Pearl Lake Diagnostic Study
Clean Water Partnership

Becker County, MN

6/27/2013
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Pelican River Watershed District

Executive Summary

The purpose of this project is to address water quality concerns associated with eutrophication in Pearl Lake (Minnesota DNR ID 03-048600) located entirely within Lake Eunice Township, Becker County. Currently no water quality diagnostic studies or lake management plans are in place, leaving questions in Pearl Lake's future administration. This project includes three years of background study to develop a foundation of knowledge on Pearl Lake's phosphorus budget, watershed & lake characteristics, and overall water quality. This body of knowledge allows more effective management of lake resources in support of beneficial uses for Pearl Lake.

Pearl Lake (03-048600) covers 281 acres, and drains an area of 577 acres. This watershed is entirely within the North Central Hardwood Forest Ecoregion. Pearl lake is a publicly accessible water of the state, within the jurisdiction of the Pelican River Watershed District; as publically accessible water, a DNR maintained asphalt ramp is located on the southern end of the lake. Pearl Lake offers recreational opportunities and aesthetic rewards for residents and visitors alike.

Fisheries surveys indicate strong populations of Walleye, Northern Pike, Largemouth Bass, Bluegill, and Brown & Black Bullhead. Walleye are stocked by the DNR on a biennial basis, due to a lack of appropriate spawning habitat and angler harvest efficiency. According to the DNR's Lake Information Report for Pearl Lake (last surveyed 2009, accessed in April 2013), the lake's Northern Pike fishery is improving, while the Bluegill population is stunting from angler preference, and the bullhead prevalence is diminishing due to commercial fishing and young-of-year netting efforts.

Phosphorus is the primary nutrient of concern for Pearl Lake's eutrophication shift. Nutrient loading is predominantly from internal loading representing approximately 49% of the phosphorous load into the lake. The watershed to lake surface area is approximately 3:1, however this represents the most pragmatically treatable area of input into the lake.

Focusing on eliminating non-compliant septic systems alone can account for as much as a 10% reduction in phosphorus inputs into the lake. Some reductions through agricultural best management practices (BMP's) may be possible, and would work in cooperation with the Becker County Soil & Water Conservation District and Natural Resource Conservation District. In lake treatment options would include alum flocculation or aeration treatments; however these treatments may not be feasible, or may be cost prohibitive in nature.

1.0 Introduction

1.1 Project Overview

The purpose of this project is to address water quality concerns associated with eutrophication in Pearl Lake (Minnesota DNR ID 03-048600), located within Lake Eunice Township of Becker County, Minnesota. Without a current water quality diagnostic study or active lake management plan in effect, future water quality improvement projects do not have an established framework or overriding set of goals. The Pearl Lake Diagnostic Study aims to present the background and options for water quality enhancement efforts. This project includes a dissemination of nutrient loading and summary of biological processes contributing to Pearl Lake's water quality concerns to date. Additionally, a summary of appropriate implementation actions is being developed in an effort to protect and improve water quality in Pearl Lake.

1.2 Water Quality Problems

The primary water quality concern in Pearl Lake is associated with eutrophication. Water quality data collected in Pearl Lake indicates that the lake is currently meeting total phosphorus (TP), Chlorophyll-a (Chl-a), and Secchi lake eutrophication standards through the summer average. However, there are recorded occurrences of each parameter breaking compliance with the standards in each of the three years in the study. Late season Secchi readings are consistently approaching the lower limit for the state standard for the North Central Hardwood Forest ecoregion (>1.4m).

Prior to this diagnostic study, very limited tributary watershed monitoring data had been collected for this lake. Coinciding with limited data on hand, the Pelican River Watershed District lacked a definitive understanding of Pearl Lake's watershed pollutant loading dynamics. Concern from area residents was raised about the significance of agricultural runoff into the lake leading to algal blooms and diminished water clarity. Additionally, the lake's water budget was analyzed in response to erratic water levels in the recent past.

Through the course of the study, an invasive aquatic species was documented and confirmed on Pearl Lake. Curly Leaf Pondweed was identified during a point-intercept survey conducted in July of 2010.

1.3 Resource Goals

Pelican River Watershed District Goals

The Pelican River Watershed District aims to maintain water quality & beneficial use of Pearl Lake through the goal of maintaining average TP, Chl-a & Secchi readings in compliance with the 12/2011 MPCA Lake Eutrophication Standards for the North-Central Hardwood Forest Ecoregion Deep Lakes (MPCA, 2012). The Deep Lake categorization fits with Pearl's 16.5m maximum depth, and holds the lake to a higher standard than NCHF Shallow Lakes.

Episodically Pearl Lake does not meet one or more NCHF Ecoregion standards for water quality. This type of occurrence can be attributable to numerous reasons, some of which are beyond reasonable control.

In 2003 the Pelican River Watershed District adopted a management strategy of holding the composite TSI for Pearl below 50, which is marginally mesotrophic in the Carlson Trophic State Index. After the 2005 Revised Management Plan was developed, the Pelican River Watershed District adopted a modified TSI Scale (***Figure 1.3***) which determined lakes to be oligotrophic, mesotrophic, "at risk", "problem", or "damaged". Pearl lake at the time was considered to be hedging "at risk".

Through this diagnostic study, it has become evident that Pearl Lake does not fit well within a TSI scale, as the individual parameters seem contradictive in application. In 2010 the mean growing season Secchi reading was 8.7 feet (TSI=45.94), TP averaged 29 μg/L (TSI 51.2), and chlorophyll-a averaged 11.5 μg/L (TSI=54.5). Through the test period of this study, as well as the 10 year average, Secchi readings have been consistently higher than the TSI model would predict. TP readings are generally similar with chlorophyll-a readings within the ten year averages.

TSI Index	Characteristics	District Lakes
Less than 35 Oligitrophic	Low nutrients and algae, very clear water, oxygen throughout the year at all depths, and cold water, oxygen loving fisheries in deep lakes.	
35-45 Mesotrophic	good clarity, few and only moderate algae blooms, low plant growth; episodes of low oxygen may begin to limit fishery.	*Big Floyd, Long, Meadow,*
46 – 50 "At Risk"	increasing incidence of nuisance algae blooms, phosphorus levels in the 25-30 ppb range, moderate to nuisance plant growth, transparencies under 10 feet during mid-summer; low oxygen in deep water imposes limitations on fish species.	*Melissa, Big Detroit, Little Detroit, Munson, Fox, Pearl, Johnson, Reeves, Little Floyd*
51 – 55 "Problem"	high incidence of nuisance algae blooms, luxuriant weed growth, summer transparencies usually less than 7 feet, phosphorus levels often over 35, shift to warm water fishery; without action deteriorating conditions will accelerate.	*North Floyd, Muskrat, Sallie*
Over 56 "Damaged"	Algae scums probable, dominance of blue-green algae, luxuriant aquatic plant growth; Undesirable for water-based recreation, deteriorating or absent game fishery, high probability of further declines in quality.	*St. Clair, Brandy, Abbey , Wine,*

Table 1.3 The Pelican River Watershed District Modified TSI Rubric

Pearl Lake Association Goals

The Pearl Lake Association is interested in maintaining beneficial recreational and aesthetic values in line of a mesotrophic, rather than eutrophic designation. Recreational purposes such as fishing, boating, and birdwatching contribute to association utility in Pearl Lake.

2.0 Lake and Watershed Characterization

2.1 Site Description

Pearl Lake (Minnesota DNR ID 03-048600) is located entire within Lake Eunice Township, Becker County, Minnesota. LiDAR data was utilized to develop an accurate

topographic model that was also used to define the 577 acre (0.9 square mile) watershed contributing to Pearl Lake. Water generally drains from the northeast to the southwest of the watershed, with an established run-out elevation of 1356.50' *amsl*.

Parameter	
Surface Area (acres)	281.1
Average Depth (ft)	11.8
Maximum Depth (ft)	54
Volume (AF)	3313
Residence Time (years)	Unknown (33.8 years)
Littoral Area (acres)	224.8
Littoral Area (%)	79.9
Watershed (acres of drainage)	577
Watershed : Lake Area Ratio, *exclusive area*	2:1

Table 2.1 Pearl Lake morphometric and watershed characteristics

2.2 Lake History

Pearl is a 281 acre lake on the western edge of the upper Pelican River in Becker County, Minnesota. The lake has a shoreline of 4.0 miles, and a NE/SW fetch of approximately one mile. It contains about 3000 acre feet of water under average conditions. About 76 % of the lake is littoral (less than 15 feet). It has a maximum depth of 54 feet, and exhibits a dimictic mixing pattern.

Pearl has a surface watershed of approximately 577 acres (exclusive of lake surface area). Unlike other neighboring lakes in an outwash zone, Pearl lies perched on morainal deposits. It is connected via a series of wetlands with Little Pearl Lake, and other wetland complexes to the West, but is poorly connected with downstream lakes and adjacent larger lakes of the main Pelican River outwash area.

Pearl Lake, as with many recreational lakes in Becker County adjacent to the city of Detroit Lakes, has developed rapidly in recent history.

2.2.1 Why a Diagnostic Study for Pearl Lake?

For the ten years between 1998 and 2007, seventy-six readings indicated Pearl's average annual clarity (Secchi) was 10.5 feet, but year to year variations were unusually high, ranging from 7.1 (1999) to 15.8 the following year. June clarity reached a high of 33 feet (2002) and was as low as 4 feet (1999). Average mid-summer (July and August) readings ranged from 4.5 (2007) to 14.5 (2000). No timeline trend was apparent.

During the same period, average seasonal TP levels were measured 62 times with an average value of 31 ppb; and like the clarity observations described above the season to season ranges in TP were considerable, from an average of 18 in 2000 to over 40 in 2006 and 2007. The median reading was 30 ppb, with several readings in excess of 50.

There was a general correspondence in the variations between the season average of total phosphorus and clarity measures. However, using the trophic state model, there is quite a large difference in the Trophic Status Indices predicted from TP and Secchi measurements. In most years this difference exceeded 10 index points, and put the lake squarely in the mesotrophic state for clarity and eutrophic state for nutrient (phosphorus).

Only 13 Chlorophyl-a observations were taken during the 1998-2007 period, so it is difficult to make generalizations; suffice it to say, the year-to-year variations corresponded roughly to the TP and Secchi patterns. DO and Temperature measurements taken during this same period suggested that there was some likelihood of internal loading problems during the mid-summer months, July and August.

In the early 2000's, complaints by lakeshore residents alerted the PRWD to water level manipulations and near-shore wetland filling. Other reports, confirmed by PRWD, involved overland flows to the lake from adjacent farmlands and pastures.

Through its permitting process the District also became aware of shoreland management practices that are known to degrade lake water quality. These include shoreline vegetation clearing, increased impervious surface in the shoreland district and others. These problems are exacerbated by the development of some properties on steep slopes that have been converted from cultivation or pasturage.

The District proposed this Clean Water Diagnostic and Feasibility project for the following reasons:

1. *The erratic results from Pearl water quality measurements*
2. *The lack of correspondence between various of Pearl's water quality parameters*

3. *The likelihood that internal loading is a growing factor in Pearl's water quality*
4. *The rapid development of Pearl's lakeshore, and nearby areas*
5. *Some problematic aspects for Pearl's lakeshore development*
6. *The possibility that Pearl is nearing a "tipping point" with respect to its water quality.*

2.3 Drainage Patterns

Pearl Lake is a perched lake, formed in morainal deposition acting as an aquitard between sandwiched glacial outwash layers. Due to the small scale of the watershed, there are no other bodies of water upstream or downstream within the Pearl lake sub-watershed. At its outlet, in years where the out flows, water integrates with a freshwater emergent wetland, assumed to infiltrate into outwash plains into Rider Lake or Loon Lake before adjoining outflow from the Pelican River system.

The Pearl Lake Watershed is divided into three distinct land drainage areas, including an area to the west (199.6 acres), and a smaller drainage to the east (34.3 acres) as well as the surrounding watershed (343.4 acres).

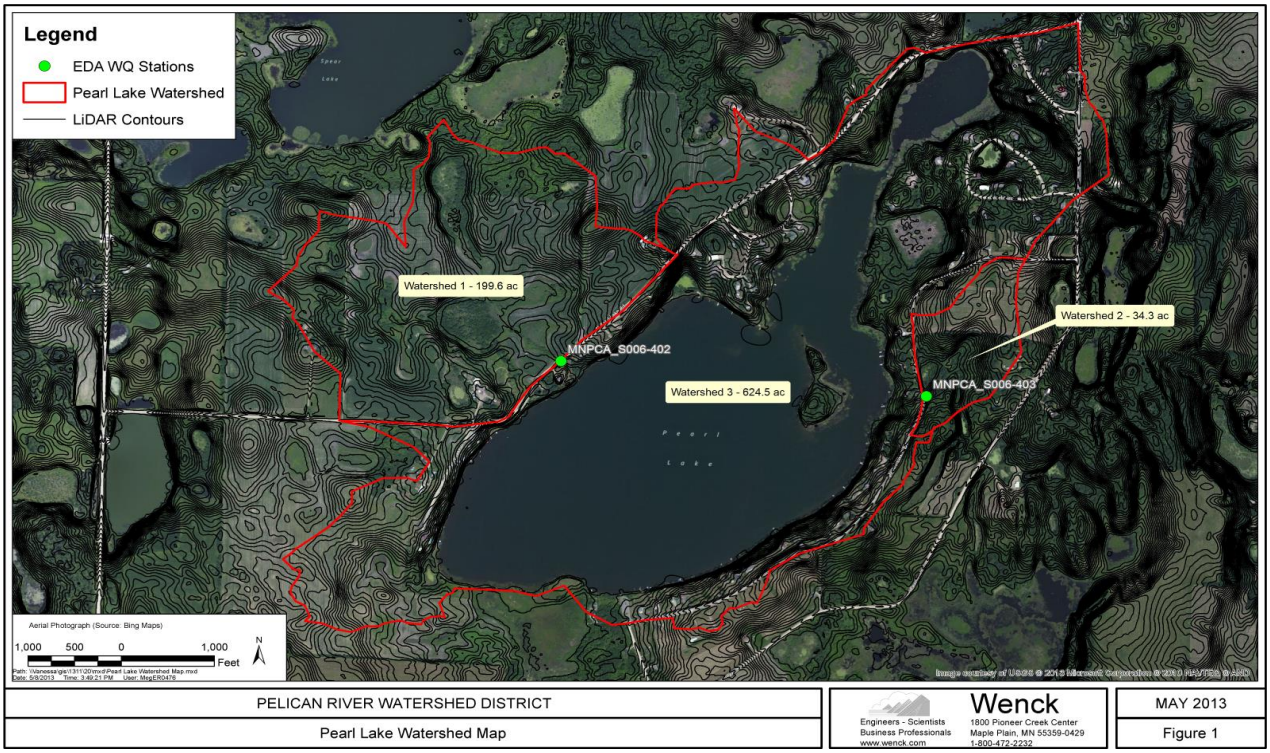


Figure 2.3 Map of the Pearl Lake direct watershed and subwatershed units

2.4 Land Use

Land use data for the Pearl Lake watershed is presented in **Table 2.4**, **Figure 2.4.1**, and **Figure 2.4.2.** A significant portion of the remaining watershed cover is undeveloped typical North-Central Hardwood Forest cover. However, this watershed has seen substantial development in the recent past, as single family low density residential development currently accounts for 13.3% of the watershed by surface area.

Pearl Lake Land Use		
	Acres	**% Cover**
Water & Wetland	302.94	35.21%
NCHF	194.15	22.57%
Agriculture	175.95	20.45%
LD Residential	114.6	13.32%
Undeveloped, NF	55.98	6.51%
Transportation	16.7	2%
	860.32	**100.00%**

Table 2.4 Distribution of Land Use Classification

Though essentially rural in character, Pearl's watershed has seen rapid growth in recent years. Lake Eunice township (in which most of its watershed lies), experienced a 30% growth in population between 2000 and 2010. Households have doubled in the same period, and over 1/3rd are held for seasonal occupancy.

Like other areas in Lake Eunice Township, the Pearl lake area has witnessed rapid conversion of agricultural uses to development in lake-oriented second homes and primary residences. In 1983 a very large part of the riparian shoreline was either cultivated or grazed; there were only 2 riparian residences. By 2003 the riparian agricultural practices were gone, and approximately 32 riparian residences were present. In 2013, there are 57 such residences and an additional 21 second tier residences (in the Shoreland District, within 1000 feet of the shoreline). There remain approximately 12 acres of cultivated land within Pearl's Shoreland District. 16% of the shoreline remains undeveloped in several large tracts, though some of this area is not suitable for development by virtue of poor drainage. Figure 2.4.1 compares aerial photos from 1939, 1965, 1991, and 2003 to demonstrate this succession.

1939

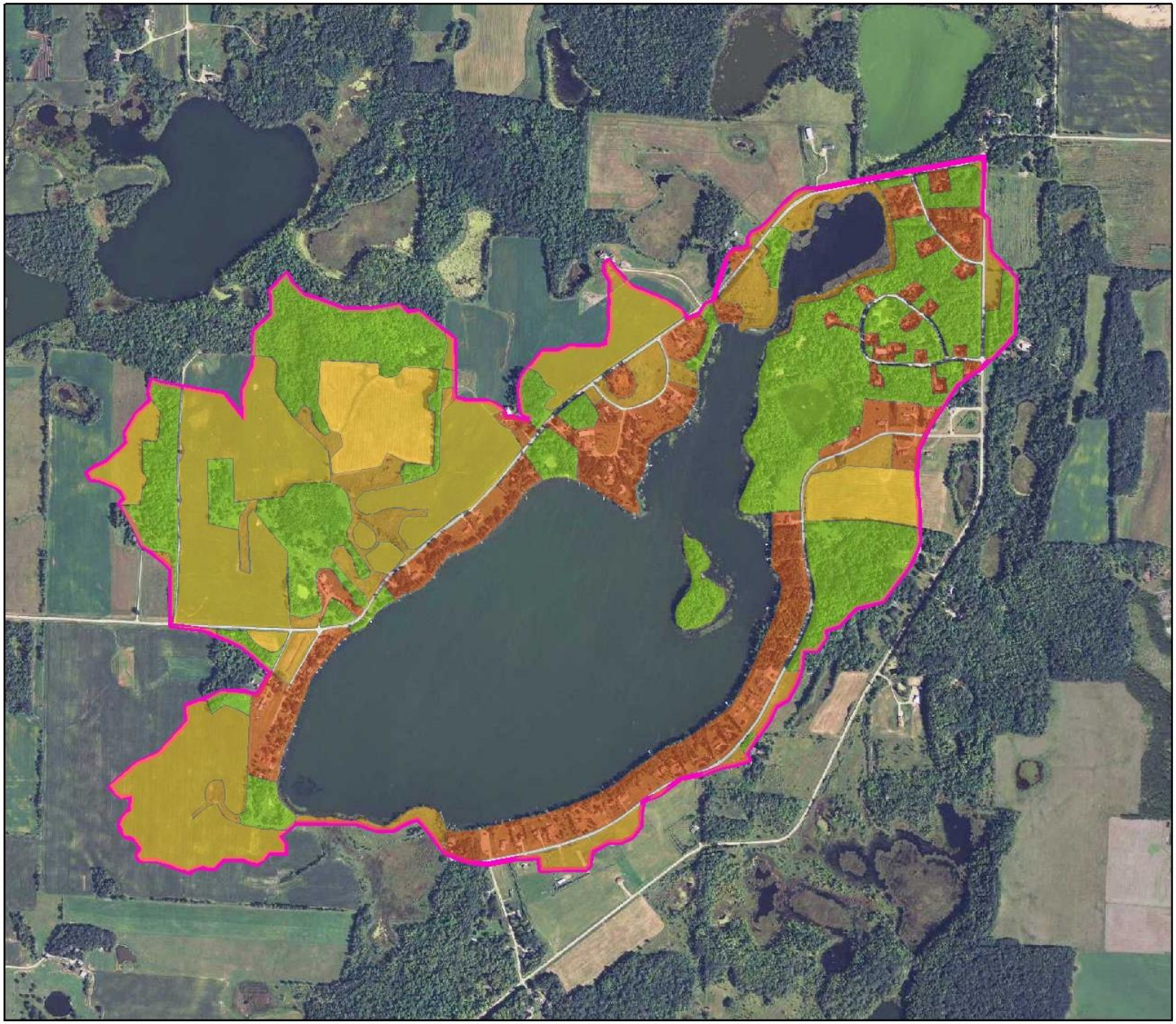
1965

1991

2010

Pearl Lake has dramatically changed over time in terms of lake morphology as well as developmental character. In the past two decades Pearl Lake has rapidly gained shoreline residential development and stabilized into the profile observed today. Historically, Pearl Lake lacked a well defined outlet, which has led to variable water levels. Within the time frame of 2000 to 2010, a well defined outlet was created setting the run-out elevation at 1356.50' above mean seal level.

Land Use Classification



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Legend

Pearl Lake

Land_Use

- Agricultural
- LDR
- NCHF
- Undeveloped
- Pearl Watershed

N

Absolute Scale 1:16,000

0 460 920 1,840 Feet

2.5 Soils

2.5 Soil Analysis

2.5.1 Drainage Classification

Figure 2.5.1 shows a drainage classification map of the Pearl Lake watershed. Drainage classification refers to an ordinal scale ranging from excessively drained to very poorly drained. Drainage classification is a coarse guide to limitations of suitable use given site conditions. In the case of Pearl Lake, the drainage classification map illustrates the infiltration potential in areas of the watershed. Low infiltration rates may indicate saturated areas or heavy clay depositions, meanwhile high infiltration may agricultural use or influence the response of septic systems.

2.5.2 Hydrological Soil Classification

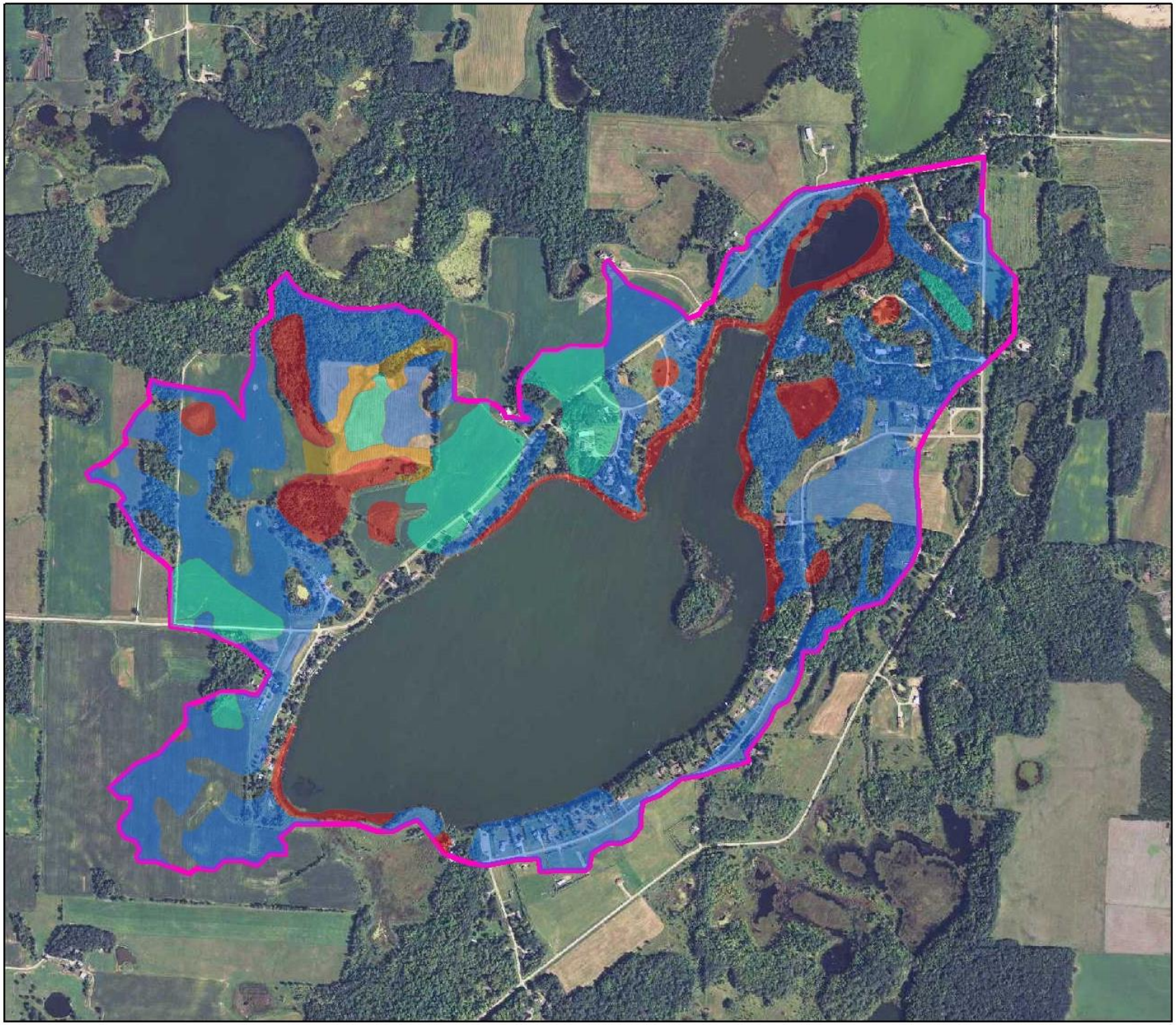
Figure 2.5.2 depicts hydrological soil classification for Pearl Lake. Hydrological soil classification alludes to the runoff potential of soil groups, classified from group A soils (sand & sandy loam) to group D soils (tight clays, etc.). Soils affected by a high water table may perform similarly to a group D soil in undrained conditions; these soils are marked with multiple designations (eg. A/D). Soils with high runoff potential are more vulnerable to erosion and more likely to transmit pollutants through surface water. Group D soils are not conducive to constructing septic drainfields, particularly in areas with high water tables.

2.5.3 Building Site Suitability

Figure 2.5.3 shows areas of the Pearl Lake watershed that feature limitations or restrictions for the placement of residential scale buildings. Site limitations include water table depth, drainage characteristics, load bearing capacity, and other physical parameters.

Sites that are more suitable are likely to have fewer issues with septic failure, foundation failure or corrosion, flooding, standing water (ponding), et cetera. Historic USGS reports show a complex soil makeup in the area surrounding Pearl Lake, including morainal deposition, and glacial outwash. The depth to groundwater around Pearl Lake is likely to be quite variable, which should be taken into account when planning additional first and second tier homes within this watershed.

NRCS Drainage Classification



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Legend

PearlSoil

Drainage Class

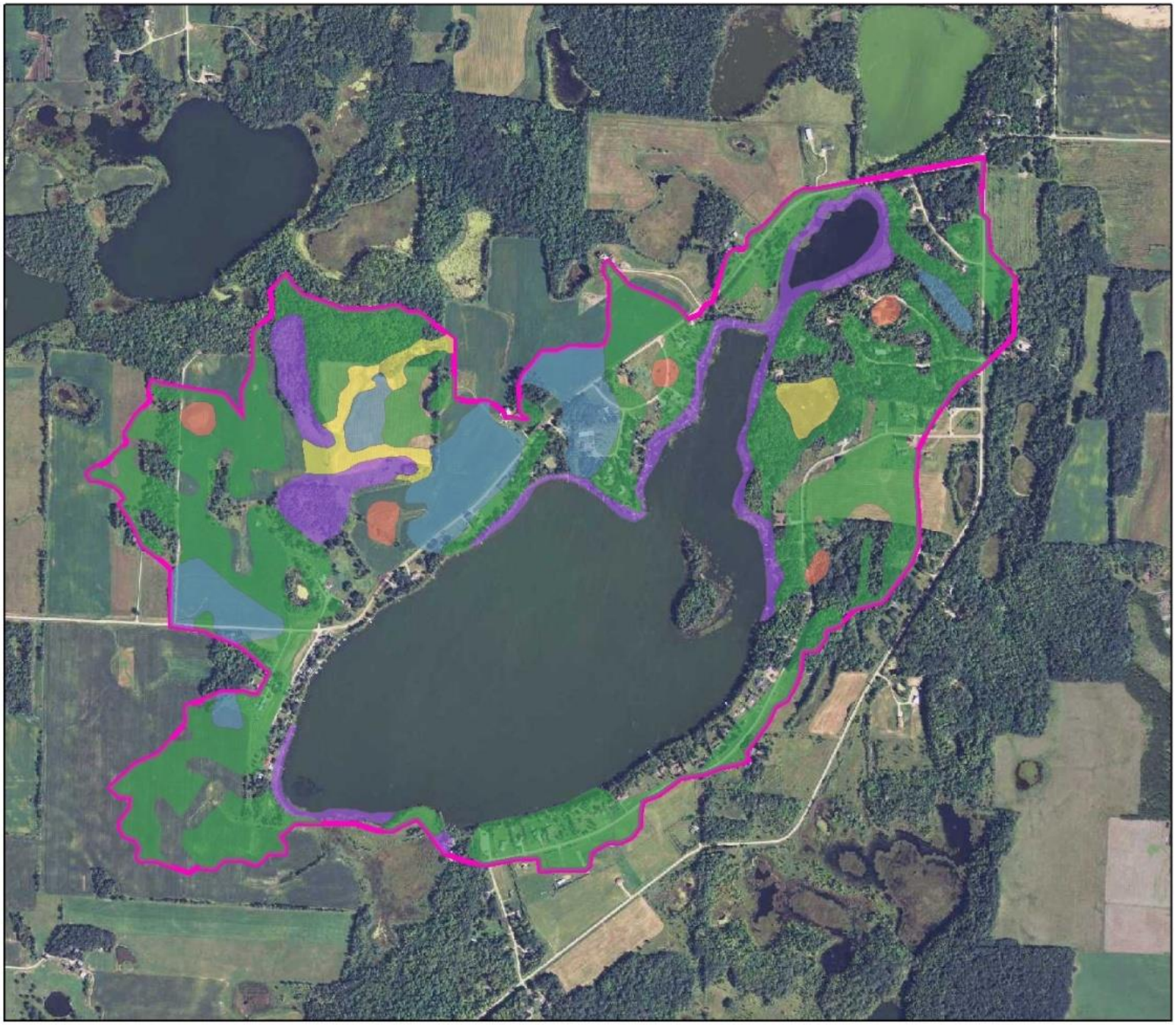
- Well drained
- Moderately well drained
- Poorly drained
- Very poorly drained
- Pearl Watershed

N

Absolute Scale 1:16,000

0 460 920 1,840 Feet

Hydric Soil Groups



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Legend

PearlSoil

Hydric Soils

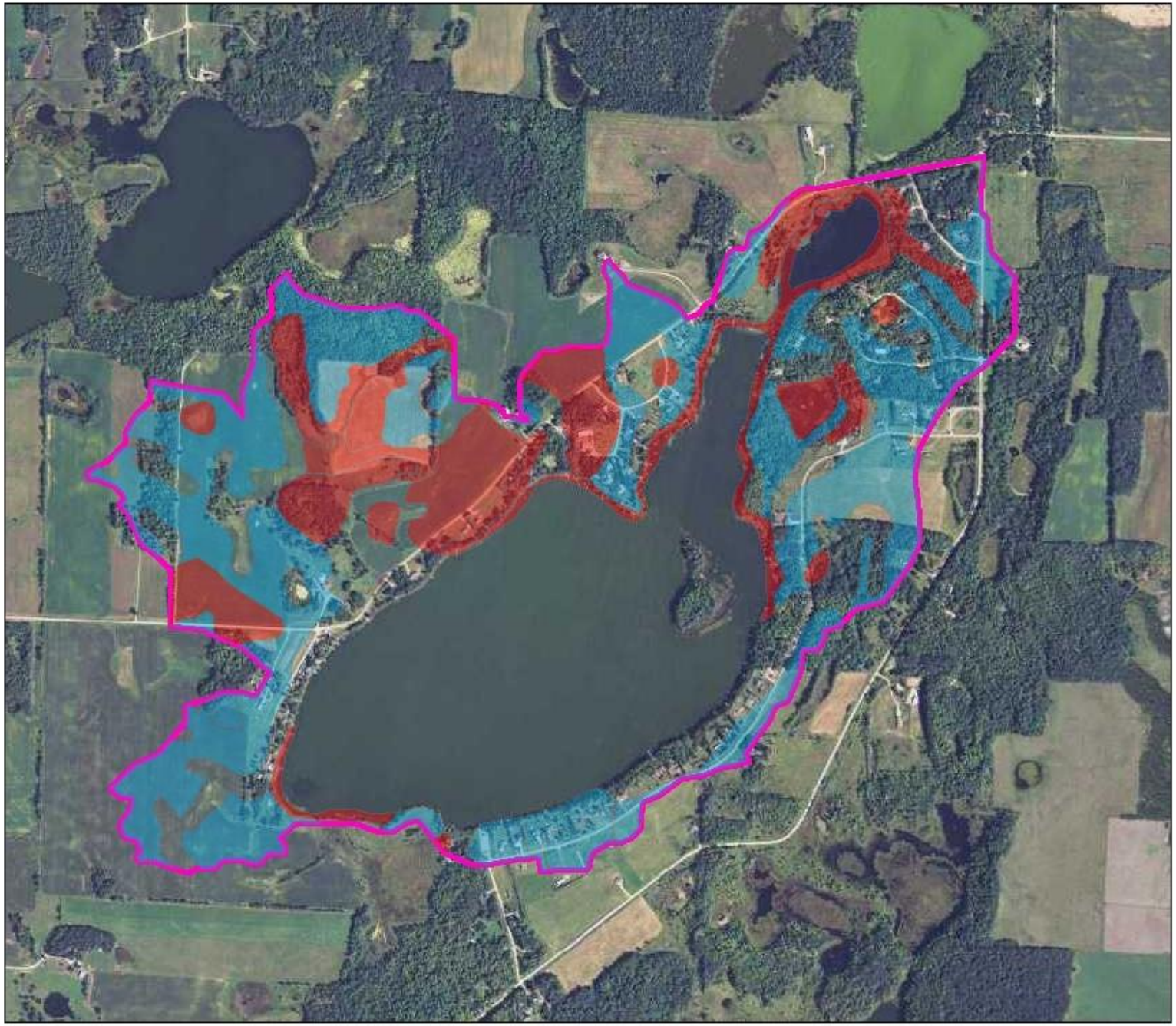
- A/D
- B
- B/D
- C
- C/D
- Pearl Watershed

N

Absolute Scale 1:16,000

0 460 920 1,840 Feet

Building Site Suitability



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Legend

PearlSoil

Suitability

- Somewhat limited
- Very limited
- Pearl Watershed

N

Absolute Scale 1:16,000

0 460 920 1,840 Feet

2.6 Recreational Uses

Pearl lake is utilized as a public resource for recreation and aesthetic value. Access to the lake is provided by a Minnesota Department of Natural Resources (MDNR) boat ramp on the southern shoreline off Pearl Lake Drive. Fisheries surveys indicate strong populations of Walleye, Northern Pike, Largemouth Bass, Bluegill, and Brown & Black Bullhead. Walleye are stocked by the DNR on a biennial basis, due to a lack of appropriate spawning habitat.

Increasing levels of development are likely to increase fishing pressure within Pearl Lake, changing population distribution and abundance characteristics within this fishery. If water quality declines in addition to the ongoing selective harvest of Walleye and other gamefish, it is likely that Pearl Lake could return to a Bullhead dominated fishery.

2.7 Watershed Modeling

Watershed runoff water quality monitoring was completed at two sites over the 2010, 2011, and 2012 seasons as water levels permitted. Sample sites were set up on the east (PL1) and west (PL2) inlets into Pearl Lake. Methods for the collection of water quality samples can be found in the 2010, 2011, & 2012 Pelican River Watershed District Annual Monitoring Plans, as well as in the proposal for the MPCA Clean Water Partnership Work Plan for the Pearl Lake Diagnostic Study (2010, revised 2011). Sampling methodology is based on *Standard Operating Procedures for Water Quality Monitoring in the Red River Watershed* (2008), by the Red Lake Watershed District and the Red River Basin Monitoring Advisory Committee.

The Pearl Lake Diagnostic Study conforms to a Quality Assurance Project Plan set forth by the Minnesota Pollution Control Agency. This plan includes standard operating procedures for sample collection and handling, as well as data acquisition & management. Adherence to the MPCA's QAPP for Pearl Lake ensures that the information collected for the Pearl Lake Diagnostic Study is reliable and useful in determining future considerations for Pearl Lake.

Due to consecutive drought years (2010-11), an extremely limited watershed scale, and placement of a monitoring station behind a clogged culvert (PL2), very little flow was

recorded going into Pearl Lake from PL2. Subsequently, there is very little recharge into the lake and episodic contribution of nutrients and suspended solids (Figures 2.6.1-3).

Station	Date	Flow	TP	TSS	OP
PL1	5/25/2010	0.54	528	8000	
PL1	6/17/2010	0.01	387	0	
PL1	7/6/2010	1.37	807	12000	577
PL1	7/29/2010	1.50	373	7000	325
PL1	8/11/2010	0.26	405	1000	347
PL1	8/14/2010	0.28	295	1000	270
PL1	5/16/2011	0.009	265	6000	195
PL1	5/31/2011	0.001	247	3000	188
PL1	6/22/2011	0.002	188	<1	164
PL1	6/28/2011	1.849	363	5000	302
PL1	8/2/2011	0.003	389	1000	293
PL2	6/28/2011	0.16	339	263000	176
PL2	7/22/2011	0.001	495	5000	354
PL2	8/2/2011	0.003	735	31000	386

Table 2.7 Stream observations during flowing conditions

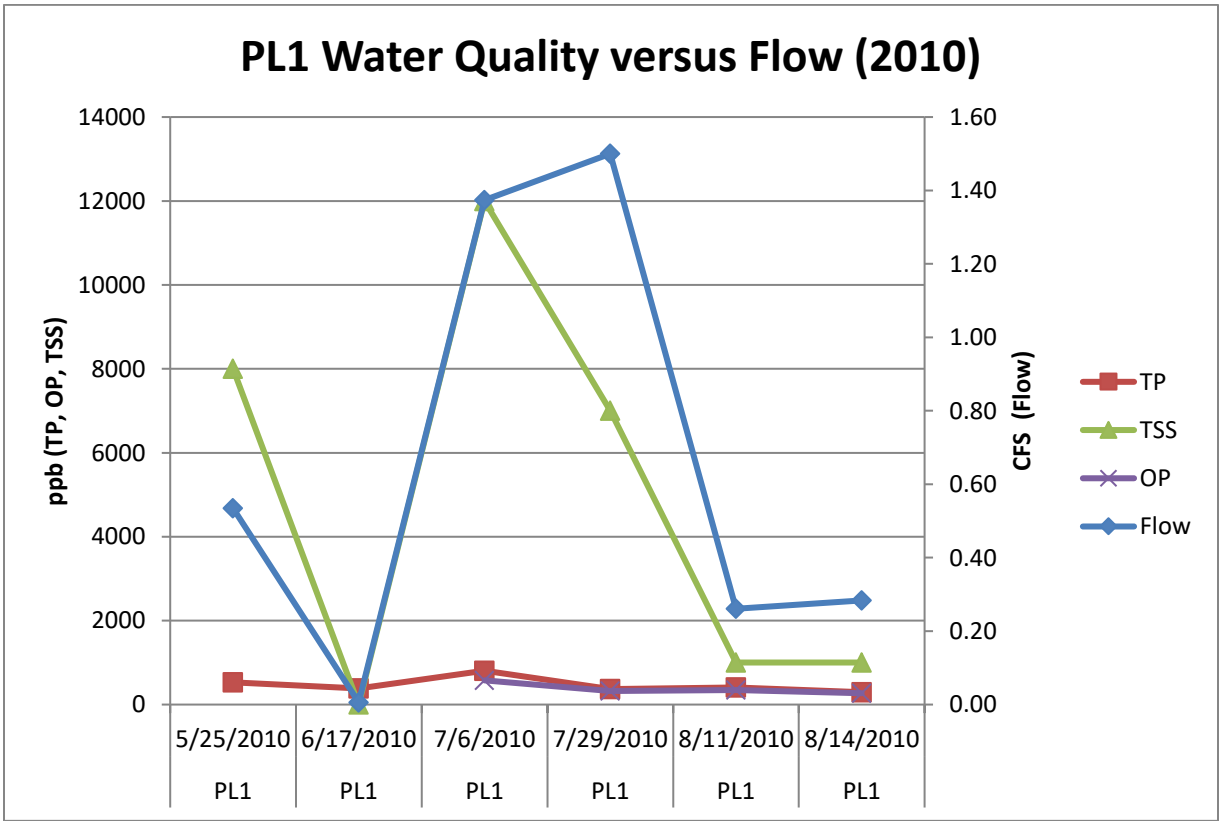

Figure 2.7.1

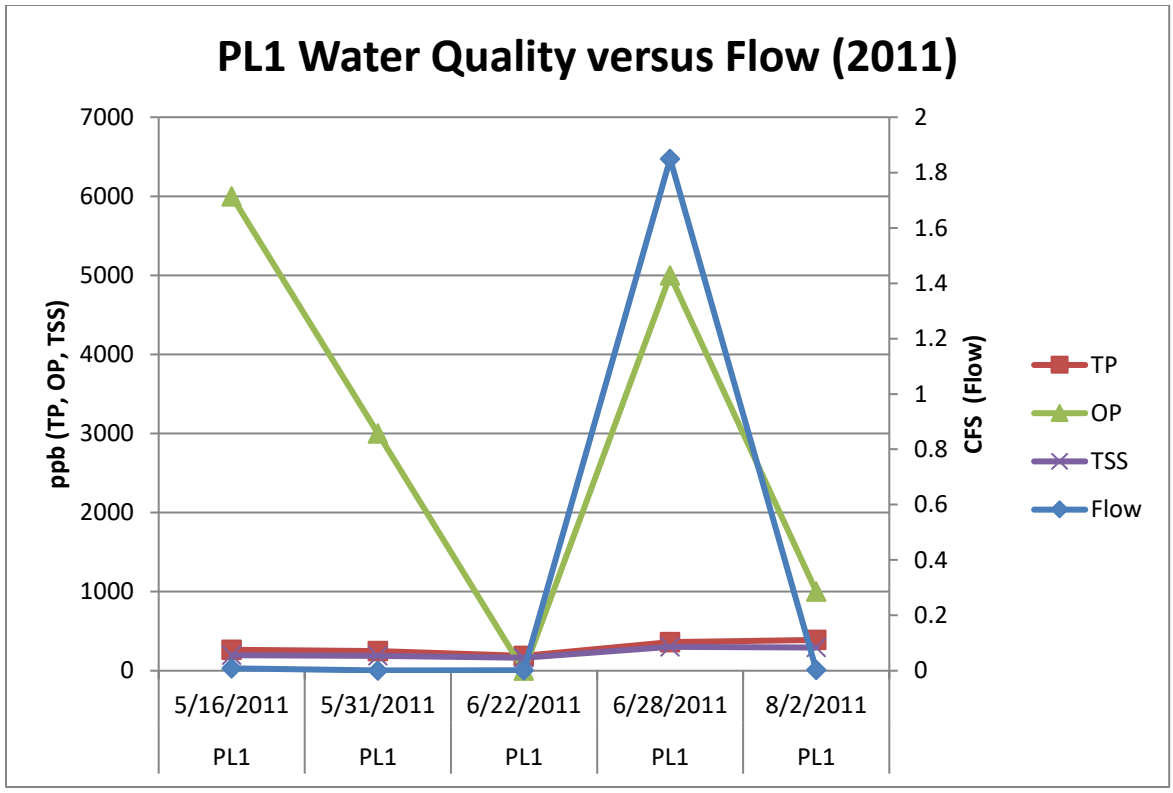

Figure 2.7.2

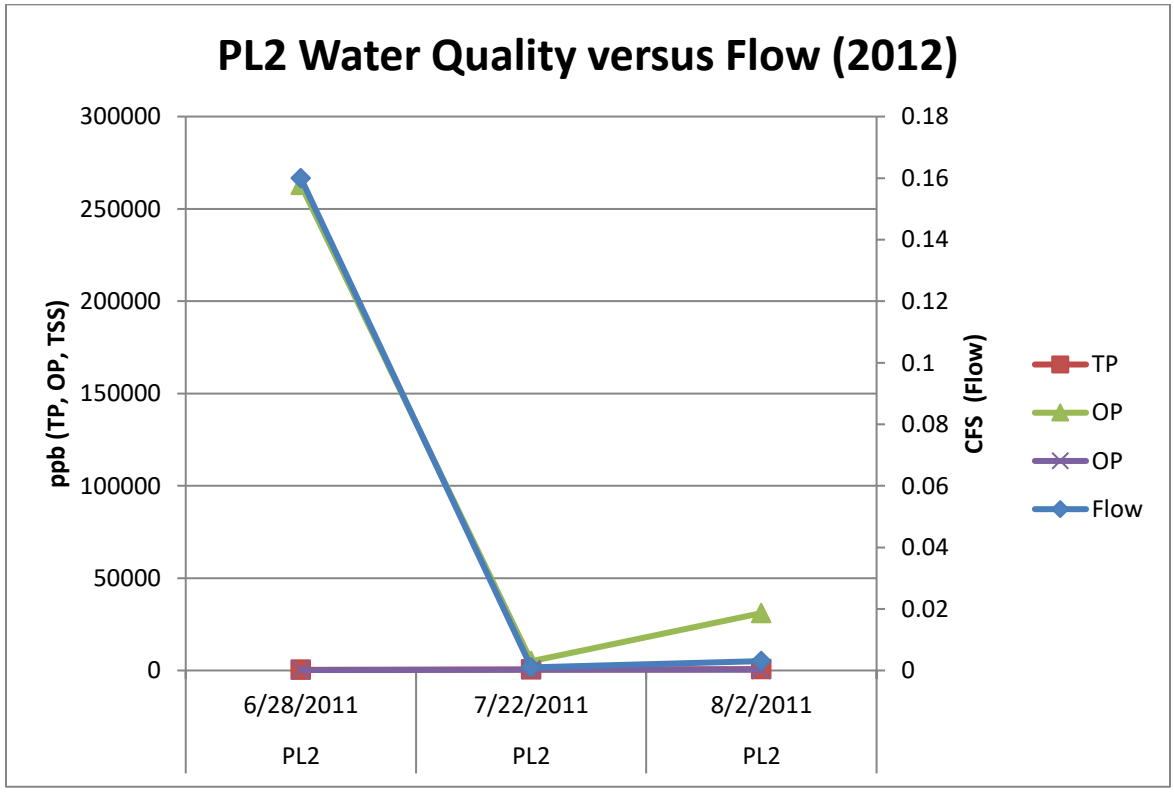

Figure 2.7.3

Water quality monitoring within the contributory watersheds provides inconclusive evidence, but this information does suggest that in wet periods a substantial level of Total Suspended Solids (TSS) flushes episodically. Also noteworthy is the concentration of Orthophosphate (OP) to Total Phosphorus (TP). Typically OP does not represent the majority of TP.

While runoff is not consistently recorded from Pearl Lake's inlets, nutrient and suspended solid loads are significant enough to warrant attention. When a watershed functions as an endorheic (closed) basin, mitigating system sediment and nutrient loading may represent one of very few treatable options to manage water quality.

2.8 Lake Water Quality

The water quality of Minnesota's lakes is often evaluated against three interrelated parameters: total phosphorous (TP), chlorophyll-a, and Secchi depth. In most freshwater lake environments, phosphorous is a limiting nutrient. A limiting nutrient is an elemental nutrient essential for algae and plant growth necessary to sustain other aquatic life forms; when limiting a nutrient is not present in a quantities other essential nutrients are found.

Within the North Central Hardwoods Ecoregion, many lakes are not phosphorous limited, instead the lake may be nitrogen limited, or limited by light availability. Pearl Lake falls within this category, phosphorous is overly abundant for the drainage system to maintain a stable condition.

Chlorophyll-a is the primary pigment of algae, and is the basis for correlating the abundance of algal biomass present within a lake system. Chlorophyll-a is an important indicator because high levels may signal anthropogenic alterations affecting a lake system. With widely variable, levels, a lake may be prone to crashing chlorophyll-a levels leading to oxygen deprivation that results in fish kills.

Secchi depth monitors water clarity, a holistic metric that allows correlated monitoring of several facets of a composite picture of water quality. The depth at which the Secchi disk can no longer be seen indicates the depth of light penetration through refractory particulates suspended in the water column. Higher Secchi depths indicate a clearer water column and lower productivity water bodies (oligotrophy); lower values indicate highly productive or eutrophic conditions. Secchi depths are correlated with chlorophyll-a and TP measurements to gain a better picture of overall lake health and are combined into an index known as the Trophic State Index (TSI).

2.9 Monitoring History of Pearl Lake

Pearl Lake has been monitored extensively by the Pelican River Watershed District over the past 15 years. In the past ten years, eight years have been monitored for chlorophyll-a in addition to TP & Secchi depth. Prior to 2003, Pearl had been monitored for total phosphorous and Secchi depth. Starting in 2011, the Pelican River Watershed District monitored a site on North (Little) Pearl, an adjacent & interconnected waterbody. Little Pearl shares commonality with Pearl Lake's extensive littoral zone, where the Pearl Lake monitoring site is an isolated deep spot in the lake.

The Pelican River Watershed District collected all water quality information utilized within this study. Methods for the collection of water quality samples can be found in the 2010, 2011, & 2012 Pelican River Watershed District Annual Monitoring Plans, as well as in the proposal for the MPCA Clean Water Partnership Work Plan for the Pearl Lake Diagnostic Study (2010, revised 2011). Sampling methodology is based on Standard Operating Procedures for Water Quality Monitoring in the Red River Watershed (2008), by the Red Lake Watershed District and the Red River Basin Monitoring Advisory Committee.

The Pearl Lake Diagnostic Study conforms to a Quality Assurance Project Plan set forth by the Minnesota Pollution Control Agency. This plan includes standard operating procedures for sample collection and handling, as well as data acquisition & management. Adherence to the MPCA's QAPP for Pearl Lake ensures that the information collected for the Pearl Lake Diagnostic Study is reliable and useful in determining future considerations for Pearl Lake. All data used in this study have been submitted to the MPCA (STORET, EQUiS).

2.9.1 Temperature and Dissolved Oxygen

Temperature and dissolved oxygen profile data were collected periodically between 1998 and 2012, with consistent data in 2010, 2011, and 2012. The Pelican River Watershed District collected temperature and dissolved oxygen data associated with the Pearl Lake Diagnostic Study. Data was collected through the use of a YSI 600XL multi-parameter Sonde. The Sonde was calibrated in accordance with the MPCA's Quality Assurance Project Plan for Pearl Lake.

Pearl lake has a moderate thermal stratification starting at approximately 5-6 meters in depth consistently in recorded data. This becomes deeper and somewhat more

pronounced as the growing season (June 1 through September 30) progresses (Figure 2.9.1a). Dissolved oxygen data also correlates with this trend.

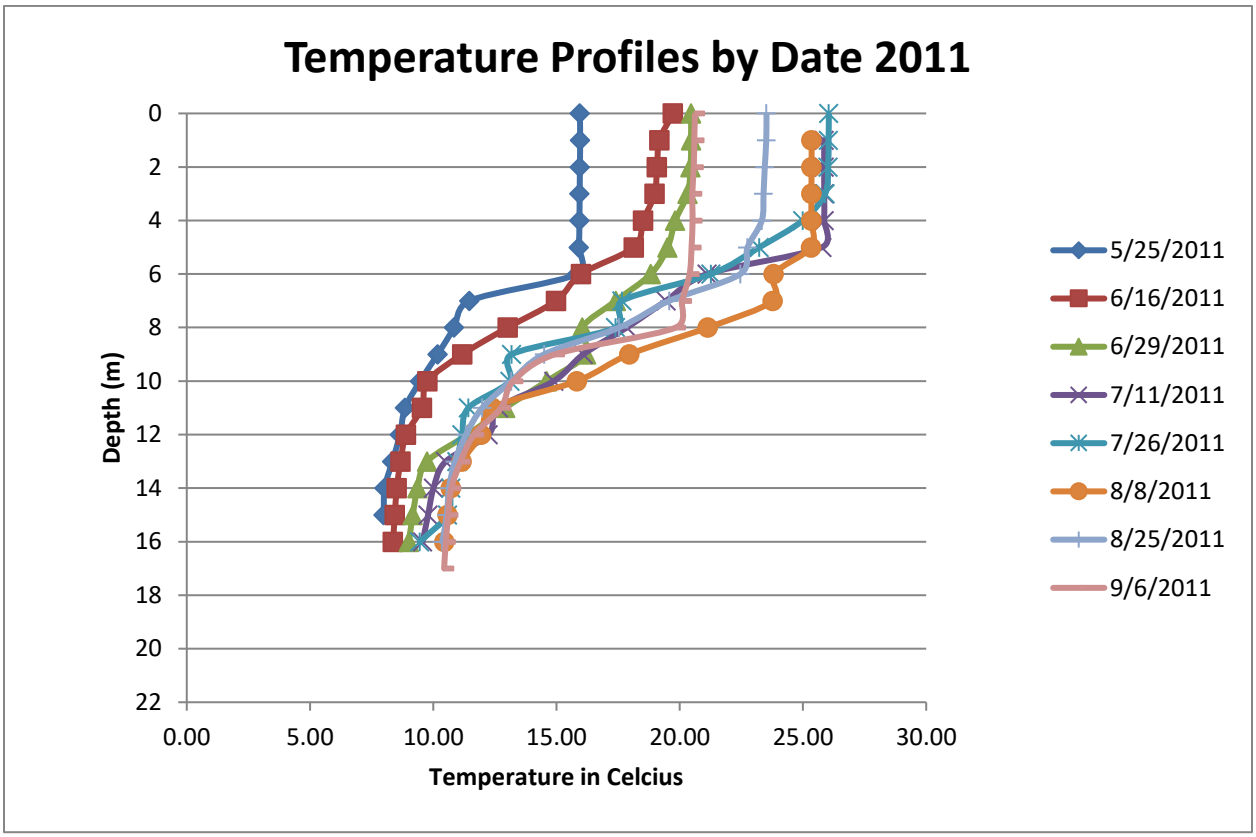

Figure 2.9.1a *Temperature profiles by depth*

Background Data on Pearl Lake for Dissolved Oxygen for the 2001, 2005, 2008 & 2009 seasons are presented below (Figures 2.9.1b-d). Data from the 2010-2012 monitoring period for the Diagnostic Study fit squarely within this trend. At depths of 6 meters or more, Pearl Lake typically displays anoxic conditions.

Anoxic conditions affect the release of phosphates from sediment accumulations, distribution of fish habitat, and organic material decomposition rates. Sudden drops in dissolved oxygen may indicate collapses of algal blooms that lead to fish kills. Pearl Lake exhibits consistent mixing to a depth of around 6 meters (approximately 20 feet), where conditions are most suitable for fish habitat.

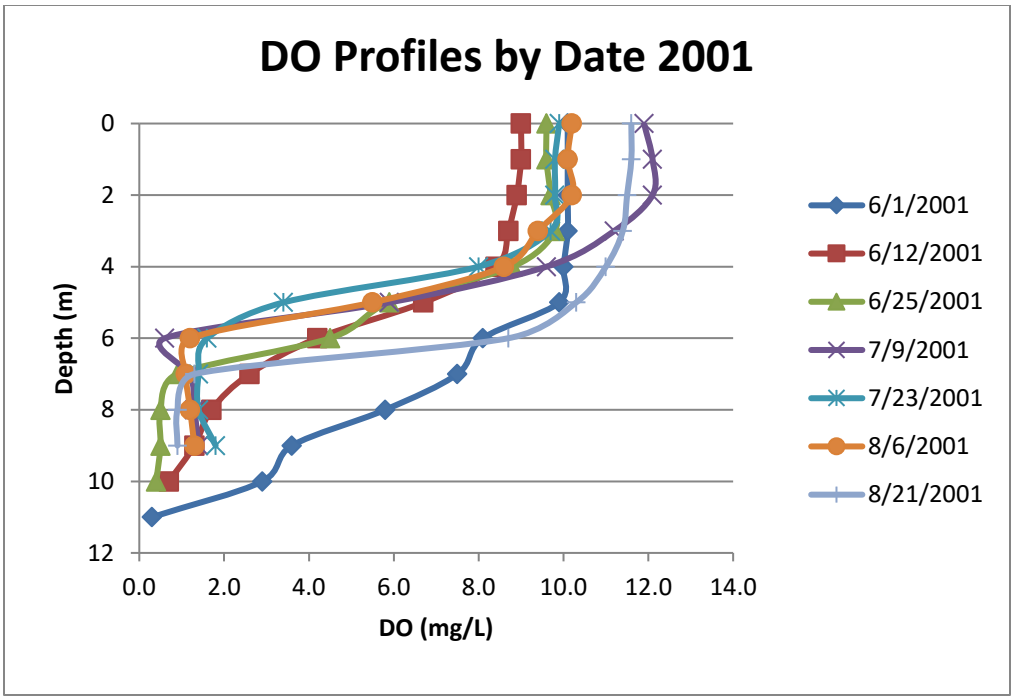

Figure 2.9.1b. *DO concentration by depth, 2001.*

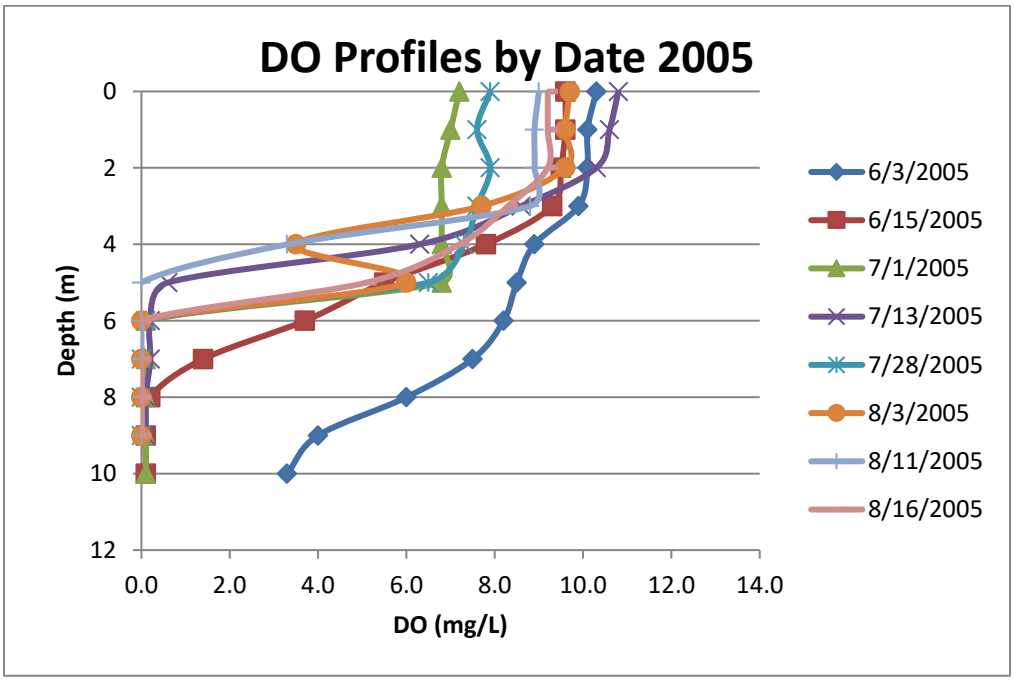

Figure 2.9.1c. *DO concentration by depth, 2005*

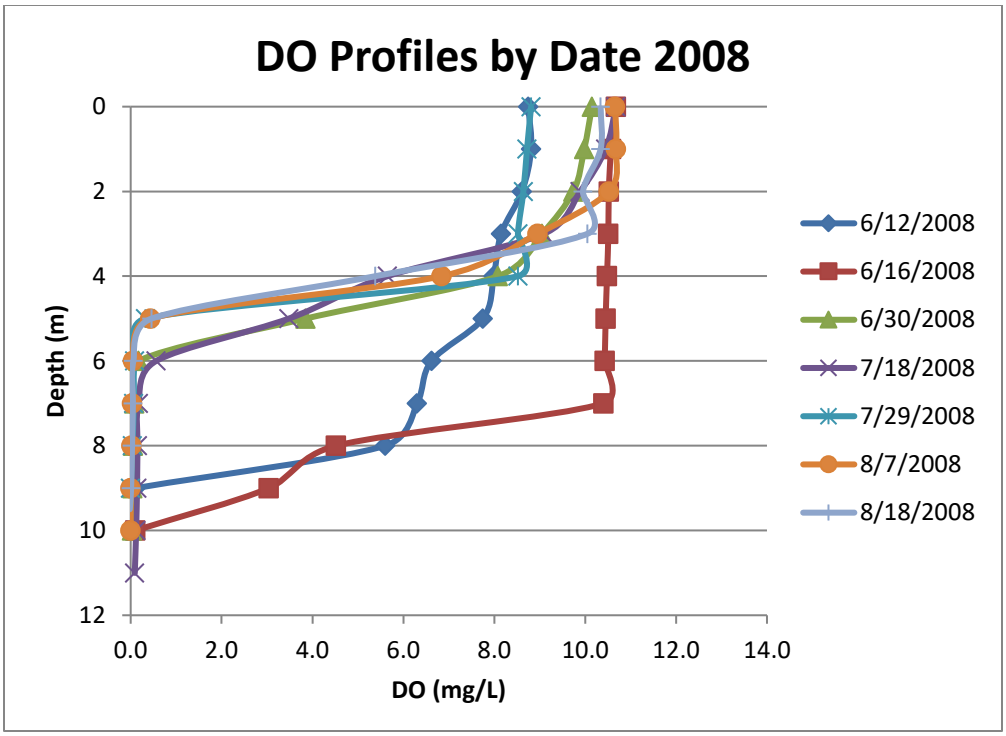

Figure 2.9.1d. *DO concentration by depth, 2008*

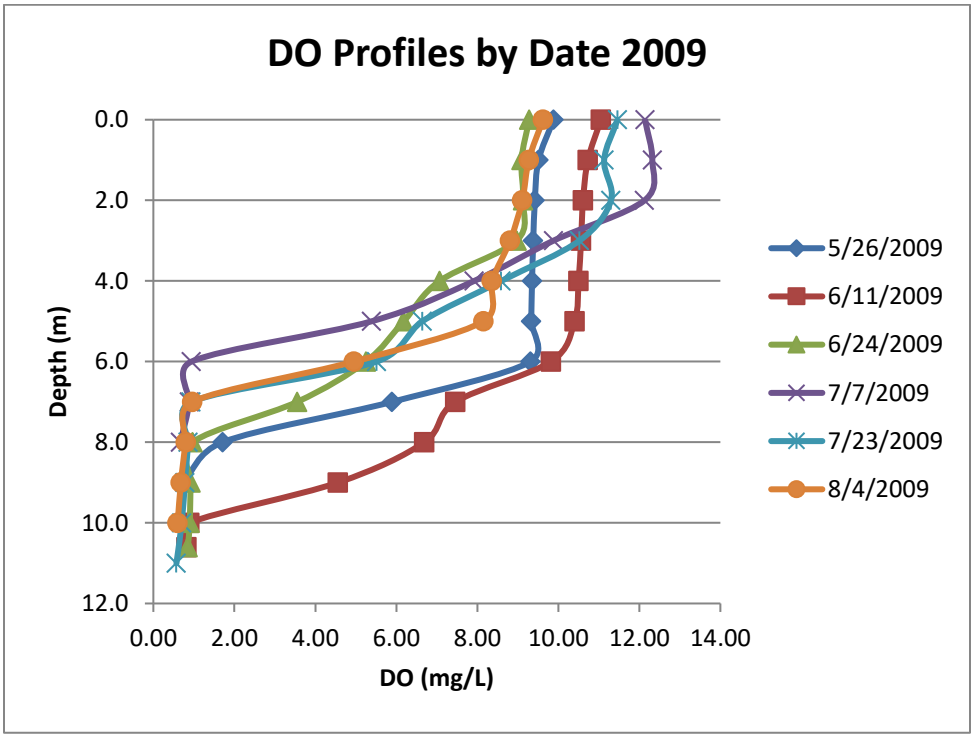

Figure 2.9.1e. *DO concentration by depth, 2009*

2.9.2 Total Phosphorus & Chlorophyll-a

Total phosphorous and chlorophyll-a levels in Pearl Lake meet state standards for growing season mean levels (<40 mg/L June 1 through Sept 30th) in each of the study years, however there are individual samples within each of the years that exceed state standard levels for the growing season in the North Central Hardwood Forest Ecoregion.

Figures 2.9.2a, 2.9.2b, 2.9.2c (years 2010, 2011, and 2012 respectively) exhibit trend data for TP & Chlorophyll-a collected by the Pelican River Watershed District during the Pearl Lake Diagnostic Study. Figure 2.9.2d demonstrates observed standard deviations in the sampled parameters throughout the diagnostic study.

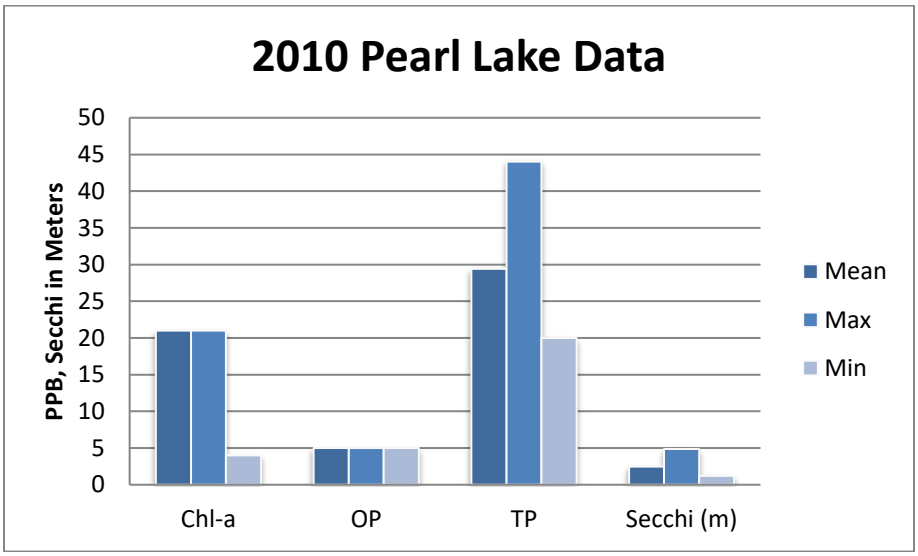

Figure 2.9.2a *2010 Growing Season Mean TP, OP, Chl-a & Secchi Depth*

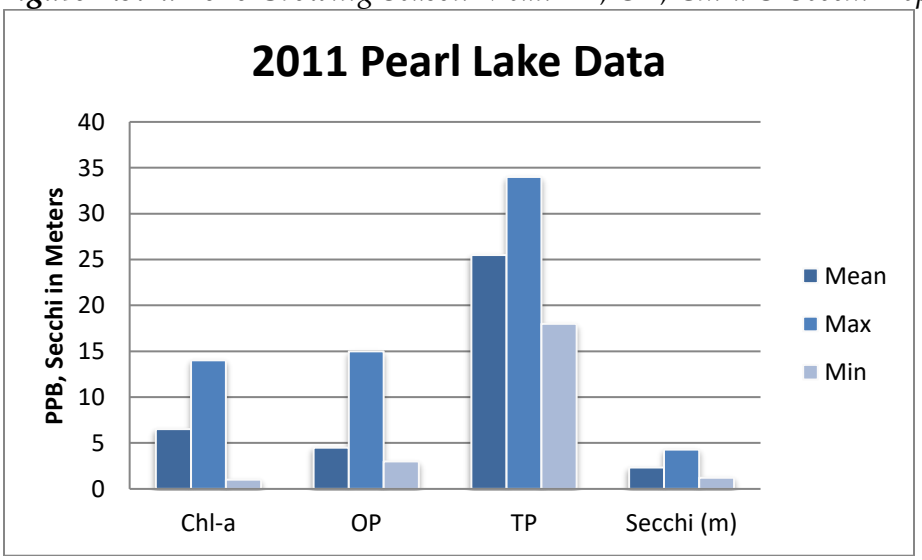

Figure 2.9.2b *2011 Growing Season Mean TP, OP, Chl-a & Secchi Depth*

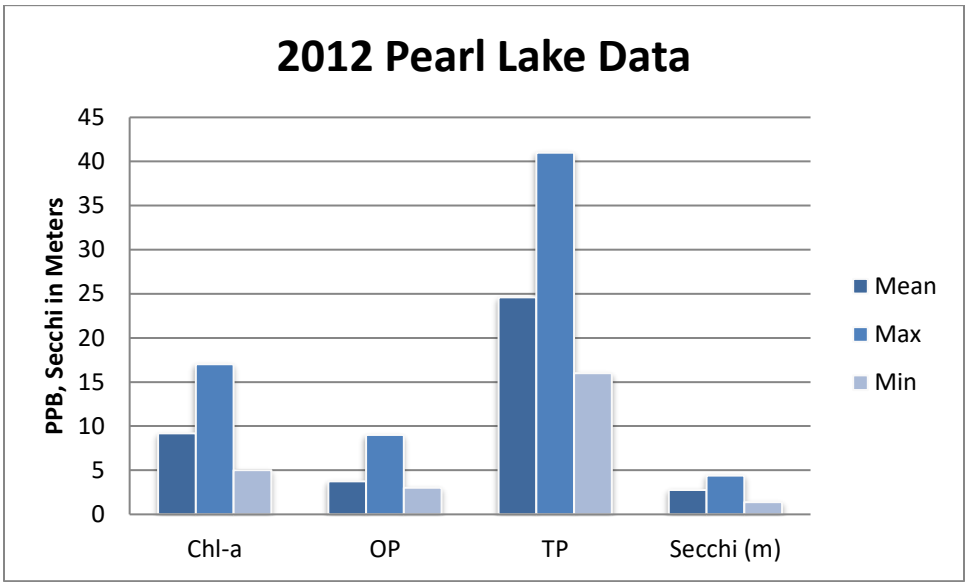

Figure 2.9.2c *2012 Growing Season Mean TP, OP, Chl-a & Secchi Depth*

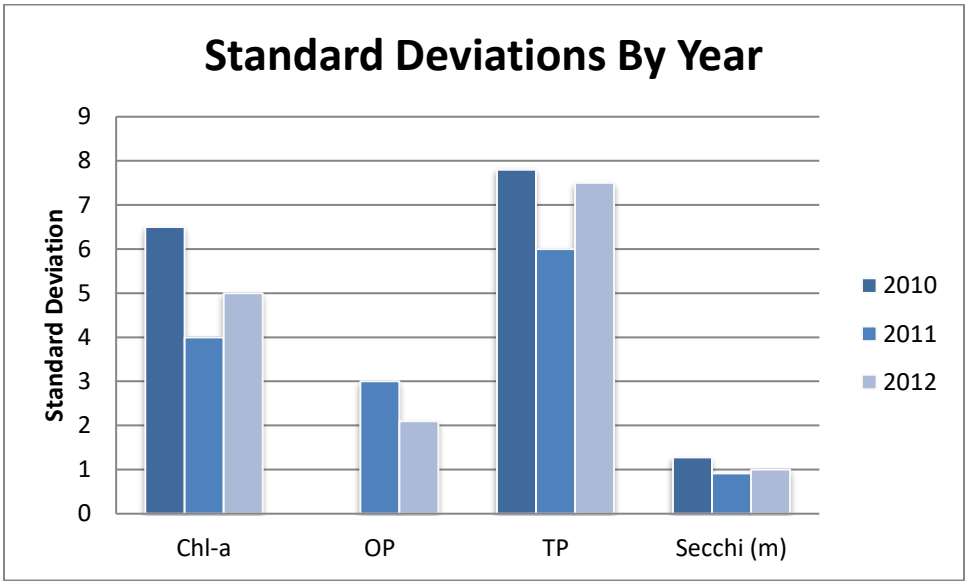

Figure 2.9.2d *Standard Deviations Observed In Study, By Year & Parameter*

2.9.3 Secchi Depth

Secchi Depth in Pearl Lake consistently neared the state standard (1.4m depth) for the North Central Hardwood Forest Ecoregion in late June, July & August of each study year, as well as in reference years. Pearl has exhibited some wild variations in the past, notably an 8.8 meter swing in June, although the results during the diagnostic study were relatively consistent.

Figures 2.9.2a, 2.9.2b, 2.9.2c (years 2010, 2011, and 2012 respectively) exhibit trend data for Secchi Depth data collected by the Pelican River Watershed District during the Pearl Lake Diagnostic Study. Figure 2.9.2d demonstrates observed standard deviations in the sampled parameters throughout the diagnostic study.

2.9.4 Water Quality Conclusions

Generally, Pearl Lake's water quality is acceptable by state standards for the North Central Hardwood Ecoregion for growing season means for the parameters of total phosphorus, chlorophyll-a, and Secchi depth. In each of the three sampled seasons of this study, each of the parameters had minimally one sample that failed to meet state standards.

Pearl Lake has the propensity to diminish in overall water quality. Modeling of the watershed and lake levels indicated that the main water export from the system came in the form of evaporation, meaning most nutrients would be deposited rather than moving through the system.

2.10 Aquatic Plants

Aquatic plants offer a myriad of benefits to lacustrine environments including spawning habitat and cover for fish, macroinvertebrate habitat, refuge from predation, and sediment stabilization. However, in high abundance and density conditions, aquatic vegetation can influence species distribution and abundance, and limit recreational beneficial use. Excessive levels of in lake nutrients can encourage establishment of non-native or invasive species including Curlyleaf Pondweed, Flowering Rush, or Eurasian Watermilfoil.

During a July 2011 Point Intercept Aquatic Plant Survey, Appendix __, PRWD staff observed Curlyleaf Pondweed growing in Pearl Lake. If invasive species, such as Curly Leaf Pondweed are allowed to establish, they can devastate native fisheries and aquatic plant communities.

The Littoral Zone is defined as lake bathymetric area less than 15 feet in depth of water. This ecotone represents the transition from terrestrial to deepwater ecosystems, and is where the vast majority of aquatic plants are found. Within this area, light penetration and nutrient availability is generally sufficient for aquatic plant habitat. In addition to plant growth, the littoral zone ecotone is critical for spawning and rearing habitat of most warm water fish community species.

In early July of 2010, while conducting a point-intercept survey of Pearl Lake, the Pelican River Watershed District discovered Curlyleaf pondweed (CLP). A small patch of less than a quarter acre was found approximatley 250 yards northeast of the public boat launch located on the south end of the lake. The patch contained sparse amounts of CLP, often showing one to two plants of CLP on each rake toss.

A 2011 point intercept survey showed that Curlyleaf pondweed was found in several more locations throughout the lake. Rake tosses at each location showed quantities of single to few CLP plants.

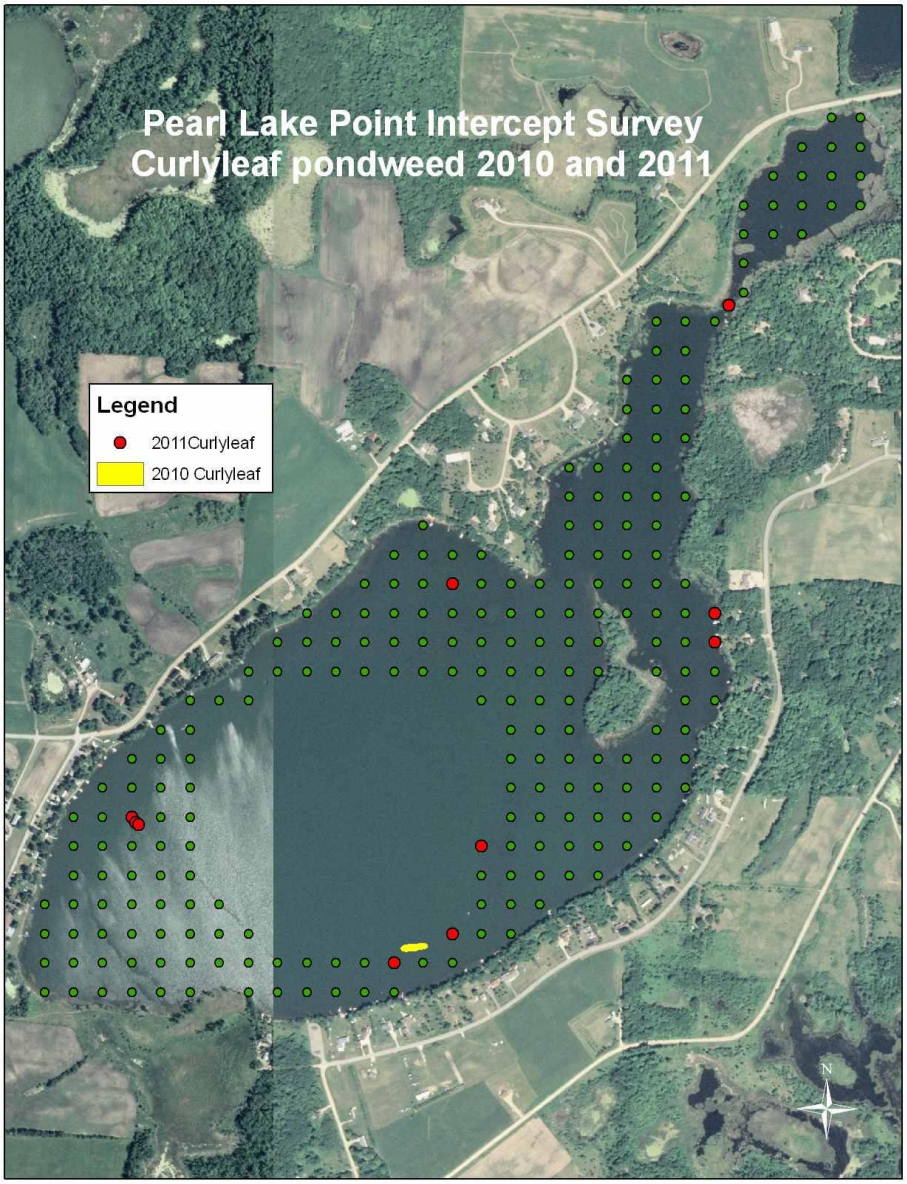

Figure 2.10.1 *Point Intercept Plot & Curlyleaf Pondweed distribution by year*

The 2011 survey showed that over 85% of the survey points had vegetation. Flat leaved pondweed (*Potamogeton zosteriformes*), narrow leaf pondweeds (*Potamogeton spp.)* and Coontail (*Ceratophyllum demersum*) were the species of greatest occurrence. Curlyleaf pondweed occurred at approximatly 3% of sampled locations.

On a scale of one to four, most of the sites that had vegetation were ranked at a one for abundance, meaning the biomass of all each species was fairly low. A ranking of four is most often equivalent to nuicance levels of vegetation growth.

Aquatic vegetation covered 85.22% of the point intercept survey delimited area, which included the entire littoral zone. Of this coverage, three predominant species were observed.

Potamogeton zosterformes was distributed across 59.37% of the surveyed area. Other narrowleaf pondweed species were distributed across a similar 51.30% of the survey sites. *Ceratophyllum demersum* (Coontail) was distributed across 41.30%. These are all beneficial native species.

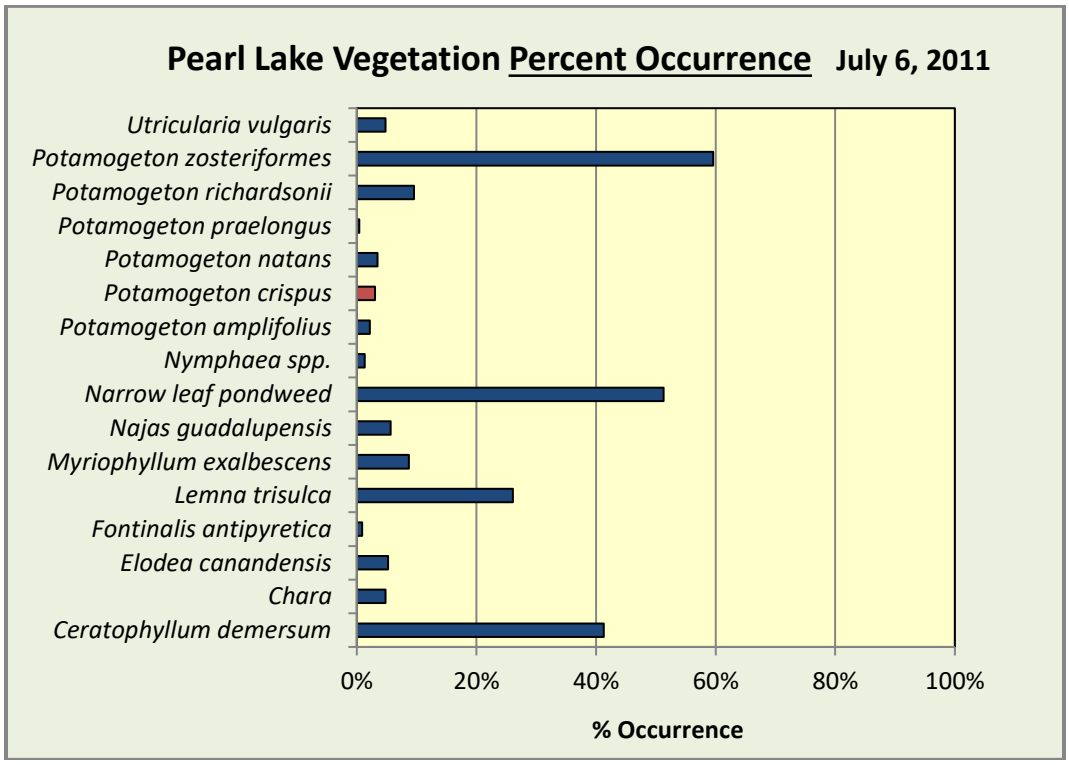

Figure 2.10.2 *Pearl Lake Vegetation Occurrence*

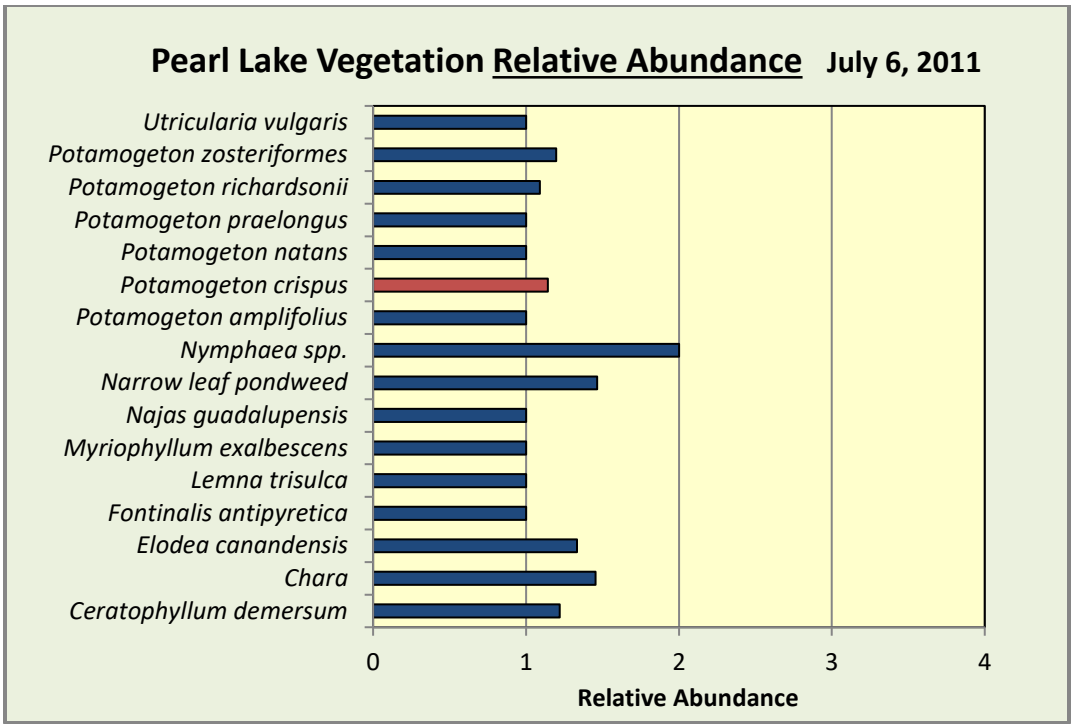

Figure 2.10.3 *Pearl Lake Vegetation Abundance*

2.11 Shoreline Habitat & Conditions

Shoreline describes the area of physical intersection of aquatic and terrestrial ecosystems. Up to a 10% of maximum littoral zone depth (1.5 feet) defines the lower limit of the Shoreline habitat, and the range extends 1.5 feet upland, covering overlapping hydrophytic vegetation species such as sedges. Natural shorelines provide many ecological benefits including wildlife habitat, shading, spawning habitat, sediment stabilization, buffer wave based erosion and generally improved biodiversity.

Shoreline habitat on Pearl Lake is fragmented. Areas of the lake remain primarily naturally vegetated. Other areas have developed extensively in the past decade, including some highly modified shoreline zones.

3.0 Nutrient Budget

3.1 Introduction

Understanding the sources of nutrients entering a lake system is equally important as understanding the effects those nutrients will have on the lake ecology. Phosphorous is the key nutrient that influences Pearl Lake's water quality.

Developing a phosphorous budget involves determination of component inputs and losses for an overall phosphorus load. Additionally lake response models are utilized to simulate how lake variables respond to changes in nutrient loads.

3.2 Watershed Modeling

As the quality of a lake is largely defined by its input sources, the watershed for a particular body of water is an important aspect for consideration. At the onset of the Pearl Lake Diagnostic Study, it was believed that the contributory watershed was approximately 3,000 acres in area, including several bodies of water. As substantially more accurate LiDAR data became available and the study progressed, the estimate of 3,000 total acres was scaled back to 858.8 surface acres, inclusive of Pearl Lake and North (Little) Pearl Lake at 281.1 combined acres at Ordinary High Water level.

Pearl Lake has an exceptionally small watershed to lake area ratio, and the watershed has been trending toward residential development over the past thirty years. Currently there are 57 riparian (waterfront) residences, and 21 additional residences within the Shoreland District – a 1000' wide buffer from the shoreline. This is a 147% increase from 2003, and a 3,800% increase over the number of residences present in 1983.

Prior to residential development, much of Pearl's shoreline was historically agricultural, with a number of natural or naturalized areas. At the onset of this study, a history of agricultural runoff appeared suspect for declining water quality in Pearl Lake; however the revised watershed delineation excluded much of the agricultural influence.

In modeling the watershed contribution to Pearl Lake, an ISCO GLS sampler was set on each of the inlets. To the West of Pearl Lake, a ditch drains 199.6 acres of predominantly farmland. To the East, 34.3 acre area of wetland and forested area drains through a minor inlet. These drainage areas were evaluated by Merritt Hydrologic & Environmental Consulting, LLC, and ground-truthed by Pelican River Watershed

District staff in 2012 and 2013 as LiDAR data became available.

The third watershed component represents the area draining directly into Pearl Lake. This area is primarily characterized by first & second tier residential development, and North Central Hardwood Forest land uses. This component is the largest by area, draining 343.4 acres. With residential development, increased stormwater runoff occurs due to additional impervious and semi-permeable surface coverage. Due to the diffuse discharge of the direct to lake watershed, there is not an appropriate means of monitoring this watershed area.

Table 3.2 summarizes watershed modeling results from Wenck Associates' technical memo to the Pelican River Watershed.

Pearl Lake Watershed Modeling Results				
Parameter	**Unit**	**Value**	**Source**	**Comments**
Total Drainage Area	Acres	577.3	Merritt/PRWD	LiDAR Derived
East Tributary Area	Acres	199.6	Merritt/PRWD	LiDAR Derived
West Tributary Area	Acres	34.3	Merritt/PRWD	LiDAR Derived
Direct to Pearl Lake	Acres	343.4	Merritt/PRWD	
Watershed Runoff	Inches	2.4	Hydrology Guide MN	
East RO Concentration	µg/L	123.3	MPCA/Wenck	Calibration factor 0.81
West RO Concentration	µg/L	80	MPCA/Wenck	Calibration factor 0.56
Direct RO Concentration	µg/L	123.4	MPCA/Wenck	Estimated on E & W RO
East Tributary P Input	lb/year	17	Wenck	
West Tributary P Input	lb/year	3	Wenck	
Direct P Input	lb/year	28	Wenck	
Total Watershed P Input	lb/year	48	Wenck	

Table 3.2 *Watershed modeling results*

3.3 Lake Response Model

The Pearl Lake Diagnostic Study project focused on in-lake modeling in addition to looking at the watershed to determine the contribution of phosphorus loading. This approach allowed the study to look not only at the internal loading characteristics, but also the externalities affecting the lake water quality.

The Pelican River Watershed District contracted Wenck Associates to develop the lake response model. The Canfield-Bachmann model was utilized, which estimates the lake

phosphorous sedimentation rate to predict the relationship between in lake phosphorous concentrations as well as phosphorus load inputs. The phosphorus sedimentation rate estimates net phosphorus losses in the water column through sedimentation to the lake substrate. This is utilized with annual phosphorus loading, mean depth and hydraulic flushing to predict in lake phosphorus concentrations.

Pearl lake was below run-out elevation for the period of the diagnostic study, which effectively disrupts an accurate depiction of the lake residence time. For the 2002 through 2011 period, growing season TP averaged 30 µg/L; but averaged 25 µg/L between 2008 & 2011 when this diagnostic study was underway – coinciding with falling lake levels. The most representative range with a predictable residence period s 2002 to 2007, where growing season TP concentration averaged 33 µg/L. Comparatively the model prediction is 37 µg/L.

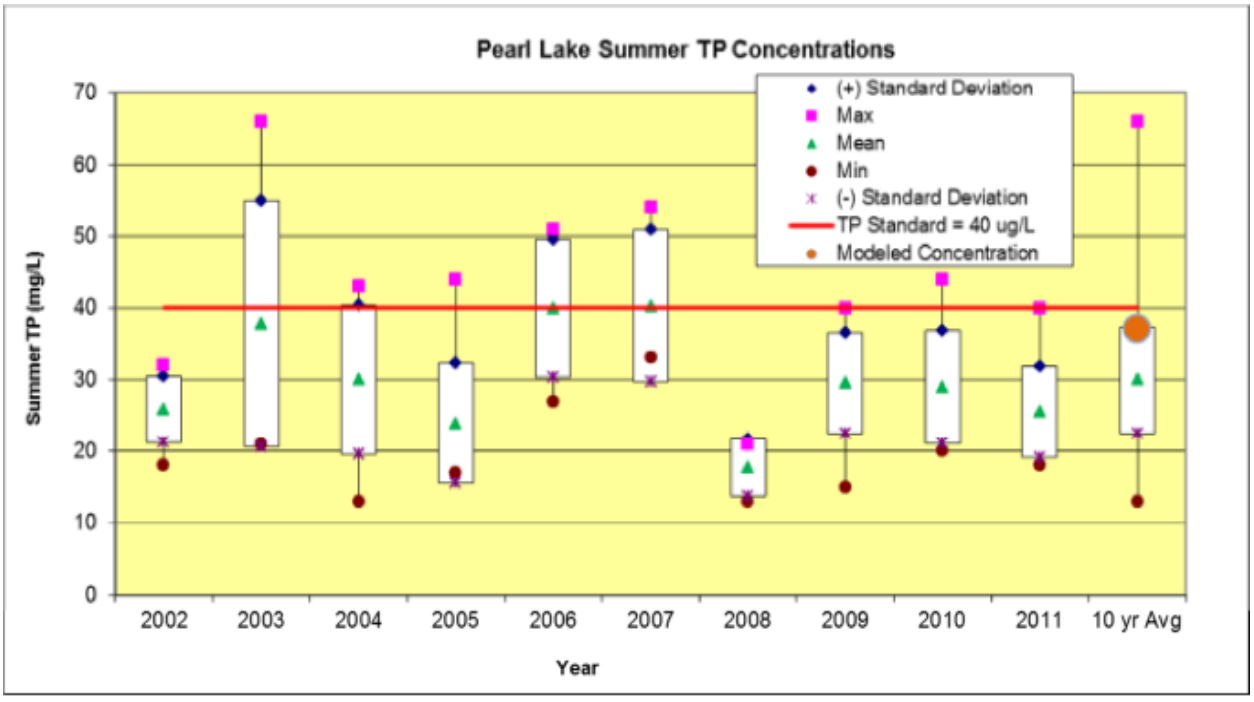

Figure 3.3 Average Summer TP Concentrations

Pearl Lake Loading Rate				
Parameter	**Unit**	**Input**	**Source**	**Comments**
Mean Depth	Feet	11.8	Merrit/DNR	GIS Bathymetry/DNR Map
Lake Volume	Acre-Feet	3313	Merritt/PRWD	GIS Bathymetry/DNR Map
Calculation Years	Years	2002-2011	MPCA	MPCA EDA Database
In-Lake Average TP Conc.	µg/L	30	Wenck/ DNR EDA DB	Calculated Mean Value
Watershed Runoff	Inches	2.4	Hydrology Guide, MN	
Groundwater Contribution	AF/Yr	-38	USGS	1975 Report
Atmospheric Loading Rate	lb/Acre/yr	0.239	Barr Engineering	Updated 2007
Atmospheric Load	lb/yr	67.2		
# Septic Systems		71		
Septic P Rload	lb/yr	26	EPA Manual/Wenck	2.8 pp @2.7g/day
Septic Failure Rate	%	6	MPCA/Wenck	
Evaporation	Inches	27.5	Hydrology Guide, MN	
Sediment Release Rate	mg/m2-day	4.8	Aquatic Restoration & Research, LLC	Report for Pearl Lake
Anoxic Factor	Days	10	Wenck/ DNR EDA DB	Calculated; Bathymetric & DO Data
Internal Loading	lb/yr	117.1	Wenck	
Non-watershed Annual Phosphorus Load	**lb/yr**	**210.3**	**Wenck**	

Table 3.4 *Lake Loading Summary*

3.4 Internal Loading

Internal loading was found to contribute 45.3% of the total phosphorous load in an average year, representing by far the largest contributing factor to the annual phosphorus load. Phosphorous release from sediment is controlled by the extent & duration of anoxia over the sediment, and the release rate through the water column.

Pearl Lake demonstrates a trend of increasing anoxia over bottom sediment, typically peaking in late summer. Anoxic conditions in lakes are expressed as the number of days that anoxia occurs over the area equal to the entire lake – referred to as the anoxic factor. The anoxic factor for Pearl Lake is 10 days.

In August of 2012 Aquatic Restoration and Research, LLC prepared a report titled

Internal Phosphorus Loading & Sediment Phosphorus Fractionation Analysis for Pearl Lake, Minnesota for the Pelican River Watershed District. The sediment release rate for Pearl lake was calculated as 4.8 mg/m^2 per day. This rate is used to estimate gross loading based on the anoxic factor for the lake (Nürnberg, 2004).

Phosphorus fractionation analysis for Pearl Lake yielded information that P mass & concentration increased linearly in the water column over sediment maintaining anoxic conditions. Increases in the number of anoxic factor days yield increases in phosphorus mass & concentration within the water column. The phosphorus release rate was calculated as 4.8 mg/m^2 d^{-1}. This rate falls within the lower quartile compared to a selection of lakes distributed throughout Minnesota. The biologically-labile phosphorus concentration accounts for 56% of the total sediment phosphorus leading to a high recycling potential.

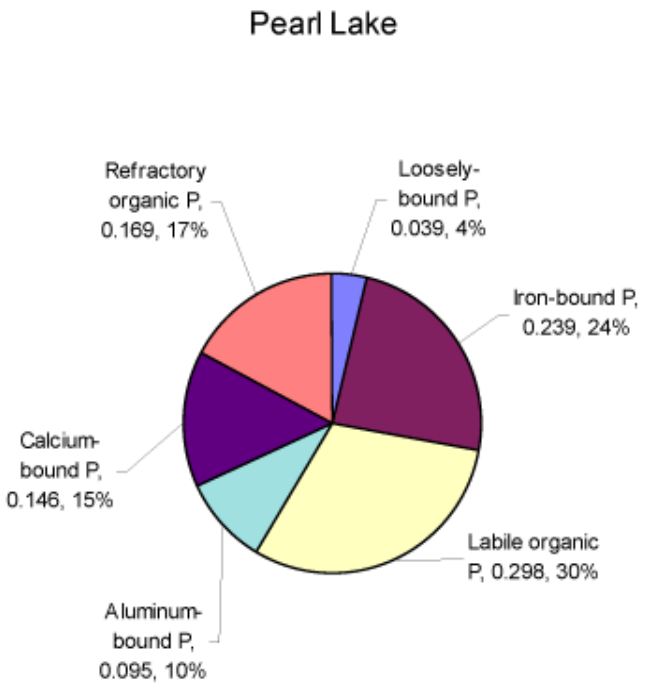

Figure 3.4.1 Distribution of phosphorus in Pearl Lake sediment core

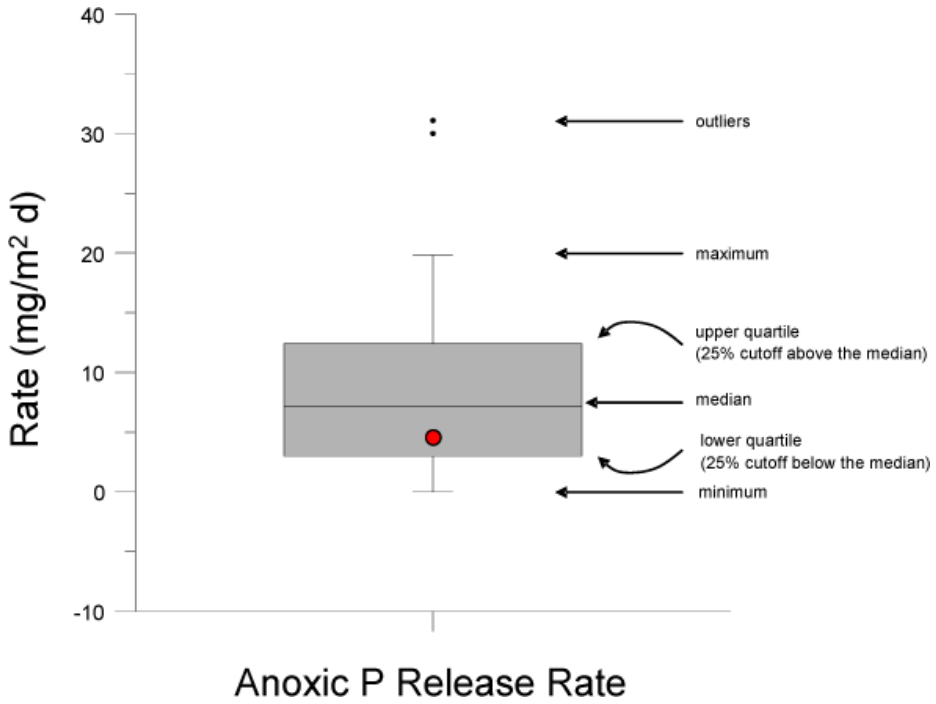

Figure 3.4.2 Anoxic release rate compared to other Minnesota Lakes (n=50). The red point represents Pearl Lake.

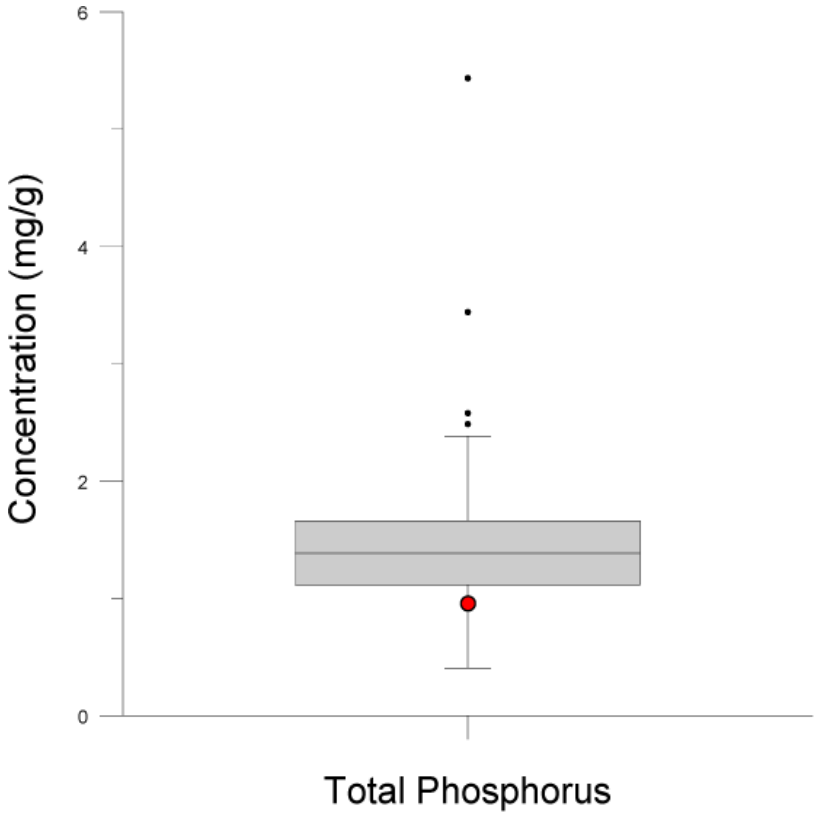

Figure 3.4.3 Total sediment phosphorous compared to other Minnesota Lakes (n=50)

3.5 Atmospheric Loading

Atmospheric loads of phosphorus result from pollen distribution, wind erosion of soil, from fires, and anthropogeninc (human based) sources like fertilizer application, and burning carbon based fuels such as gas, oil, or coal. Phosphorus can also enter the atmosphere in vapor form through decomposing materials including sewage effluent, landfills, and compost sites. Atmospheric deposition can be a very significant component of a nutrient budget; this is the case in Pearl Lake.

Atmospheric deposition of phosphorous occurs in two ways. Wet deposition occurs through particulate bound phosphorus contact with precipitation (rain, drizzle, fog, sleet, hail, frost, snow). Dry deposition refers to deposition of very fine particles with bound phosphorus. This may occur in the form of dust, ash, or pollen. (BARR, 2007)

Pearl Lake has a large surface area for the volume of water contained, as evidenced by the littoral dominance of the lake, in addition to a small collection basin. As such, Pearl Lake is particularly susceptible to atmospheric deposition of phosphorus.

4.0 Hydrological Analysis

Merritt Hydrological and Environmental Consulting assisted the Pelican River Watershed District in determining the water budget for Pearl Lake, including the delineation of the lake's contributory watershed. Pearl Lake is a perched lake, resting in a clay aquitard sandwiched between layers of sand and gravel glacial outwash. This aquitard largely isolates it from neighboring lakes that share a connection between hydrologically through the glacial outwash, except in the events of high water events or years where OHW levels are exceeded, thus allowing limited additional inputs and losses. The very limited groundwater interaction was confirmed through the installation of a field observation well and remote level monitoring equipment.

Monitoring the primary inlets to the lake, the Pelican River Watershed District installed ISCO GLS samplers, which sample area / velocity cross sections (flow rate) at 15 minute intervals, and continuously as storm events are detected. The resulting information was

that flow is seasonal and episodic, where base flow conditions are not present at all times. This information leads to an understanding that the inputs into Pearl Lake are minor, which is in concurrence with the small watershed finding. The largest water budget contribution to Pearl Lake is precipitation entering the lake directly, followed by surface runoff and subsurface drainage.

Merritt Hydrologic and Environmental Consulting provided information for Pearl Lake's runout elevation in addition to a hydrograph of Pearl Lake surface elevation readings from 1996 through 2012 (Figure 4.0).

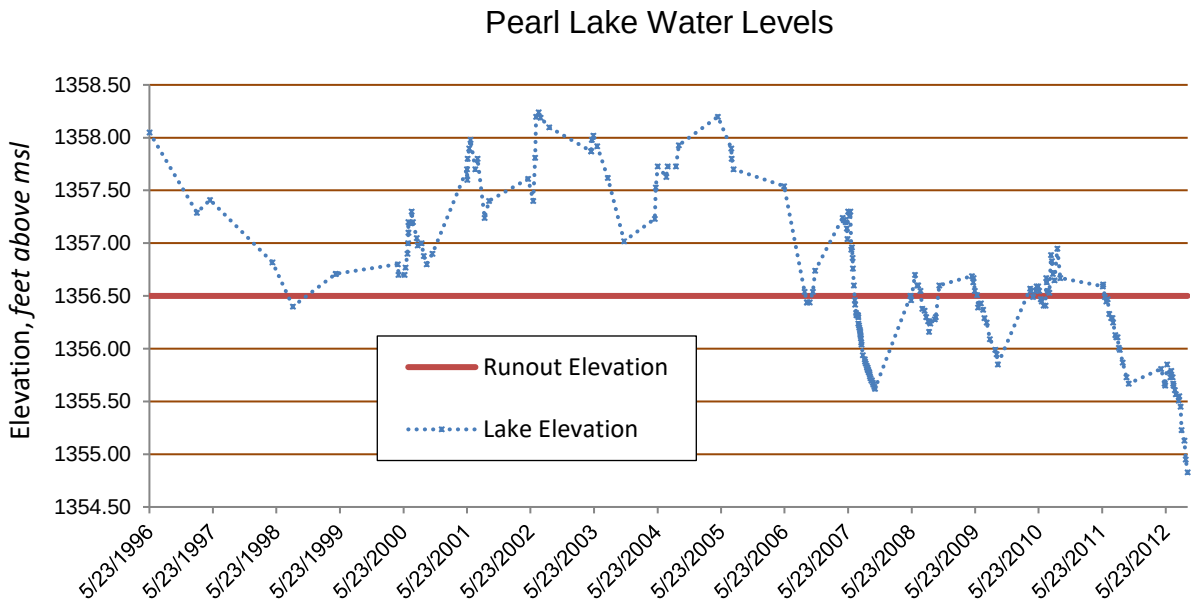

Figure 4.0 Lake elevation and runout elevation

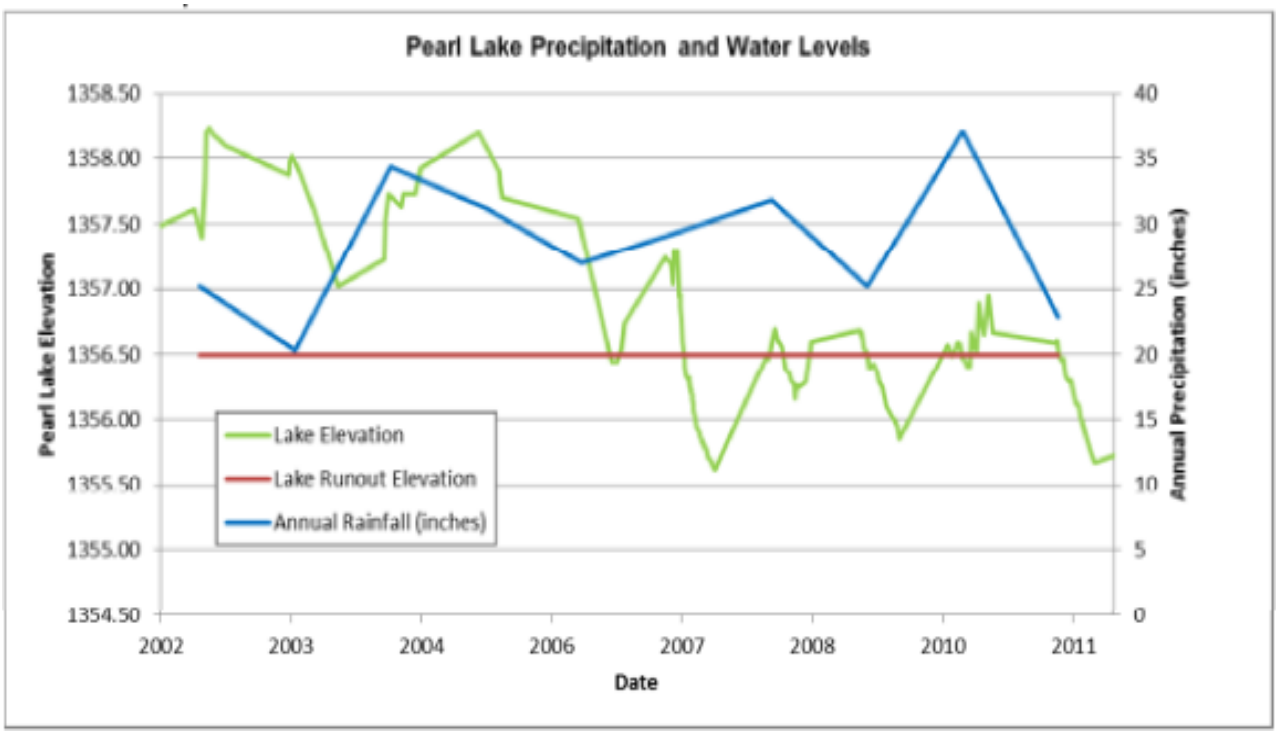

Figure 4.1 Observed Lake Elevation versus Annual Precipitation

Data from 2002 through 2011 provides little correlation between precipitation and elevations for Pearl Lake, nor the lake run out elevation (Figure 4.1). One possible explanation of this discrepancy is the inclusion of a defined outlet structure that was put in within the past decade. This could explain the level drop starting in approximately 2006 and relative stabilization around the 1356.5' run out elevation. Responding to the lower than run out trending elevations observed in figure 4.0, precipitation totals for 2011 and 2012 have been lower than the 30-year average of 27.46" average at 22.9" and 23.8" per year respectively.

5.0 Management & Implementation Plan Development

The purpose of this plan is to outline management activities to protect and improve water quality in Pearl Lake.

5.1 Management Plan Principles

Management plan principles are drawn from goals outlined in the 2005 Pelican River Watershed District Revised Management Plan.

1. **Maintenance of Biological Integrity**

The Pelican River Watershed District and the residents of Pearl Lake recognize the significance in maintaining a healthy biological community within Pearl Lake. Ecological integrity includes sustainable nutrient, aquatic plant, zooplankton, macroinvertebrate, and fish populations & concentrations. Healthy ecosystems contribute to high water quality within the ecoregion standards.

2. **Integration of Watershed and Shoreland Best Management Practices (BMP's)**

The Pearl Lake Diagnostic Study revealed that the majority of Peal Lake's phosphorous budget comes from sources that are impossible (atmospheric deposition) or likely cost prohibitive (internal loading) to control. However, this also emphasizes the importance of shoreland and watershed best management practices including filtering buffers, and shoreline revegetation. Decreasing the phosphorus input is critical to maintaining or improving water quality in Pearl Lake.

3. **Stewardship & Outreach**

Pearl Lake Association members and residents will be provided opportunities to gain a greater understanding of their contribution to Pearl Lake. PRWD intends to recruit volunteer lake monitors & provide training for Secchi disk readings. Additionally, PRWD & the Becker County Soil & Water Conservation District will hold an informational session and design charrette for residents interested in natural shoreline restoration and buffer installation.

5.2 Watershed District Activities

The Pelican River Watershed District will lead outreach, education, and coordination of implementation efforts of the Pearl Lake Management Plan. A description of the Pelican River Watershed Districts duties follows.

5.2.1 Coordination of Efforts

Watershed districts are established within the State of Minnesota to coordinate water resource policies and activities within defined jurisdictions. The Pelican River Watershed District maintains and may expand the following duties.

- Provide advice and assistance to local communities on their implementation activities;
- Research and disseminate information on changing BMP technology practices;
- Collect implementation activity data;
- Maintain water quality collection program;
- Maintain watershed models; and

- Conduct public hearings on proposed projects.

5.2.2 Rules on Development and Redevelopment

The Pelican River Watershed District currently operates under rules established for the 2005-2015 Revised Management Plan. Updating these rules with additions such as a zero net runoff regulation can positively affect water quality in Pearl Lake. A new revised management plan effective 2015 is within the near future for the Pelican River Watershed District.

5.2.3 Load Reductions through Development and Redevelopment

As development and redevelopment of earlier phases occurs along the perimeter of Pearl Lake, more stringent regulations may be established to reduce the amount of runoff, more effectively treat septic effluent, or otherwise influence lake water quality.

5.2.4 Better Site Design

The Pelican River Watershed District Rules require minimization of new impervious surface coverage and management of increased runoff volumes in new development as well as in redevelopment situations. The use of rain gardens, native plantings, and reforestation are encourages as a means of increasing infiltration, evapotranspiration, and filtration of lake bound runoff.

5.2.5 Education and Outreach

The Pelican River Watershed District strives to promote education and outreach opportunities within the district. In July of 2013, the Pelican River Watershed District will partner with the Becker County Soil and Water Conservation District to provide a Restore Your Shore educational meeting and charette. A charette is a planning tool that allows a group of participants to collaborate on a common problem, situation, or example in a graphic manner. The purpose of this activity is to provide additional information on shoreline revegetation practices that not only stabilize the shoreline, but also increase filtration, add biodiversity & habitat, and provide aesthetic appeal.

In 2014 The Pelican River Watershed District will partner with the award winning Blue Thumb – Planting for Clean Water program. This partnership will greatly enhance access to educational materials for the residents of Pearl Lake interested in shoreline restoration and enhancement.

Significant possible reductions in phosphorus loading of Pearl Lake are found in the direct watershed component primarily, and in the agricultural area to the West of the lake. The direct watershed area is responsible for 58.33% of the watershed contribution to the annual phosphorus load, or 10.85% of the overall annual phosphorus load.

Ensuring that all septic systems are in compliance, in addition to shoreline re-vegetation and restricting impervious surface coverage increases, will help lower direct watershed phosphorus inputs.

The subwatershed area to the West drains an area of approximately 199 acres. The calculated phosphorus load from this drainage is 17 pounds per year. It may be possible to lower this load through best management practices executed in cooperation with the Becker County Soil and Water Conservation District and the USDA Natural Resource Conservation District Becker county office.

5.2.6 Shoreline Management and Restoration

Shoreline restoration provides stabilization, habitat, and aesthetic benefits in addition to modest reductions in phosphorus load reductions. Typical residential developments within this area include turf grass maintained to a rip-rapped shoreline. Ideally, greater than 75% of the shoreline would feature native vegetation.

Resources are available through the Pelican River Watershed District and Becker County Soil and Water Conservation District. Residential landowners should be encouraged to participate in educational opportunities and in shoreline restoration.

5.3 Lake Management

5.3.1 Curly-leaf Pondweed

Curly-leaf Pondweed was identified during point intercept surveys conducted by PRWD in 2010 and 2011, abundance and density had increased from 2010 to 2011. Curly-leaf pondweed at this time does not represent a significant contribution toward phosphorus loading. Future monitoring should take place to track changes in Curly-leaf Pondweed population within Pearl Lake.

As Curly-leaf Pondweed completes its life cycles and washes near shore, decomposition can lead to localized hypoxic or anoxic conditions triggering sediment bound phosphorus release. Management of Curly-leaf Pondweed is an important step in managing for recreational use and biological diversity within Pearl Lake.

5.3.2 Watershed Management

At the onset of the Pearl Lake Diagnostic Study it was assumed that a significant amount of agricultural land drained into Pearl Lake from the West. With enhanced remote sensing capabilities afforded though the release of LiDAR data, the watershed was re-evaluated and found to be substantially smaller than originally thought.

However, there is still room for improvement within the 199 acre agricultural area draining into Pearl Lake from the West. This basin was found to contribute 17lbs of phosphorus annually. Figure **5.3.2a** shows an area where a small grass waterway might be appropriate, and Figure **5.3.2b** demonstrates an ideal placement for a native buffer strip planting. Effectively capturing the sediment may mean up to an 80% reduction in phosphorus loading, as phosphorus is primarily sediment bound.

Establishing native plant cover in the shoreline area similarly acts as a buffer, while also establishing valuable wildlife habitat, increasing biodiversity, stabilizing the shoreline, and can offer aesthetic appeal. PRWD and the Becker County Soil & Water Conservation District are partnering for community outreach and education efforts on Pearl Lake, and a cost share program may be available to residents in the future.

Figure 5.3.2a Linear drainage, Possible Grassed Waterway

Figure 5.3.2b Corn planted in close proximity to ditch

5.3.3 Internal Loading

Reducing the internal load of sediment released phosphorus is generally associated with a phosphorus binder, such as aluminum sulfate (also known as alum), a hypolimnetic aeration system, or both. The cost of alum treatment is widely based on coverage and dosing rate, however treatment for Pearl Lake could easily be over $100,000. Prevalence of rough fish, including bullhead species, can significantly reduce the efficacy of alum treatments. Where alum treatment is suitable, internal loading rates are diminished by approximately 50%.

Hypolimnetic aeration is most suitable for areas with well defined problematic areas (Peterson, 1978). Pearl Lake's bathymetry is predominantly within the littoral zone, making hypolimnetic aeration treatment cost prohibitive and unsuitable in Pearl Lake.

Modeling and sediment fractionation analysis indicates that internal loading contributes over 45% of the annual phosphorus load for Pearl Lake. An average modeled year contributes 117.1 pounds of phosphorus to the overall load. An

additional 67.2 pounds of phosphorous are the result of atmospheric deposition, which has no direct control.

5.3.4 Trophic Management

The modeling results demonstrate a total phosphorus concentration of 37 μg/L, this varies significantly from recorded growing season averages. One potential explanation for this occurrence is the falling lake elevation since 2006. As Pearl Lake has been functioning essentially as an endorheic basin through the study, an accurate model for the 10 year average was not possible. Residence time was based on a smaller number of years, which can skew the data somewhat. This figure came in at 33 μg/L, which is much closer to the 37 μg/L model output than the 30 μg/L mean in the 10 year period.

Table 5.3.4 (following page) shows the average load reduction schedule for the modeled 37 μg/L concentration of total phosphorus (TP) in Pearl Lake. Highlighted in green is representative of 2002-2007, which was used to model residency in Pearl Lake. Highlighted in orange is the 10 year average TP concentration of 30 μg/L, which would represent a 30% load reduction in Pearl Lake. The last three years have averaged in the 29 to 25 μg/L TP concentration range, which is nearing the long term goal of maintaining Pearl Lake as a mesotrophic classified lake.

Average Load Reduction (TP) for Pearl Lake					
Load		Modeled In-Lake Water Quality Parameters			Trophic Status Index
Reduction [%]	Net Load [lb]	[TP] µg/L	P Sedimentation [lb]	TP Outflow [lb]	TSI [TP]
0%	258	37	251	7	56.2
5%	245	36	238	6	55.8
10%	232	35	226	6	55.4
15%	219	34	213	6	54.9
20%	206	33	200	6	54.4
25%	193	32	188	6	53.9
30%	***180***	***30***	***175***	***5***	***53.4***
35%	167	29	162	5	52.8
40%	155	28	150	5	51.4
45%	142	27	137	5	50.7
50%	129	25	124	4	49.8
55%	116	24	112	4	48.9
60%	103	22	99	4	47.8
65%	90	21	87	4	46.5
70%	77	19	74	3	46.5
75%	64	17	61	3	45.1
80%	52	15	49	3	43.3
85%	39	13	36	2	40.9
90%	26	10	24	2	37.6
95%	13	7	12	1	31.8

Table 5.3.4 Average Load Reduction

To ensure that Pearl Lake's TP and Chlorophyll-a TSI ratings are within the range of mesotrophy, a 50% reduction in total phosphorus is necessary. Even if all watershed sources of phosphorus were eliminated, this is not an attainable feat. In-lake alum treatment and or hypolimnetic aeration would be necessary to augment the reductions from the modeled annual loading rate of Pearl Lake.

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