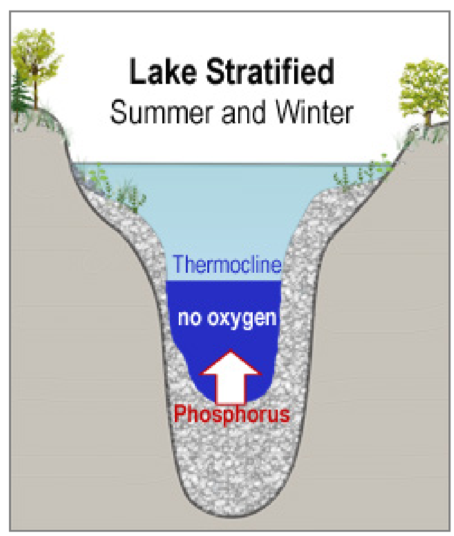

Figure 28. Internal loading in a lake.

Internal loading occurs most at areas where there is a lot of phosphorus and a lot of phosphorus loading. PGOLID's long-term monitoring program has shown that the highest area for internal loading in PGOLID is Pelican Lake's Fairhills bay (Figures 30 & 31). This is most likely because the Pelican River flows into this bay first from Little Pelican, and much of the sediment and nutrients drop out before flowing into the main basin of Pelican Lake.

The way internal loading is monitored, is to collect a water sample from the top of the lake and the bottom of the lake and compare the phosphorus concentrations. In addition, dissolved oxygen and temperature profiles are collected, where the dissolved oxygen and temperature are recorded at two foot intervals from the surface of the lake to the bottom. If the phosphorus concentration at the bottom of the lake is higher than at the top, and the dissolved oxygen is less than 3 mg/L at the bottom of the lake, internal loading is occurring.

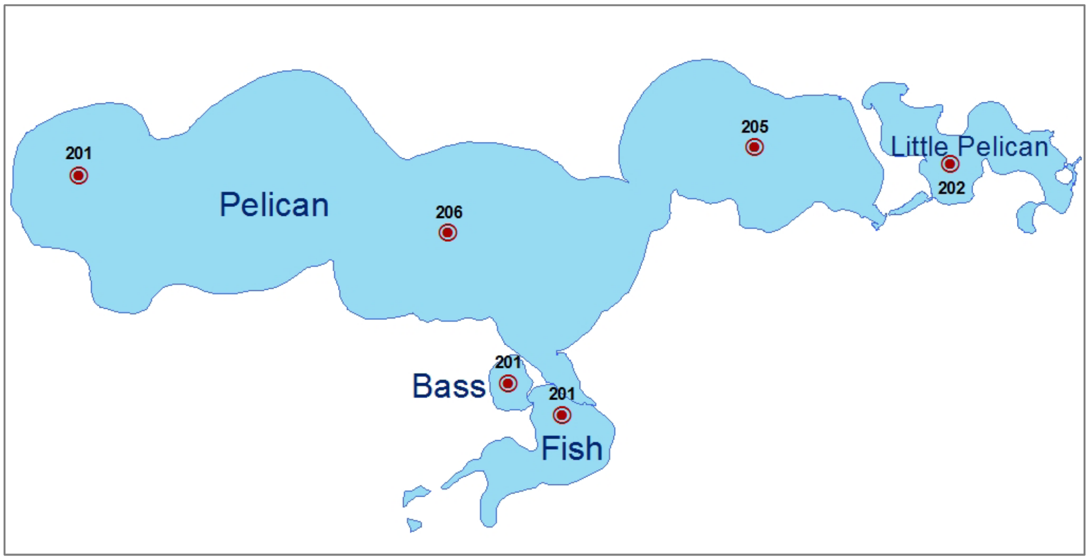

Figure 29. Lake monitoring sites for each PGOLID lake.

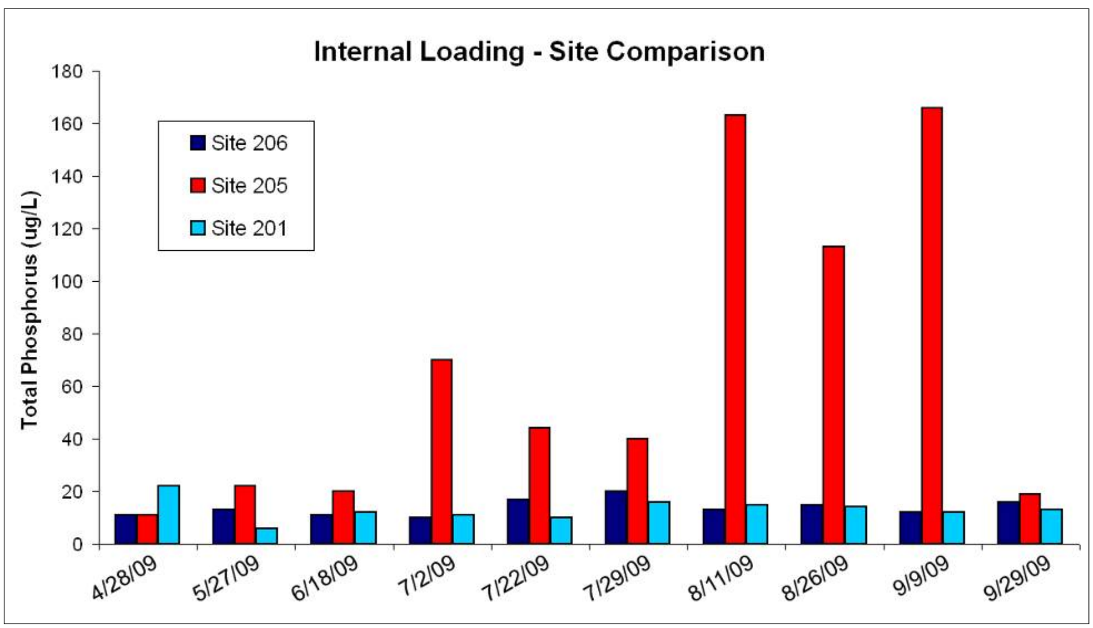

Figure 30. Lake bottom phosphorus concentrations at three sites in Pelican Lake.

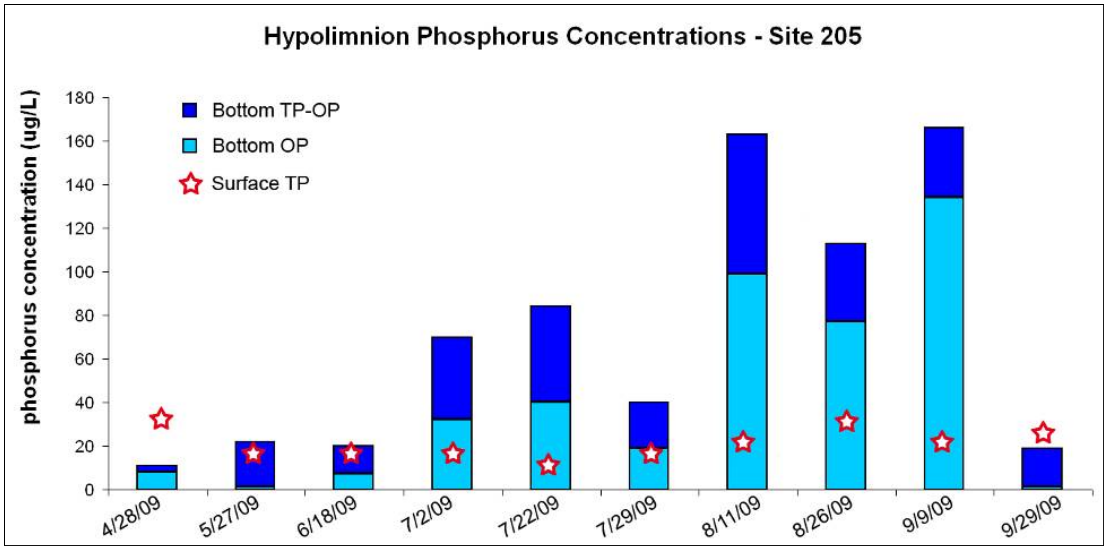

Figure 31. Internal loading occuring in Pelican Lake's Fairhills Bay when the bottom phosphorus concentration is higher than the surface phosphorus concentration.

Figure 32 shows that the bottom of the lake in Fairhills Bay had no oxygen on the same days as the phosphorus concentrations were high (Figure 28).

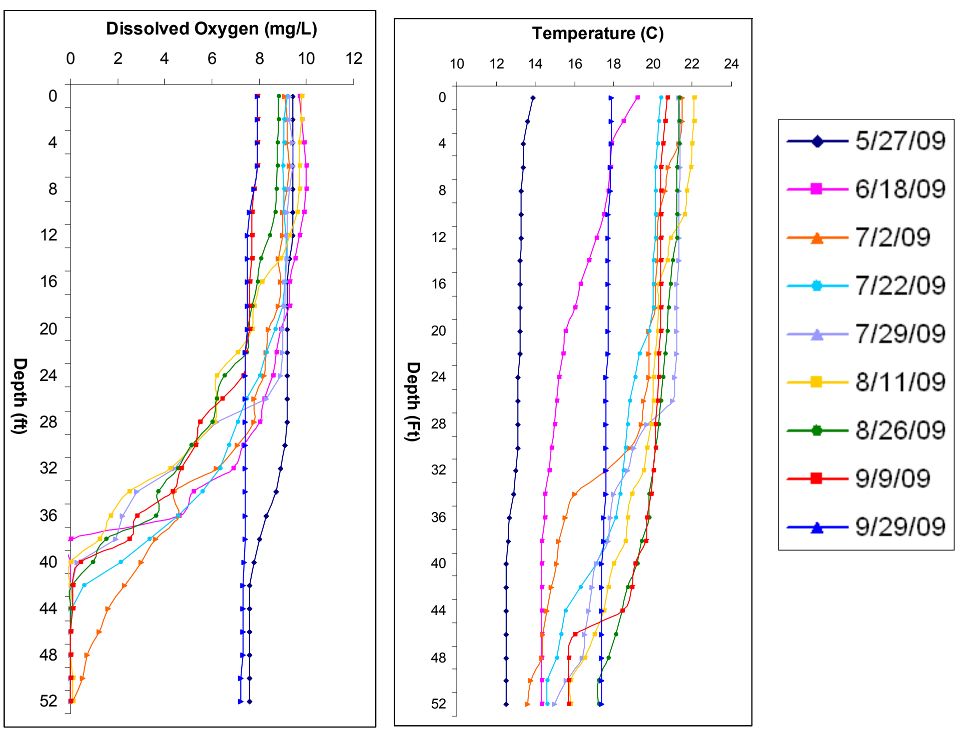

Figure 32. Dissolved Oxygen and temperature profiles at site 205 (Fairhills Bay) of Pelican Lake.

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4. MODEL

Segments

When setting up the segments of the model, each lake was considered its own segment; however, it was decided to split Pelican Lake into two segments: Fairhills Bay and Main Bay (Figure 33). The reason Pelican Lake was split is because of the internal loading occurring in Fairhills Bay that is not occurring in the Main Bay (Figure 30). In addition, a very long time ago when water levels were lower, there is evidence that Fairhills Bay was more separate from the Main Bay of Pelican Lake than it is today.

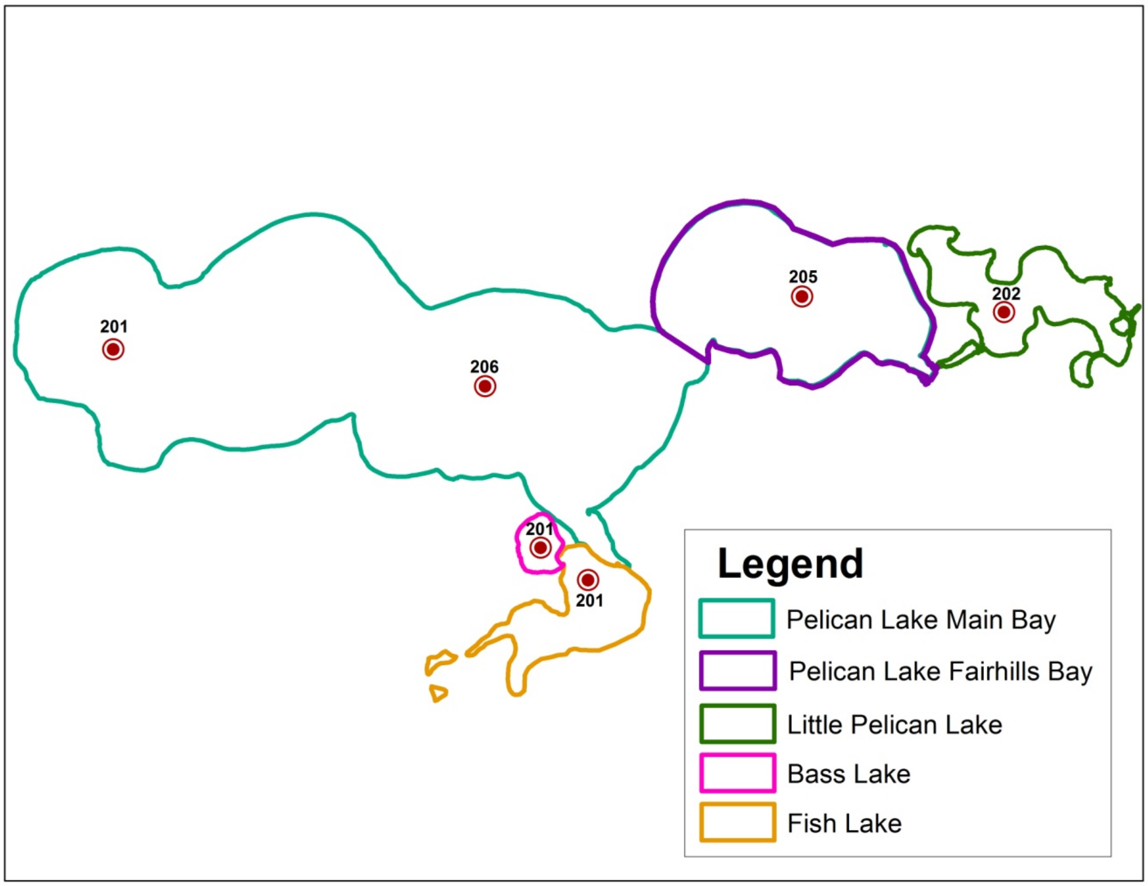

Figure 33. Map of the different segments for the model.

Model Year

The initial model was run with 2009 data because it was a very typical year for precipitation, with approximately 26 total inches (Figure 34). In addition, even though Zebra mussels were found that year, they hadn't begun to impact the lake yet.

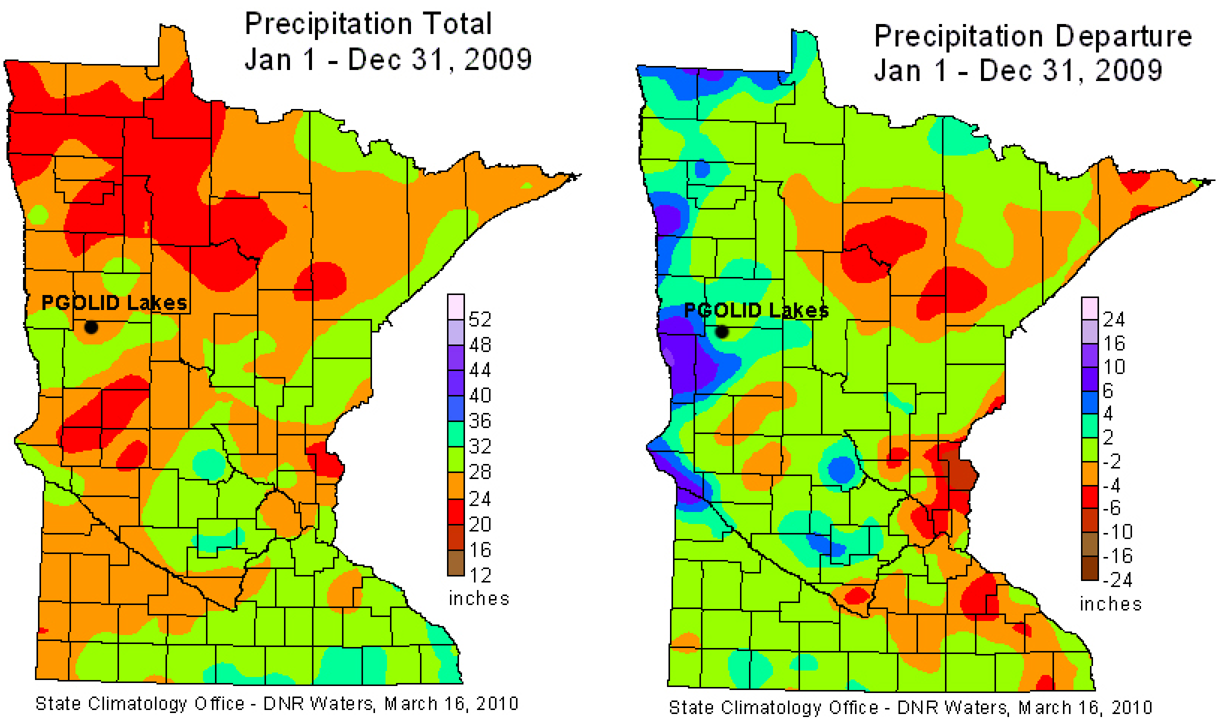

Figure 34. 2009 precipitation total and departure from the historical average.

Model Fit

To determine if the model is working correctly with the data input, the observed water quality results are compared to the predicted results from the model. The inputs to the PGOLID model resulted in a good fit between the observed lake water quality and the predicted lake water quality, which means that the model is acting as it should.

The phosphorus results from the model show that all the lakes are right on between the predicted and observed phosphorus concentrations (Figure 35). The only site that is further apart is Little Pelican; however, the error bars still cross each other, which means they're statistically overlapping. Figure 32 shows that the model is predicting a lower phosphorus concentration for the lake than what was observed. One reason for this could be the flow data from the Pelican River. The PGOLID data set has approximately 15 flow readings per year, but to get a very specific picture of flow it is helpful to have daily flow readings. This can be done by installing a data logger at the Highway 20 Pelican River site.

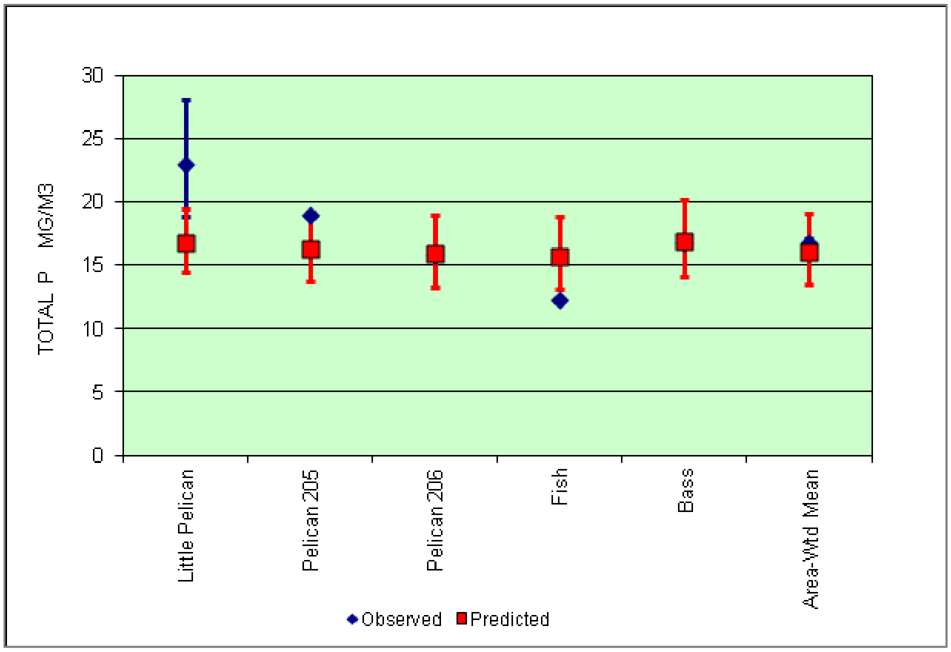

Figure 35. 2009 model output for phosphorus concentrations comparing the observed water quality results to the predicted results from the model.

The chlorophyll a and Secchi graphs show a very close fit as well, with Secchi depth showing the best fit (Figures 36-37).

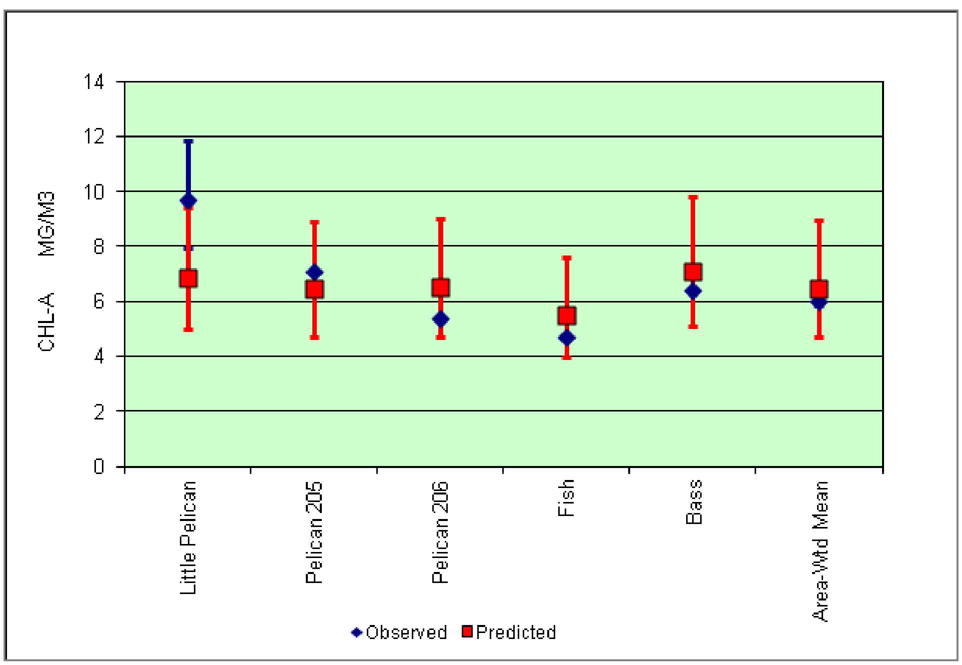

Figure 36. 2009 model output for chlorophyll a concentrations comparing the observed water quality results to the predicted results from the model.

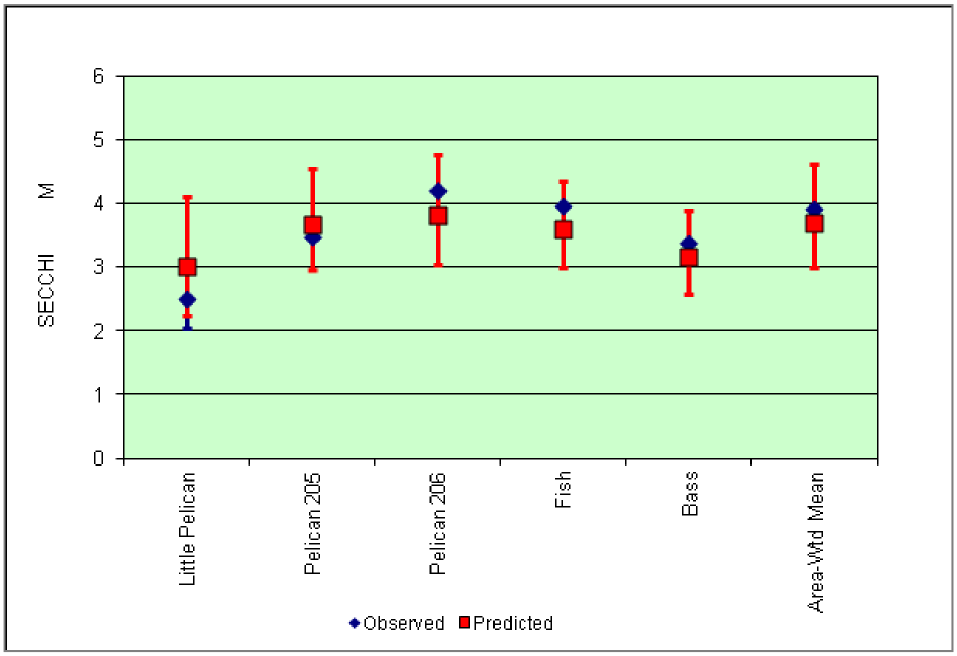

Figure 37. 2009 model output for Secchi depth comparing the observed water quality results to the predicted results from the model.

Calibration

To test the robustness of the model, a different year's monitoring data is inserted to see if it is still a good fit. The data set from 2010 was used to calibrate the model. 2010 was considered a wet year with approximately 38 total inches of precipitation, which is approximately 12 inches over the historical average (Figure 38). Even though 2010 was a wet year, it actually fit the model better than 2009 (Figures 39-41). This means that the monitored flow could be underestimated for the inlets.

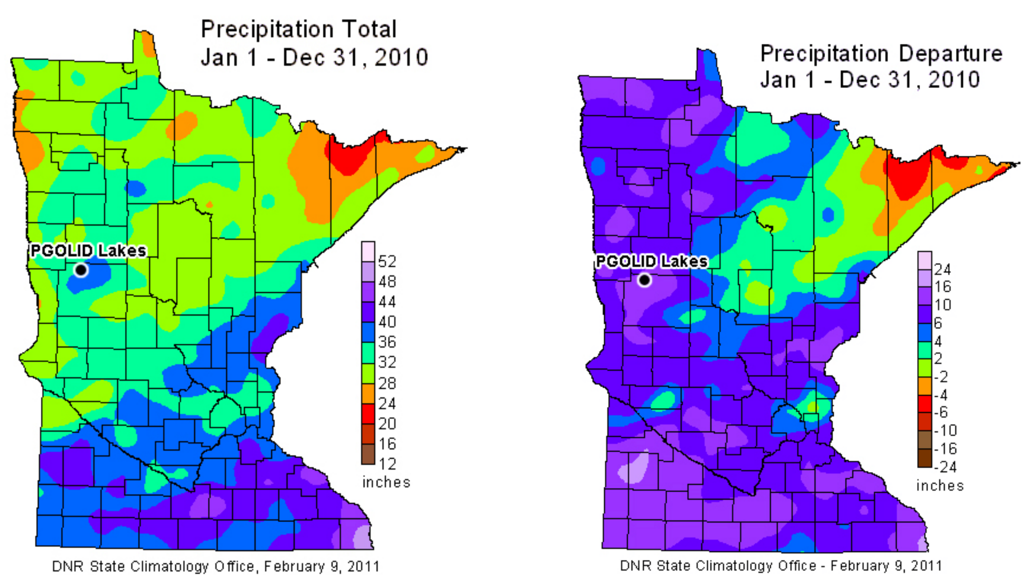

Figure 38. Total precipitation and departure from the average for 2010.

The 2010 model still shows Little Pelican Lake with a lower predicted phosphorus concentration than observed, but the numbers are closer than for 2009 (Figure 39).

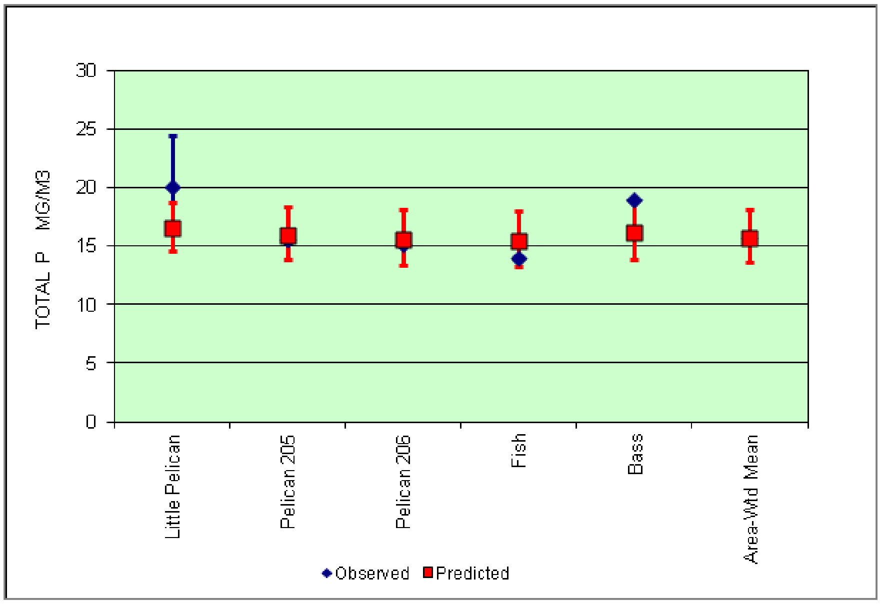

Figure 39. 2010 model output for phosphorus concentration comparing the observed water quality results to the predicted results from the model.

The model output for chlorophyll a and Secchi depth shows the observed and predicted numbers as almost identical (Figures 40-41).

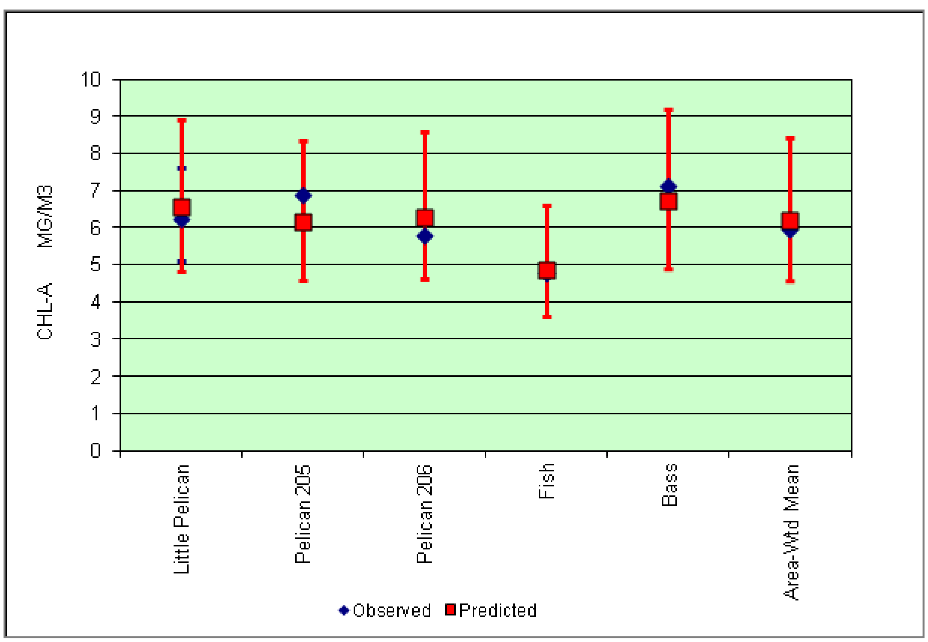

Figure 40. 2010 model output for chlorophyll a concentration comparing the observed water quality results to the predicted results from the model.

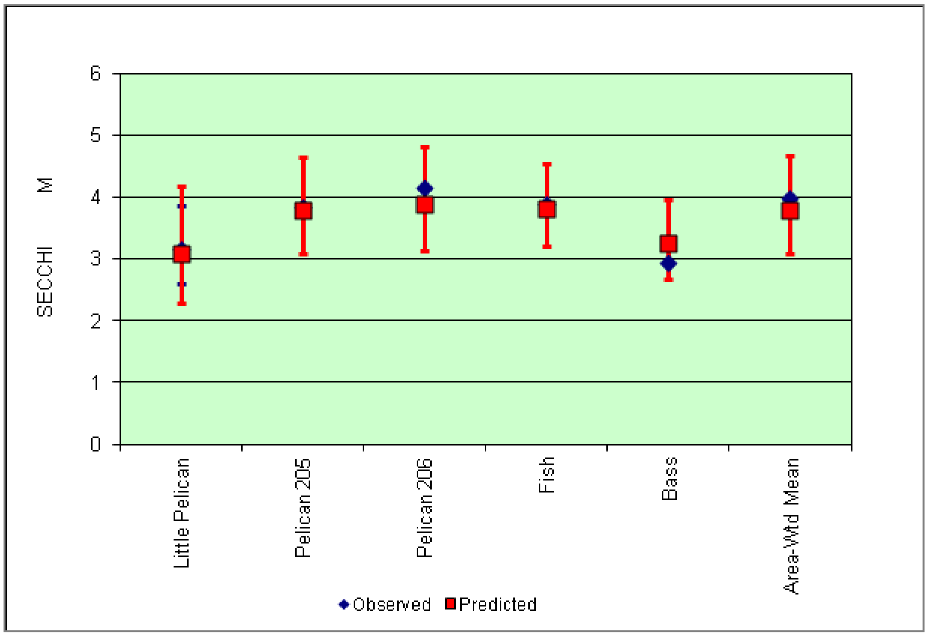

Figure 41. 2010 model output for Secchi depth comparing the observed water quality results to the predicted results from the model.

4. RESULTS AND DISCUSSION

Overall Summary

The model output for each lake shows the percentage of phosphorus loading from each of the different sources (Table 5, Figure 42). Little Pelican, Pelican, and Fish Lakes look somewhat similar because they have major inflows from the Pelican River. Bass Lake looks different from the other lakes because it is fairly isolated, with no major inlets. The connection between Bass and Fish Lakes does not appear to move much water back and forth, but there is undoubtedly some exchange (11%, Figure 42).

Table 5. Model output of phosphorus loading proportions from 2009.

	Little Pelican Lake	Pelican Fairhills Bay	Pelican Main Bay	Fish Lake	Bass Lake
Inlet Loading	94.1%	73.8%	77.0%	96.2%	10.5%
Internal Loading	2.4%	16.6%	7.0%	1.0%	11.1%
Precipitation	1.9%	4.5%	11.5%	1.6%	30.4%
Shoreline Runoff	1.1%	0.9%	2.2%	0.7%	31.0%
Septic Systems	0.6%	1.1%	2.3%	0.5%	17.0%

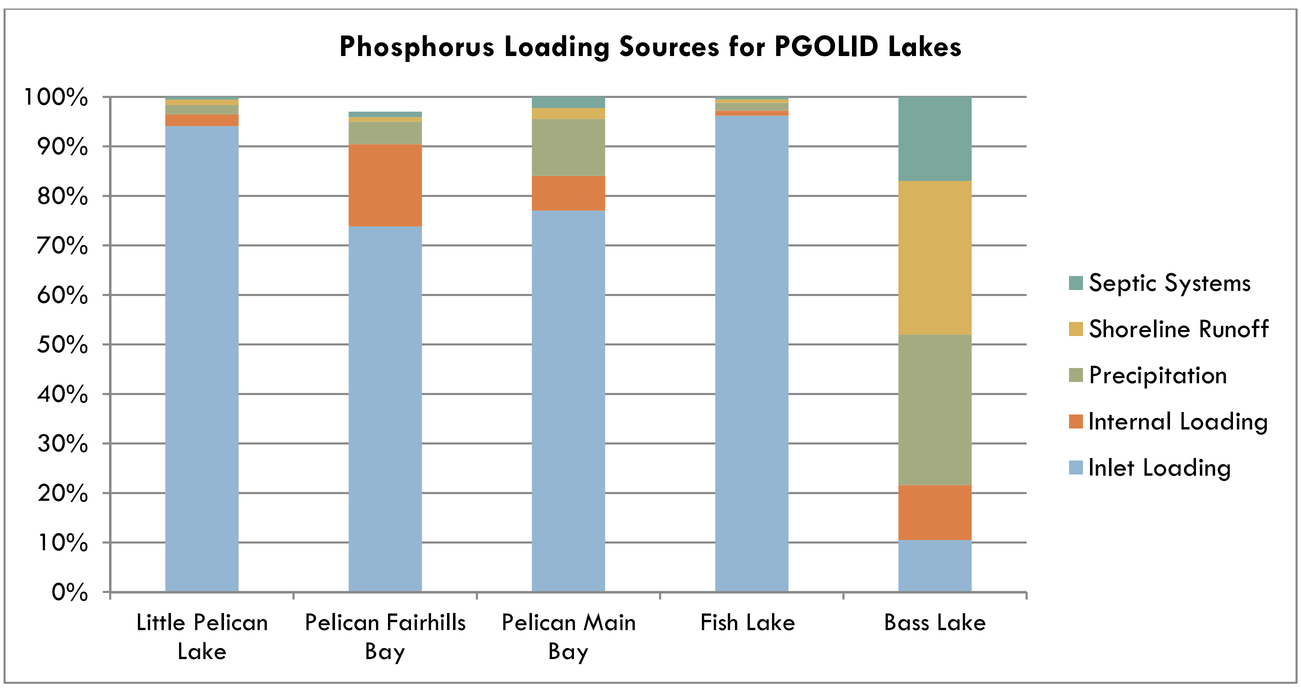

Figure 42. Phosphorus loading sources to the PGOLID Lakes.

Implications

Because the Pelican Group of Lakes have so much water flowing through them, they are continually flushed out. This is good, because much of the nutrients coming into the lake go back out of the lake (Figure 43). The nutrients that stay in the lake are taken up by plants and algae and settle down into the sediments.

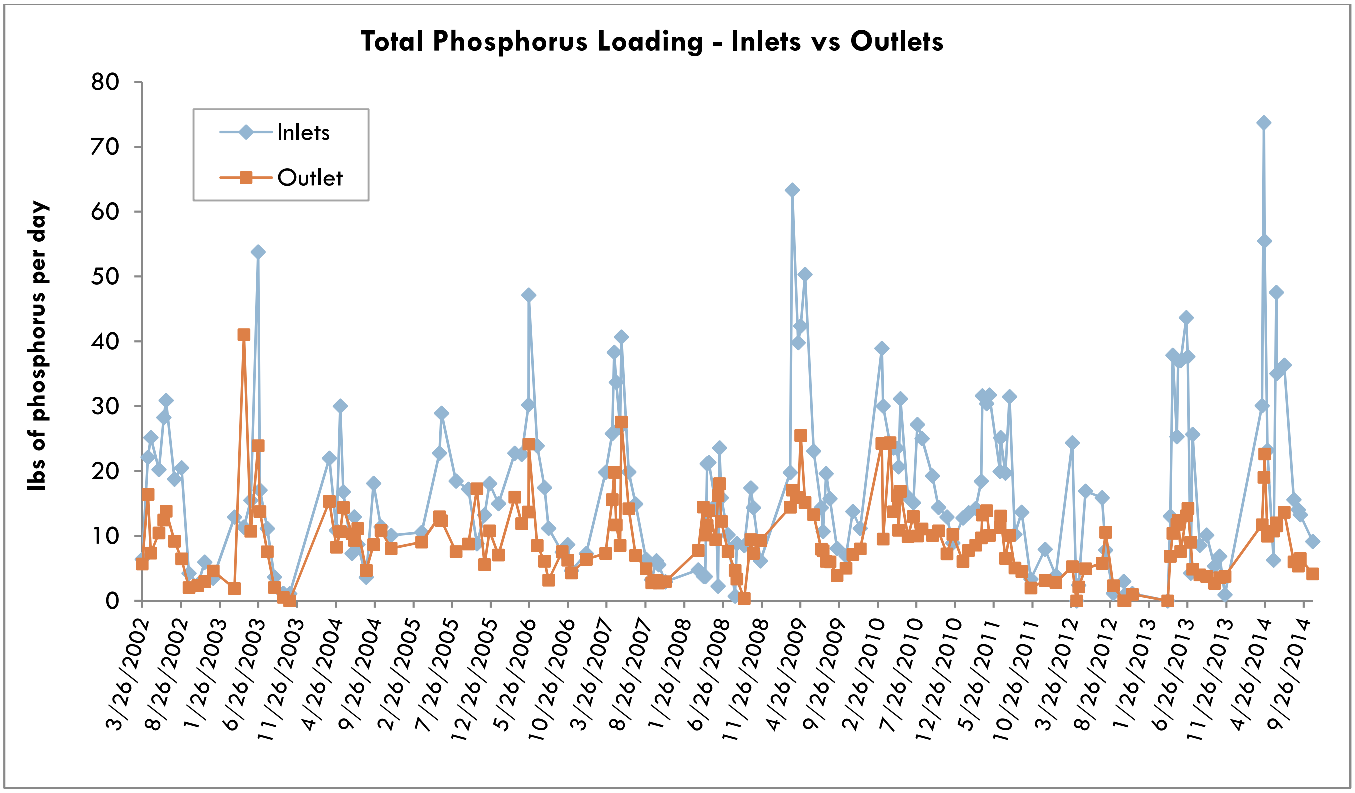

Figure 43. Total inlet vs. outlet loading for Pelican Lake.

Septic Systems

Septic systems are a phosphorus source to the lake that can be controlled. Because of the Pelican River flow through the lakes, septic systems do not have much impact on the lake. Bass Lake, however, is different. Because there is not the water exchange occurring in Bass Lake, the septic system nutrients stay in the lake. It is still important to make sure the septic systems in the lake remain in good working order.

Shoreline Runoff

Shoreline runoff is a phosphorus source to the lake that can be controlled. Because of the Pelican River flow through the lakes, shoreline runoff is not a major source of phosphorus to the lake, but it does still affect it, especially in localized areas. Shoreline runoff can fuel plant growth in swimming areas near shore. PGOLID has been implementing a Shoreline Restoration Program with a DNR Shoreline Habitat Restoration Grant since 2009. Restoring turf lawns to native grasses, wildflowers, trees and shrubs, and limiting the impervious surface in new development will limit future shoreline runoff.

Precipitation

Shoreline runoff is a phosphorus source to the lake that cannot be controlled. The amount of phosphorus loading from precipitation is determined by the surface area of the lake. The more surface area the lake has, the more rain it receives directly from rainfall. Bass Lake had the highest loading from precipitation, but this is because it has very little inlet loading. Of the other segments, the Main Bay of Pelican Lake had the most phosphorus loading from precipitation because it has the largest surface area. There is nothing that can be done to limit phosphorus loading from precipitation.

Internal Loading

Internal loading is a phosphorus source to the lake that can be somewhat controlled. It is based on the morphometry (size and depth), and biology of the lake, but it is also based on the amount of phosphorus in the lake. Limiting external phosphorus inputs to the lake can help reduce the amount of internal loading in a lake. Internal loading is most prevalent in Fairhills Bay of Pelican Lake. This is because this bay is deep enough to stratify (separate into a warm top layer and cold bottom layer) and it receives nutrients and sediment from the Pelican River. Little Pelican Lake has the highest in-lake phosphorus of all the PGOLID lakes, but because it is shallow it does not fully stratify in the summer. The water column remains fairly mixed, and so the bottom of the lake has oxygen present, which keeps the phosphorus in the sediments from releasing in to the water.

Inlet Loading

Inlet loading is a phosphorus source to the lake that can be somewhat controlled. The best way to manage inlet loading is to maintain good relationships with upstream neighbors, and to monitor for any problems that could arise. If problems are detected they can hopefully be fixed before the impact to the lake is large. PGOLID has been implementing a stream monitoring program since 2001.

The largest source of phosphorus to the PGOLID Lakes is the Pelican River (Figures 45-46). This means much of the phosphorus comes from upstream in the watershed such as Detroit Lakes (Figure 44). It is difficult to control phosphorous inputs upstream in the watershed. PGOLID maintains good working relationships with upstream entities such as the Pelican River Watershed District and the City of Detroit Lakes.

Spring Creek also contributes phosphorus loading to Pelican Lake (20%, Figure 47). PGOLID maintains a good working relationship with the Cormorant Lakes Watershed District, and have a signed agreement for how much water can be discharged from Big Cormorant Lake into Spring Creek.

Figure 44. The entire watershed for PGOLID Lakes.

Bob Creek is a minor phosphorus source to Pelican Lake (5%, Figure 47). PGOLID has worked with a farmer along the creek to increase stream buffers to better protect the stream's water quality.

Individual Lake Results

Little Pelican

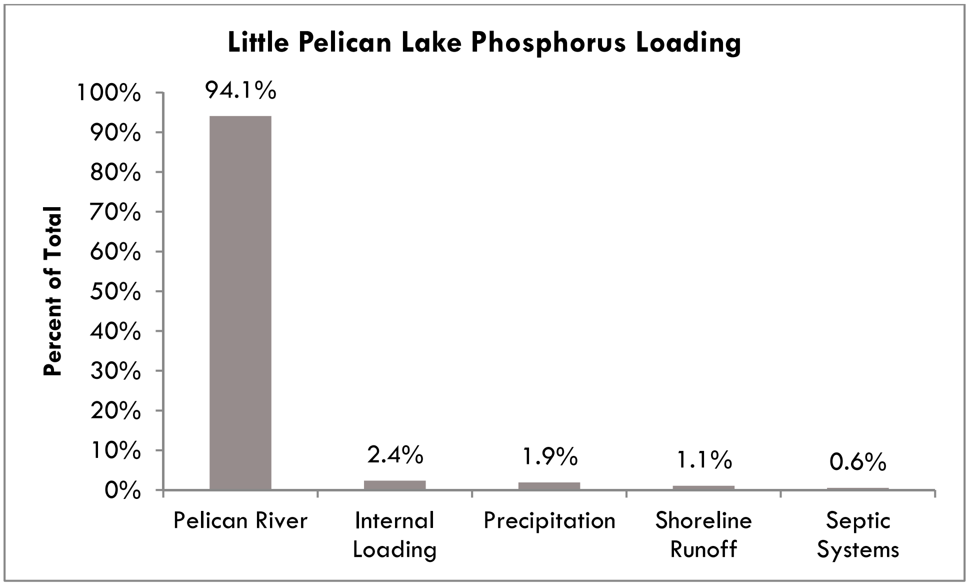

Figure 45. Little Pelican Lake phosphorus loading sources.

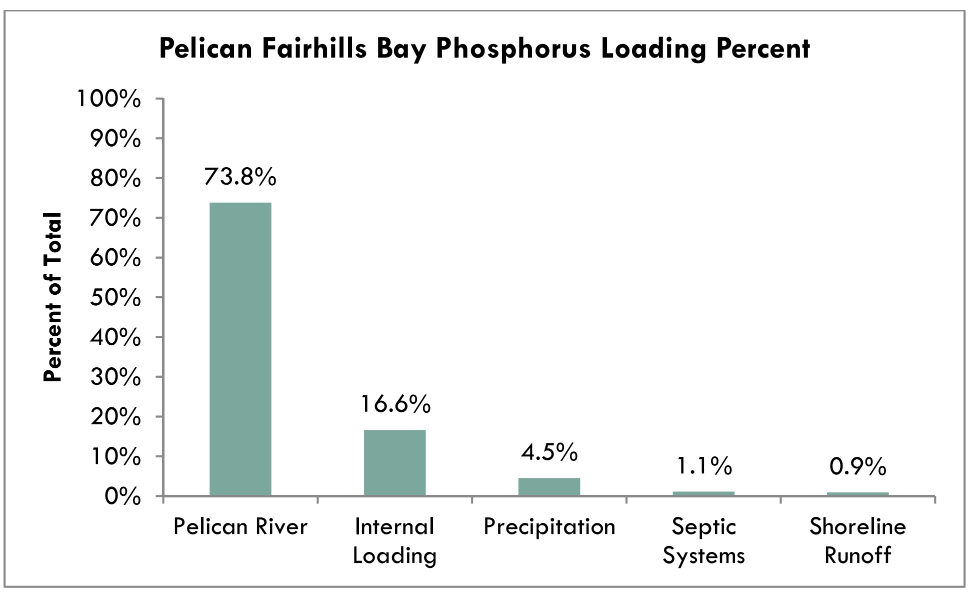

Figure 46. Pelican Lake Fairhills Bay phosphorus loading sources.

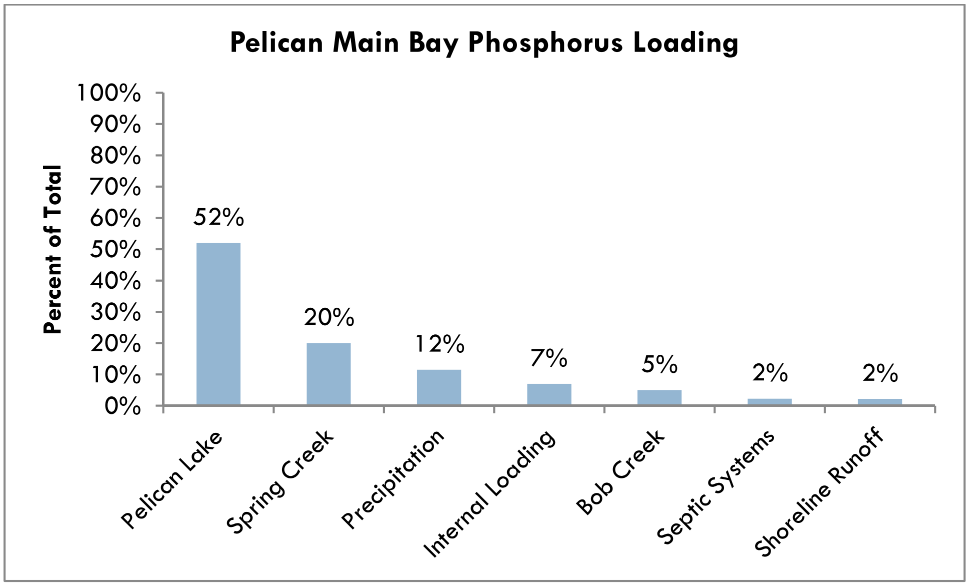

Figure 47. Pelican Lake Main Bay phosphorus loading sources.

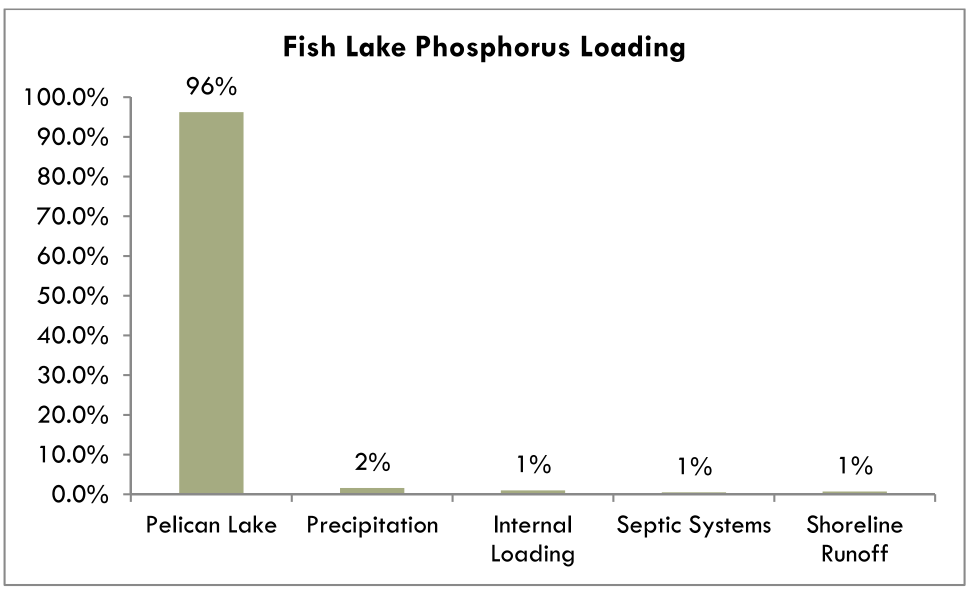

Figure 48. Fish Lake phosphorus loading sources.

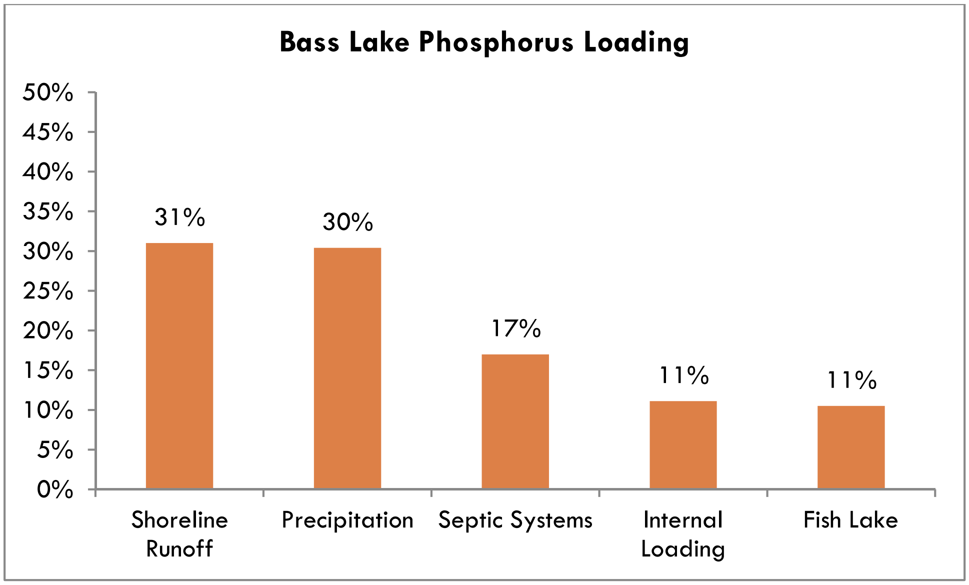

Figure 49. Bass Lake phosphorus loading sources.

5. NEXT STEPS

2013 – Zebra mussel Impact

Pelican Lake has seen a significant increase in clarity since 2011 that is most likely due to Zebra mussels. Because Zebra mussels affect the clarity and not the phosphorus concentrations, we would predict that the model would not fit the data well since 2011.

2013 was considered a wet year with approximately 30 total inches of precipitation, which is approximately 5 inches over the historical average (Figure 50).

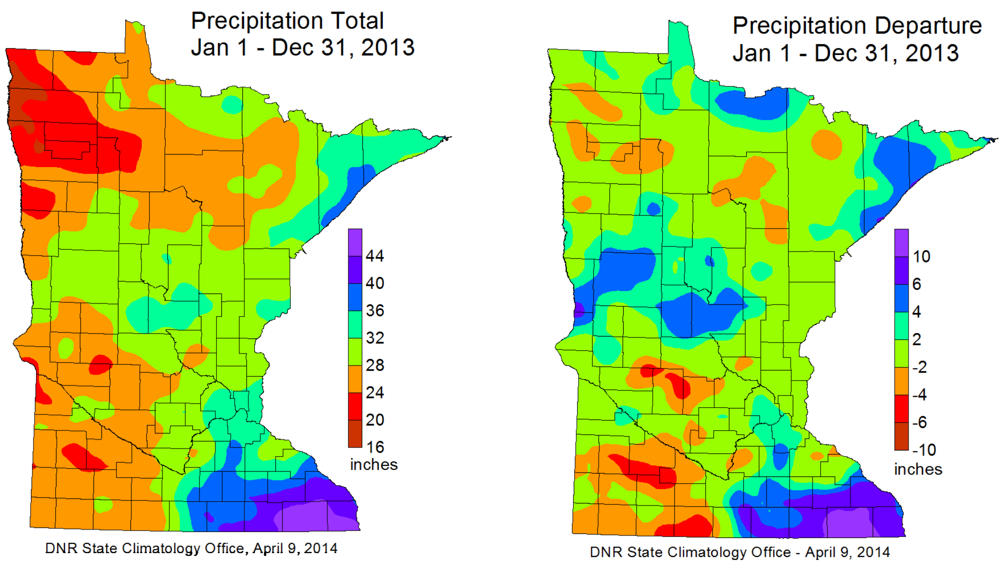

Figure 50. Total precipitation and departure from the average for 2013.

Figures 51-53 show the fit of the model. The phosphorus concentration fit the model fairly well, because Zebra mussels have little effect on the phosphorus concentration in the lake (Figure 48)

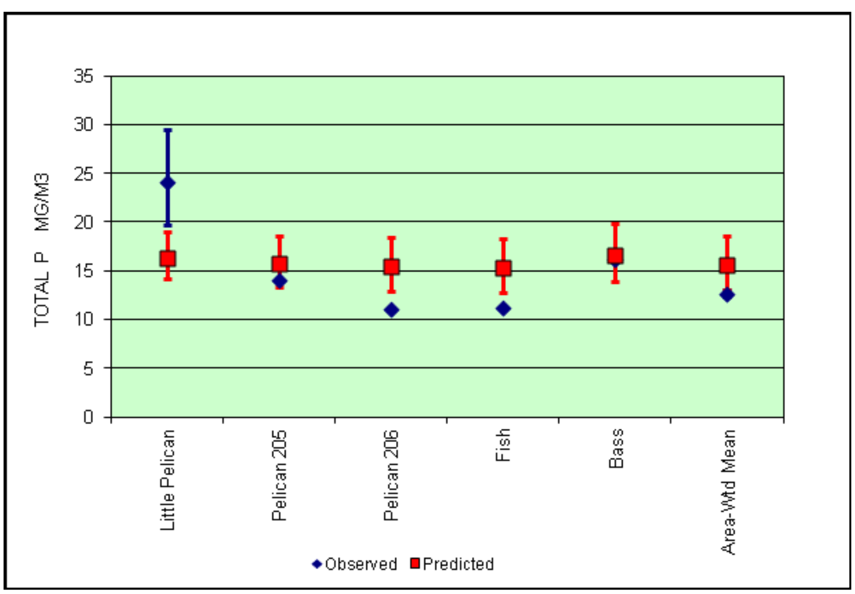

Figure 51. 2013 model output for phosphorus concentrations comparing the observed water quality results to the predicted results from the model.

The chlorophyll a and Secchi depth output from the model do not fit well (Figures 52-53). This is most likely due to the impact of Zebra mussels. To run future models on Pelican Lake, a correction factor for Zebra mussels will need to be made.

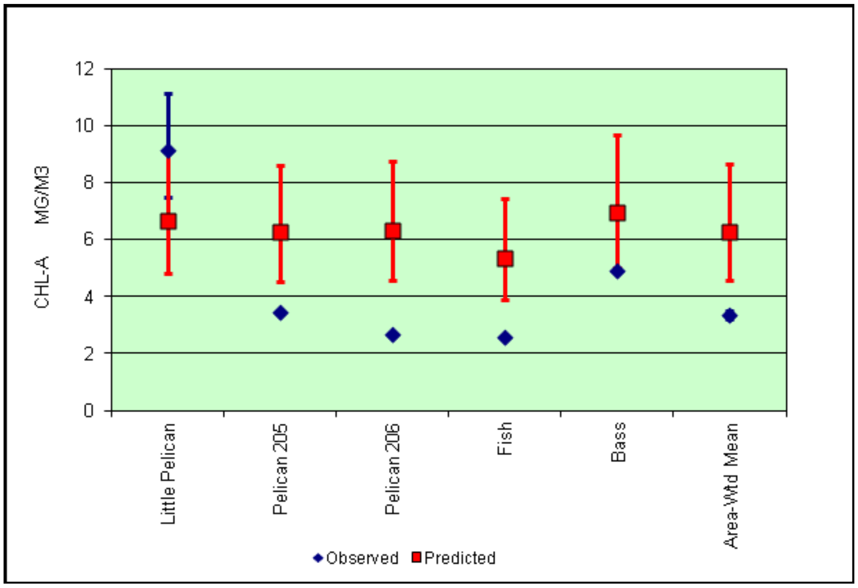

Figure 52. 2013 model output for chlorophyll-A concentrations comparing the observed water quality results to the predicted results from the model.

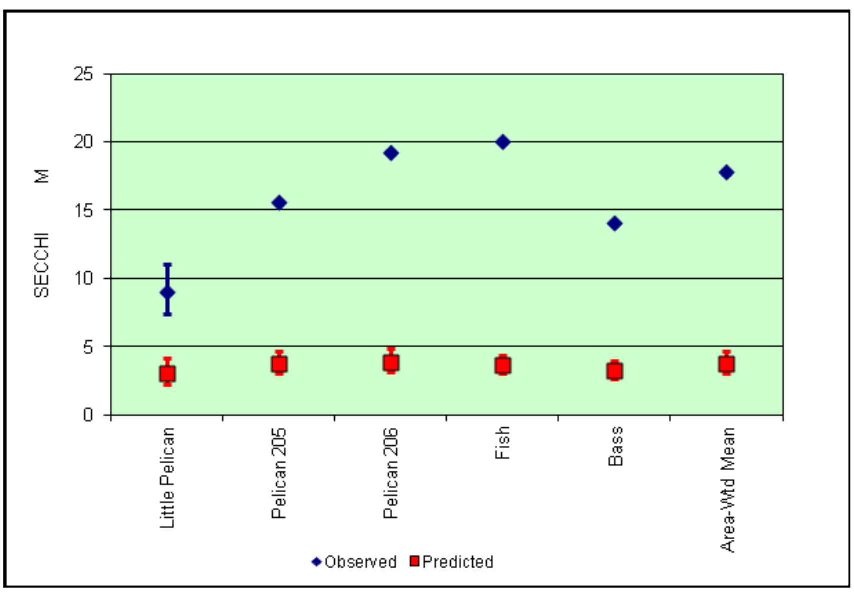

Figure 53. 2013 model output for secchi depth comparing the observed water quality results to the predicted results from the model.

The overall proportion of phosphorus loading for 2013 is similar to previous years (Figure 54).

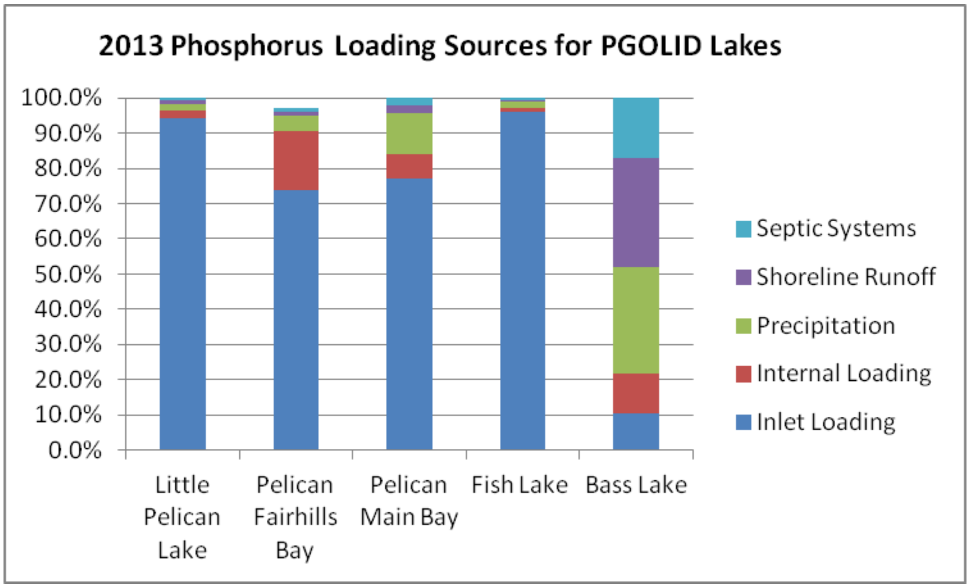

Figure 54. Phosphorus loading sources to the PGOLID Lakes in 2013.

Future scenarios

50% more Bob Creek Loading Scenario

A future scenario where Bob Creek supplies 50% more loading the current loading rate was run in the model. The results show almost no change from the 2009 typical loading scenario (Table 6, Figure 55).

Table 6. Loading proportions under the 50% more Bob Creek Loading scenario.

	Little Pelican Lake	Pelican Fairhills Bay	Pelican Main Bay	Fish Lake	Bass Lake
Inlet Loading	94.1%	73.4%	77.5%	96.3%	10.7%
Internal Loading	2.4%	16.4%	6.9%	1.0%	11.1%
Precipitation	1.9%	4.5%	11.3%	1.6%	30.4%
Shoreline Runoff	1.1%	0.9%	2.2%	0.6%	31.0%
Septic Systems	0.6%	1.1%	2.2%	0.5%	16.9%

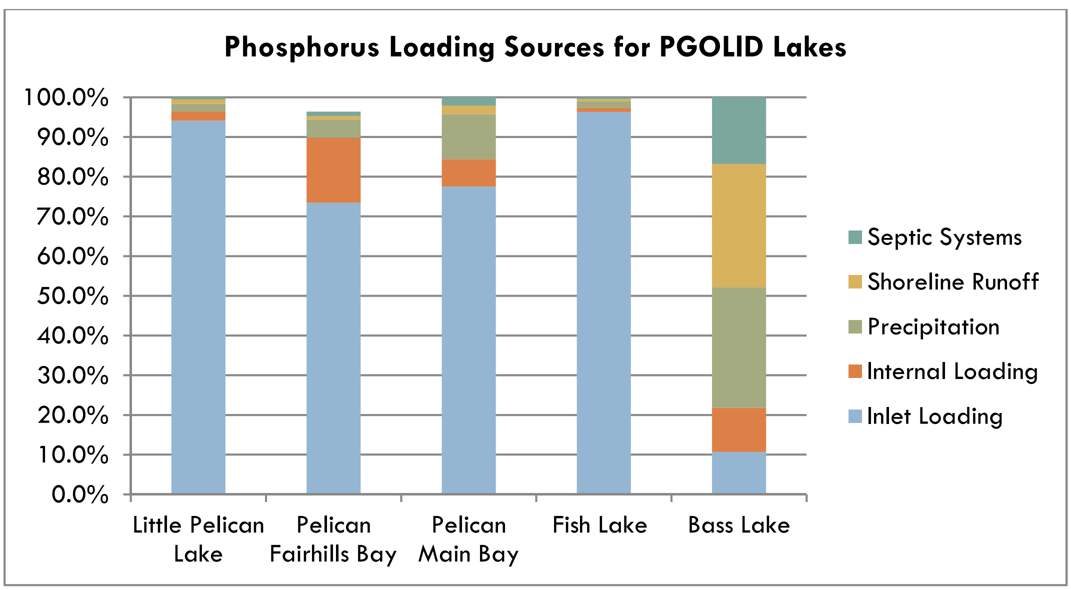

Figure 55. Phosphorus loading sources to the PGOLID Lakes if Bob Creek contributed 50% more loading

50% more Pelican River Loading Scenario

A future scenario where the Pelican River supplies 50% more loading the current loading rate was run in the model. The results show an increase in the inlet loading proportion from the 2009 typical loading scenario of about 6% in Pelican Lake, 2% in Little Pelican Lake, and <1% in Fish and Bass Lake (Table 7, Figure 56).

Table 7. Loading proportions under the 50% more Pelican River Loading scenario.

	Little Pelican Lake	Pelican Fairhills Bay	Pelican Main Bay	Fish Lake	Bass Lake
Inlet Loading	96.0%	80.2%	82.4%	97.2%	10.4%
Internal Loading	1.6%	12.1%	5.3%	70.0%	11.1%
Precipitation	1.3%	3.3%	8.8%	1.2%	30.4%
Shoreline Runoff	70.0%	70.0%	1.7%	50.0%	31.0%
Septic Systems	40.0%	80.0%	1.7%	40.0%	17.0%

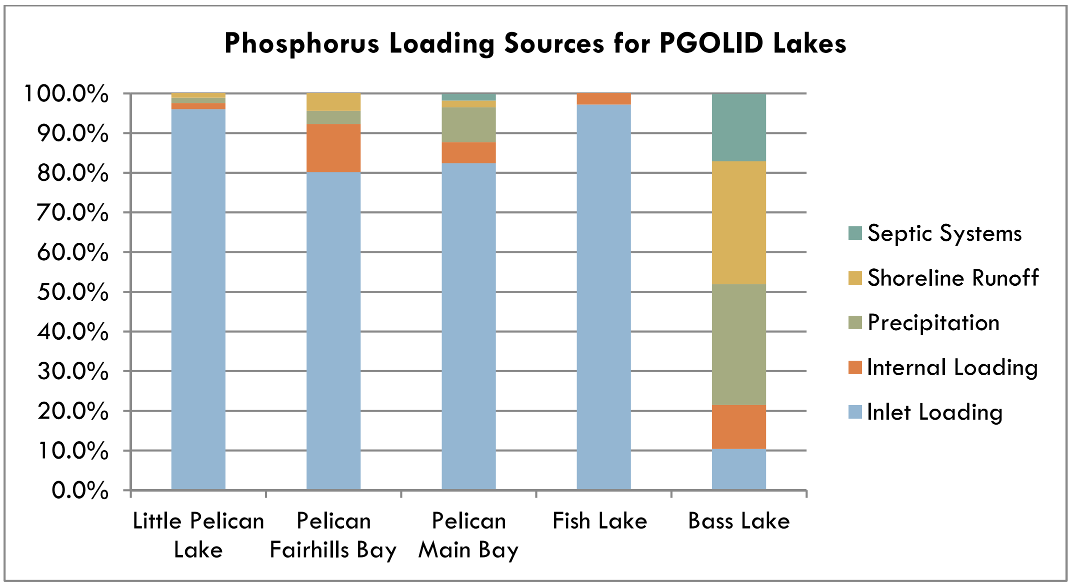

Figure 56. Phosphorus loading sources to the PGOLID Lakes if Pelican River contributed 50% more loading

50% more Septic System Loading Scenario

A future scenario where septic systems provide 50% more loading the current loading rate was run in the model. The results show an increase in the septic loading proportion from the 2009 typical loading scenario of about 6% in Bass Lake, 1% in Pelican Lake, 2% in Little Pelican Lake, and less than 1% in Fish and Little Pelican Lakes (Table 8, Figure 57). Septic systems affect Bass Lake the most because it has no major inlet flow though flushing it out.

Table 8. Loading proportions under the 50% more septic system loading scenario.

	Little Pelican Lake	Pelican Fairhills Bay	Pelican Main Bay	Fish Lake	Bass Lake
Inlet Loading	93.8%	76.6%	76.2%	96.1%	9.8%
Internal Loading	2.3%	16.4%	6.9%	1.0%	10.2%
Precipitation	1.9%	4.5%	11.3%	1.6%	28.0%
Shoreline Runoff	1.1%	0.9%	2.2%	0.5%	28.5%
Septic Systems	0.9%	1.6%	3.4%	0.8%	23.4%

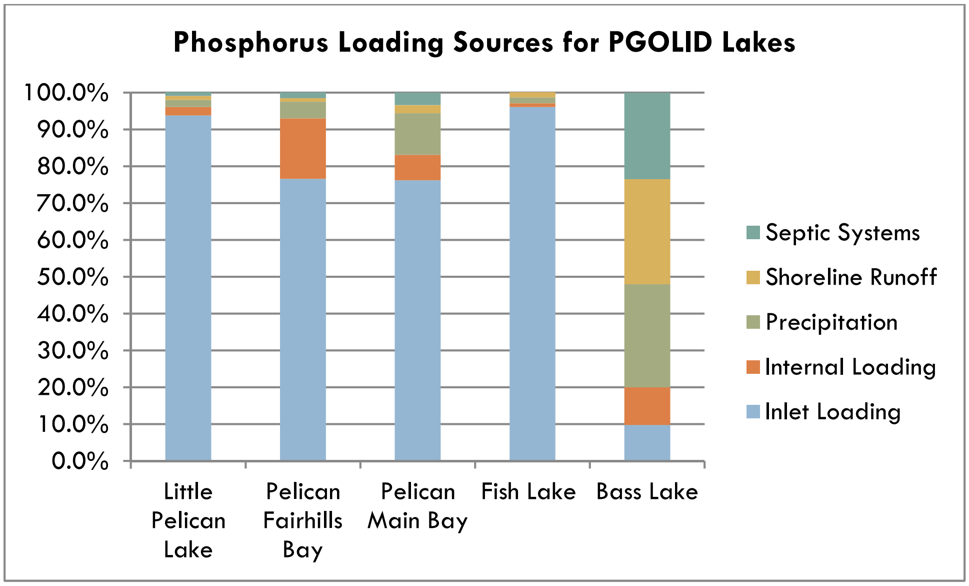

Figure 57. Phosphorus loading sources to the PGOLID Lakes if septic systems contributed 50% more loading

50% more Shoreline Runoff Scenario

A future scenario where shoreline runoff provides 50% more loading the current loading rate was run in the model. The results show an increase in the shoreline runoff proportion from the 2009 typical loading scenario of about 9% in Bass Lake, 1% in Pelican Lake, and less than 1% in Fish and Little Pelican Lakes (Table 9, Figure 58). Shoreline runoff affects Bass Lake the most because it has no major inlet flow through to flush it out.

Table 9. Loading proportions under the 50% more shoreline runoff scenario.

	Little Pelican Lake	Pelican Fairhills Bay	Pelican Main Bay	Fish Lake	Bass Lake
Inlet Loading	93.6%	76.7%	76.3%	96.0%	9.2%
Internal Loading	2.3%	16.4%	6.9%	1.0%	9.6%
Precipitation	1.9%	4.5%	11.3%	1.6%	26.3%
Shoreline Runoff	1.6%	1.4%	3.2%	1.0%	40.2%
Septic Systems	0.6%	1.1%	2.2%	0.5%	14.7%

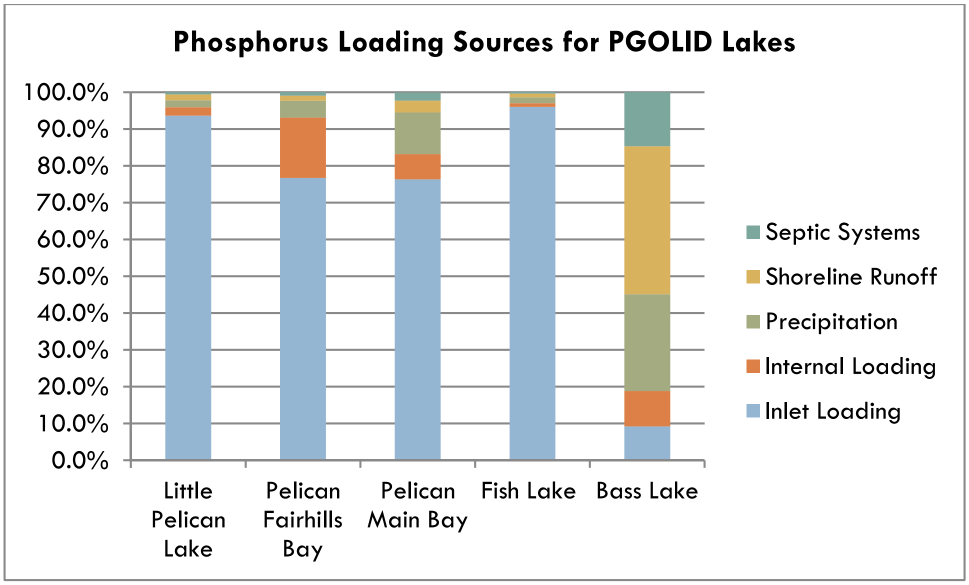

Figure 58. Phosphorus loading sources to the PGOLID Lakes if shoreline runoff contributed 50% more loading

50% more Spring Creek Loading Scenario

A future scenario where Spring Creek provides 50% more loading the current loading rate was run in the model. The results show an increase in the shoreline runoff proportion from the 2009 typical loading scenario of about 2% in Pelican Lake, and less than 1% in Fish, Bass, and Little Pelican Lakes (Table 10, Figure 59).

Spring Creek loading has implications with PGOLID's upstream neighbor, the Cormorant Lakes Watershed District. The model shows that an increase in outflow from Big Cormorant Lake will not affect Pelican Lake's phosphorus loading much.

Table 10. Loading proportions under the 50% more Spring Creek loading scenario.

	Little Pelican Lake	Pelican Fairhills Bay	Pelican Main Bay	Fish Lake	Bass Lake
Inlet Loading	94.1%	78.1%	78.6%	96.5%	11.0%
Internal Loading	2.4%	15.8%	6.5%	90.0%	11.0%
Precipitation	1.9%	4.3%	10.7%	1.5%	30.2%
Shoreline Runoff	1.1%	0.9%	2.0%	0.6%	30.8%
Septic Systems	0.6%	1.0%	2.1%	0.5%	16.9%

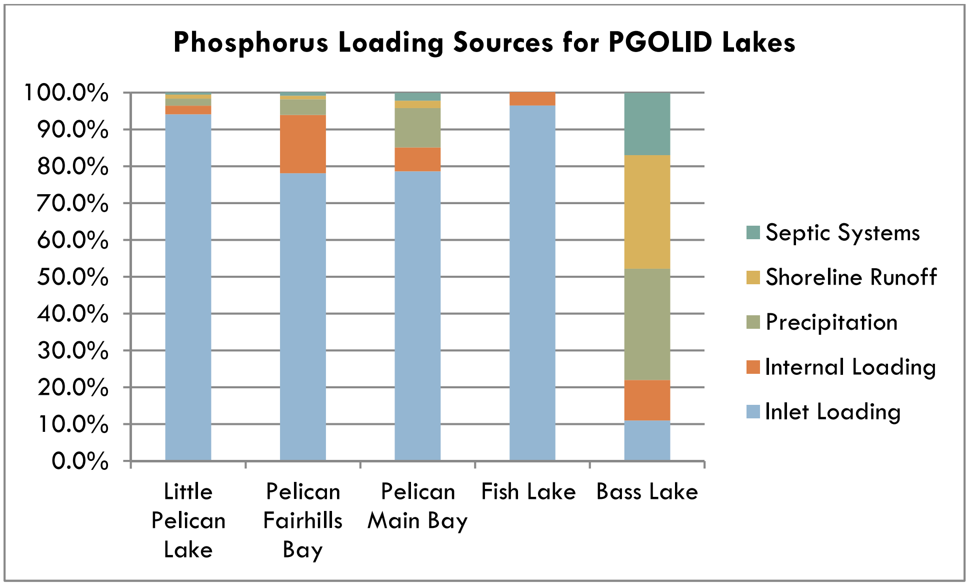

Figure 59. Phosphorus loading sources to the PGOLID Lakes if Spring Creek contributed 50% more loading