Wenck File #2538-02
June 2015

Eagan Neighborhood Lakes TMDL and Management Plans Report

Prepared for:

CITY OF EAGAN

MINNESOTA POLLUTION CONTROL AGENCY

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wq-iw7-40e

ACKNOWLEDGMENT

From April 29, 2012, to April 28, 2015, the Neighborhood Lakes Management Plans Clean Water Partnership project was provided grant support through Minnesota Grant Agreement #43429.

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Margin of Safety	An explicit margin of safety (MOS) of 5% of the load has been set aside to account for any uncertainty in the lake response models. The 5% MOS was considered reasonable for all of the modeled lakes due to the quantity of watershed and in-lake monitoring data available.	Section 4.1.3, p. 4-4
Seasonal Variation	Seasonal variation is accounted for through the use of annual loads and developing targets for the summer period, where the frequency and severity of nuisance algal growth will be the greatest.	Section 4.1.5, p. 4-4

EPA/MPCA Required Elements	Summary	TMDL Page Number
Reasonable Assurance	The goals of the TMDL study are consistent with the objectives of the City of Eagan's Water Quality and Wetland Management Plan, and the stakeholder process has generated commitment and support from affected local government units. Several sources of technical assistance and funding are available to execute the Implementation Plan.	Section 6.1, p. 6-1
Monitoring	This plan discusses two types of monitoring needed to assess progress in meeting water quality standards.	Section 6.4, p. 6-2
Implementation	This plan identifies water quality goals and projects needed to reach those goals. Implementation will be conducted using Adaptive Management, a cyclical feedback process that is repeated until the established goals are met.	Section 5.2, p. 5-1
Public Participation	The public was invited to participate during three public meetings.	Chapter 7.0, p. 7-1

Executive Summary

In 2014, the Minnesota Pollution Control Agency listed Carlson (MNDNR ID# 19-0066-00), Fitz (MNDNR ID# 19-0077-00), Holz (MNDNR ID# 19-0064-00), and LeMay (MNDNR ID# 19-0055-00) Lakes as impaired for aquatic recreation under Section 303(d) of the Clean Water Act. In addition to the impaired lakes, the City of Eagan requested that this report include management strategies for lakes that are not currently listed as impaired for aquatic recreation to ensure that lakes with high water resource value are protected. These unimpaired lakes include Bald (MNDNR ID# 19-0061-00), Bur Oaks (MNDNR ID# 19-0259-00), Cliff (MNDNR ID# 19-0068-00), Hay (MNDNR ID# 19-0062-00), LP-30 (MNDNR ID# 19-0053-00), North (MNDNR ID# 19-0136-00), O'Leary (MNDNR ID# 19-0056-00) and Quigley (MNDNR ID# 19-0155-00). The watersheds of these lakes fall primarily within the city's boundaries, however, some watersheds do fall within the boundaries of Inver Grove Heights (LP-30 and Hay Lake) and Apple Valley (Cliff Lake). The land use within the impaired and protection lake watersheds primarily includes residential, industrial and commercial land use.

The purpose of this report is to develop total maximum daily load allocations for lakes that were classified as impaired for aquatic recreation due to excessive nutrient loading. In addition to providing allocations for impaired lakes, watershed nutrient reduction strategies have been developed for protection lakes (lakes not currently listed as impaired). This study analyzed each subwatershed by developing refined water and phosphorus budgets, including internal loading, for lakes within the City of Eagan boundaries to identify implementation actions to improve and protect water quality. The water and phosphorus budgets include the development of lake response models for the impaired and protection lakes to refine our understanding of internal versus external loading and target reductions to meet water quality goals. The watershed management and TMDL study also investigates fish and plant communities in the lakes to develop an understanding of the health of the biological communities and how these conditions may affect water quality. This detailed modeling process ultimately led to the calculation of watershed and internal phosphorus load reduction goals. Overall load reductions for impaired lakes range from 22 to 54 percent reduction from current loading.

Phosphorus reduction goals developed for each lake were supplemented with detailed phosphorus reduction strategies and implementation plans. This allows the City of Eagan to integrate water projects with land use planning and development objectives to accomplish water quality goals through efficient use of public funding. The plan includes watershed and internal phosphorus reduction projects with detailed cost estimates and phosphorus load reduction estimates to assist the city's lake nutrient management process. These projects include stormwater basin improvements, tree boxes, rain gardens, iron enhanced sand filters, street sweeping, underground filtration systems, aquatic fish and plant control, and aluminum sulfate additions. The projects listed in the implementation plan, in addition to others developed by the city, were selected to maximize the likelihood of each impaired and protection lake meeting water quality standards in the future.

1.0 Introduction

1.1 PURPOSE

Since the early 1990s, the City of Eagan (city) has engaged in intense and sustained management of its lakes and their watersheds in a comprehensive approach to improve water quality by reducing in-lake total phosphorus (TP) concentrations. The City focused extensive efforts in the mid- to late-1990s on Fish and Schwanz lakes, which are Eagan's two highest priority lakes, through diagnostic/feasibility studies (City of Eagan, 1994 and 1992, respectively) and Clean Water Partnership (CWP) projects supported by MN Pollution Control Agency (MPCA) grants (Macbeth and Storland, 2002 and 2001, respectively). Recently, it finalized a 2007-2010 TMDL study of both lakes, also supported by a MPCA grant (City of Eagan, 2010). In 2012, the City prepared state-of-the-art water quality management plans for Eagan's next highest priority lakes, Blackhawk and Thomas (Wenck 2012).

This resource investigation and protection project is supported by a MPCA CWP grant and is co-sponsored by the Gun Club Lake Watershed Management Organization which has since disbanded and been replaced by the Eagan-Inver Grove Heights Watershed Management Organization. There are two parts to this study. The first part develops TMDLs for four impaired lakes in the City of Eagan. Similar to a TMDL effort, the second part evaluates in-lake water quality, assesses TP loads, and proposes implementation plans to address needs in water bodies not designated as impaired. Ultimately, the project provides direction for implementing priority system improvement projects and activities to protect and improve these lakes, consistent with Eagan's Water Quality & Wetland Management Plan (WQWMP; City of Eagan, 2007).

The purpose of the plan is to develop proactive lake management plans for 12 lakes in Eagan that fulfill the following expectations:

1. Satisfies TMDL study and report requirements for impaired listed lakes, including the development of allocations to achieve loads that would allow the lakes to meet established water quality standards.
2. Identifies protection activities for non-impaired lakes to maintain water quality and improve the overall ecological health of the lake
3. Articulates implementation elements to achieve any recommended phosphorus reductions.
4. Provides coherent strategies to improve the recreational suitability of the lakes that may be in addition to the phosphorus reductions called out in the protection plans or TMDLs above.

Note that because this project was funded through the CWP program, it is fulfilling the specific objectives of that grant and is not intended to align with the required components of a Watershed Restoration and Protection Strategies (WRAPS) report, as outlined in Minn. Stat. 114D.26. This report does, however, emphasize implementation planning and therefore contains detailed plans to restore and protect the subject lakes.

1.2 WATER QUALITY CHARACTERIZATION GOALS

The water quality characterization goals of this project were: 1) quantify the maximum TP loadings that would still allow water quality standards to be met and 2) identify TP reduction strategies for source areas to restore or protect waters.

1.3 TOTAL MAXIMUM DAILY LOADS

Section 303(d) of the Clean Water Act establishes a directive for developing Total Maximum Daily Loads (TMDLs) to achieve Minnesota water quality standards established for designated uses of State water bodies. Under this directive, the State of Minnesota is recommending in its draft 2014 303(d) List (as of the preparation of this report) that TMDLs be prepared to address excess nutrients in 4 of the 12 lakes of this project. The goal of a TMDL study is to quantify the pollutant reductions needed to meet State water quality standards. This report presents the results of the study.

A TMDL is defined as the maximum quantity of a pollutant that a water body can receive and continue to meet water quality standards for designated beneficial uses. Thus, a TMDL is simply the sum of point sources and nonpoint sources in a watershed. A TMDL can be represented in a simple equation as follows:

$$\begin{aligned} \text{TMDL} = {} & \Sigma \text{ Wasteload Allocation (WLA; Point Sources)} \\ & + \Sigma \text{ Load Allocation (LA; nonpoint sources)} \\ & + \text{Margin of Safety (MOS)} \end{aligned}$$

The Wasteload Allocation (WLA) is the sum of the loads from all point sources and the Load Allocation (LA) is the sum of the load from all nonpoint sources. The Margin of Safety (MOS) represents an allocation to account for variability in environmental data sets and uncertainty in the assessment of the system. Other factors that must be addressed in a TMDL include seasonal variation, future growth, critical conditions, and stakeholder participation.

This TMDL report provides WLAs, LAs and MOS needed to achieve the state standard for each parameter in each of the lakes in this study proposed to be on the impaired waters list.

1.4 IMPAIRMENT SUMMARY

This report addresses four draft 2014 lake impairments in the City of Eagan. The MPCA's projected schedule for TMDL completions, as indicated on Minnesota's 303(d) impaired waters list (as noted in Table 1.1), implicitly reflects Minnesota's priority ranking of this TMDL. Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the water body; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

Table 1.1. Proposed lake impairments addressed in this TMDL.

Lake ID	Name	Year Listed	Priority
19-0066	Carlson[1]	2014	2016
19-0077	Fitz[2]	2014	2016
19-0064	Holz[2]	2014	2016
19-0055	LeMay	2014	2016

[1] The state incorrectly refers to this lake as Quigley; a name change to Carlson is underway.

[2] The state refers to these lakes as Unknown

The report also addresses eight lakes that are not considered impaired. These lakes were evaluated for protection (Table 1.2).

Table 1.2. Lakes assessed for protection in this study.

Lake ID	Name
19-0061	Bald
19-0259	Bur Oaks
19-0068	Cliff
19-0062	Hay
19-0053	LP-30
19-0136	North
19-0056	O'Leary[1]
19-0155	Quigley[1, 2]

[1] Determined to be a wetland and not a shallow lake.

[2] The state incorrectly refers to this lake as Carlson; a name change to Quigley is underway.

1.5 BENEFICIAL USE CLASSIFICATIONS

This TMDL report addresses exceedances of the state standards for nutrients in four lakes in the City of Eagan. A discussion of beneficial water use classes in Minnesota and the standards for those classes is provided in order to define the regulatory context and explain the rationale behind the environmental result of the TMDL. All waters of Minnesota are assigned classes based on their suitability for the following beneficial uses (Minn. Rules Ch. 7050.0140 and 7050.0220):

1. Domestic consumption
2. Aquatic life and recreation
3. Industrial consumption
4. Agriculture and wildlife
5. Aesthetic enjoyment and navigation
6. Other uses
7. Limited resources value

After each water body is assigned a beneficial use, they are also assigned a subcategory if applicable. So, for the aquatic life beneficial use, the life category that is targeted for protection is one of the classes below. This is important since each of these categories has different requirements to support a healthy biological community. For example, cold water species such as trout are more sensitive to dissolved oxygen concentrations and therefore require higher minimum dissolved oxygen concentrations.

A. Cold water sport fish (trout waters), also protected for drinking water
B. Cool and warm water sport fish, also protected for drinking water
C. Cool and warm water sport fish, indigenous aquatic life, and wetlands, and
D. Limited resource value waters

"2B" water is intended to protect cool and warm water fisheries, while"2C" water is intended to protect indigenous fish and associated aquatic communities, and a "3C" classification protects water for industrial use and cooling. All Class 2 surface waters are also protected for industrial, agricultural, aesthetics, navigation, and other uses (Classes 3, 4, 5, and 6, respectively). Minn. Rules Ch. 7050 contains general provisions, definitions of water use classes, specific standards of quality and purity for classified waters of the state, and the general and specific standards for point source dischargers to waters of the state.

The designated beneficial use for Class 2 waters (the most protective use class in the project area) is as follows (Minn. Rules Ch. 7050.0140):

> **Class 2 waters, aquatic life and recreation**. Aquatic life includes all waters of the state which do or may support fish, other aquatic life, bathing, boating, or other recreational purposes, and where quality control is or may be necessary to protect aquatic or terrestrial life or their habitats, or the public health, safety, or welfare.

All of the lakes in this report are "2B" waters.

1.6 WATER QUALITY STANDARDS FOR DESIGNATED USES

The criteria used for determining stream and lake impairments are outlined in the MPCA document Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment – 305(b) Report and 303(d) List, April 2014. The applicable water body classifications and water quality standards are specified in Minnesota Rules Chapter 7050. Minnesota Rules Chapter 7050.0470 lists water body classifications and Chapter 7050.0222 (subp. 5) lists applicable water quality standards for Minnesota water bodies.

Under Minnesota Rules 7050.0150 and 7050.0222, Subp. 4, the lakes addressed in this study are within the North Central Hardwood Forest ecoregion, with numeric targets dependent on depth as listed in Table 1.3. Therefore, this TMDL presents load and wasteload allocations and estimated load reductions, assuming an end point of ≤60 µg/L and ≤40 µg/L total phosphorus for shallow lakes and deep lakes, respectively.

Table 1.3. Numeric standards for lakes in the North Central Hardwood Forest Ecoregion.

Parameters	Shallow[1] Lake Standard	Deep Lake Standard
Total Phosphorus (µg/L)	≤60	≤40
Chlorophyll-*a* (µg/L)	≤20	≤14
Secchi disk transparency (meters)	≥1.0	≥1.4

[1] Shallow lakes are defined as having a maximum depth of 15 feet or less, or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone).

In addition to meeting a respective phosphorus limit of 60 µg/L and 40 µg/L for shallow and deep lakes, chlorophyll-*a* and Secchi depth standards must also be met. In developing the lake nutrient standards for Minnesota lakes (Minn. Rule 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (Heiskary and Wilson, 2005). Clear relationships were established between total phosphorus as the causal factor and chlorophyll-*a* and Secchi disk as the response variables. Based on these relationships it is expected that by meeting the phosphorus targets of 60 µg/L and 40 mg/ for shallow and deep lakes, the chlorophyll-*a* and Secchi standards will likewise be met. According to the WQWMP, the city's goals for lakes are consistent with the NCHF standards. Thus, an Eagan lake does not meet its intended condition if the TP and either the chlorophyll-*a* or the Secchi depth standard is exceeded.

1.7 DETERMINATION OF IMPAIRMENT

The criteria used for determining impairments are outlined in the MPCA document Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment – 305(b) Report and 303(d) List, April 2014. The applicable water body classifications and water quality standards are specified in MR Chapter 7050. 0407 and MR 7050.2222 (5), respectively.

As shown in Table 1.4, both Bald and Cliff lakes were categorized as having insufficient information to determine their impairment status at the time of their assessment. This was done because the lakes do not meet the total phosphorus portion of the standard, but do meet the chlorophyll-a and Secchi disk portions. The City opted to be proactive and reduce loading to meet the total phosphorus targets as a voluntary protection measure to better assure the lakes do not become impaired. A nutrient budget and targets to meet the State water quality standards for both of these lakes are included in this report. The targets are nonbinding until the point these lakes are assessed as impaired and a TMDL is required.

Table 1.4. Lake impairment status for the 12 lakes in this study.

Lake	Lake ID	Type	Status[1]
Bald	19-0061-00	Shallow	IF
Bur Oaks	19-0259-00	Shallow	FS
Carlson	19-0066-00	Deep	NS
Cliff	19-0068-00	Shallow	IF
Fitz	19-0077-00	Shallow	NS
Hay	19-0062-00	Shallow	FS
Holz	19-0064-00	Shallow	NS
LP-30	19-0053-00	Shallow	FS
LeMay	19-0055-00	Shallow	NS
North	19-0136-00	Shallow	FS
O'Leary	19-0056-00	Wetland	Determined to be a wetland.
Quigley	19-0155-00	Wetland	Determined to be a wetland.

[1] NS-Not supporting; FS-Fully supporting; IF-Insufficient information

2.0 Watershed and Lake Characterization

2.1 OVERVIEW

All lakes in this study are completely or partially contained within the municipal boundaries of Eagan, MN (Figure 2.1). Fitz, LP-30, and Bur Oaks Lake have drainage areas that extend into neighboring Inver Grover Heights. Study lakes are considered relatively small (area <15 acres) when compared to lakes typically used for recreation in the State of Minnesota. Historical aerial photos of the lakes are included in Appendix A.

2.2 HISTORY OF THE LAKES AND THEIR WATERSHEDS

2.2.1 Fitz, Holz, LP-30, and Hay Lakes

Four lakes in the southeast area of the City of Eagan include Fitz, Holz, LP-30, and Hay (Figure 2.2). LP-30 receives some drainage from the City of Inver Grove Heights and ultimately drains to Hay Lake (total drainage area of 327 acres). The outlet of LP-30 drains through a 12-inch diameter pipe to a wetland before flowing into Hay Lake. The southern portion of the Hay Lake watershed includes two upstream lake watersheds (Fitz and Holz) that have a combined size of 318 acres. The Fitz Lake outlet is connected to a 12-inch storm sewer that drains directly to Holz Lake. Holz Lake drains to a small wetland through a 12-in storm sewer, which then drains directly to Hay Lake.

This group of lakes drains stormwater runoff from approximately 808 acres to Thomas Lake which ultimately drains to the Minnesota River through Blackhawk Lake. Lake management plans were previously developed for Thomas and Blackhawk Lakes (Wenck 2012).

2.2.2 Quigley and Carlson Lakes

For purposes of applying water quality standards and making 303(d) assessments, in 2014 the MPCA determined Quigley to be a wetland rather than a shallow lake. Quigley and Carlson lakes also drain to Blackhawk Lake although Quigley Lake drains first to Carlson Lake. Carlson Lake is the only deep lake in this study and receives drainage from 664 acres. The names of these lakes may be confused because historically they have been locally called “Quigley Lake” for the shallow northeastern basin and “Carlson Lake” for the deep southwest basin. The State of Minnesota officially refers to these lakes oppositely: Carlson as the shallow basin and Quigley as the deep basin. This report follows the local naming convention for the lakes. An effort to officially change the names is underway.

This watershed was divided into four subwatersheds to help characterize general flow patterns. The four sub-watersheds, Carlson-North, Carlson-South, Carlson-Direct, and Quigley-Direct, generally flow from east to west. The Quigley Lake watershed consists of only one direct subwatershed that drains by gravity directly to Carlson Lake. The Carlson-North subwatershed outlet flows directly to Carlson Lake, while the Carlson-South subwatershed outlet to Carlson Lake is controlled by the Oak Park Chase lift station (Figure 2.3). The outlet of Carlson Lake is controlled by the Carlson lift station (Figure 2.3).

2.2.3 Cliff and Bald Lakes

Cliff Lake is in the southwest part of the city and receives drainage from 619 acres. The lake is just west of Highway 35E while its drainage area is mostly east of Highway 35E. The general flow direction in the Cliff Lake watershed is from south to north with the Cliff-East and Cliff-South watersheds contributing 70% of the total discharge that reaches Cliff Lake. Prior to discharging, the Cliff-South, Cliff-West, and Cliff-East watersheds are routed to a MnDOT stormwater pond directly upstream of the lake (Figure 2.4).

Cliff Lake has a unique outlet structure that acts as a skimmer with a higher overflow outlet above the normal outlet (Figure 2.5). The structure has clogged in the past, raising the overall water level of the lake. Additionally, corrugated metal piling was placed in front of the skimmer to prevent trash and debris from getting into the structure, raising the water level from one-half foot to a foot. This obstruction was removed in 2013, and water levels are expected to be fairly stable in the future. However, clogging by trash and debris may continue to cause some fluctuations in water elevations.

Bald Lake has a relatively small watershed that covers 103 acres with no upstream lakes. For this study, the watershed has been split into three sub-watersheds, including Bald-Southeast, Bald-Northwest, and Bald-Direct areas. The general flow direction is from west to east with the largest water yield coming from Bald-Northwest (44%).

2.2.4 Bur Oaks and North Lakes

Bur Oaks and North lakes are in the northeastern part of the city that is characterized by commercial and industrial development. Bur Oaks Lake, consisting of two distinct shallow lobes separated by a small channel, drains into North Lake and eventually to the Minnesota River. The Bur Oaks Lake watershed covers approximately 944 acres and has three primary watersheds. The Bur Oaks-North watershed drains to the Highway 55 lift station that pumps stormwater directly to Bur Oaks Lake. The Bur Oaks-South watershed drains north through a heavily industrial area via gravity drainage directly to Bur Oaks Lake. The Bur Oaks Park lift station is located at the lake's outlet and pumps stormwater to North Lake via a 12-inch sewer main (Figure 2.6).

The North Lake watershed covers approximately 1,396 acres that includes the drainage area of the Bur Oaks Lake watershed. Of the annual water yield to North Lake, 55% is from the Bur Oaks watershed. The North Lake watershed has a relatively large direct-drainage area and two smaller upstream watersheds that have a relatively small water yield to North Lake.

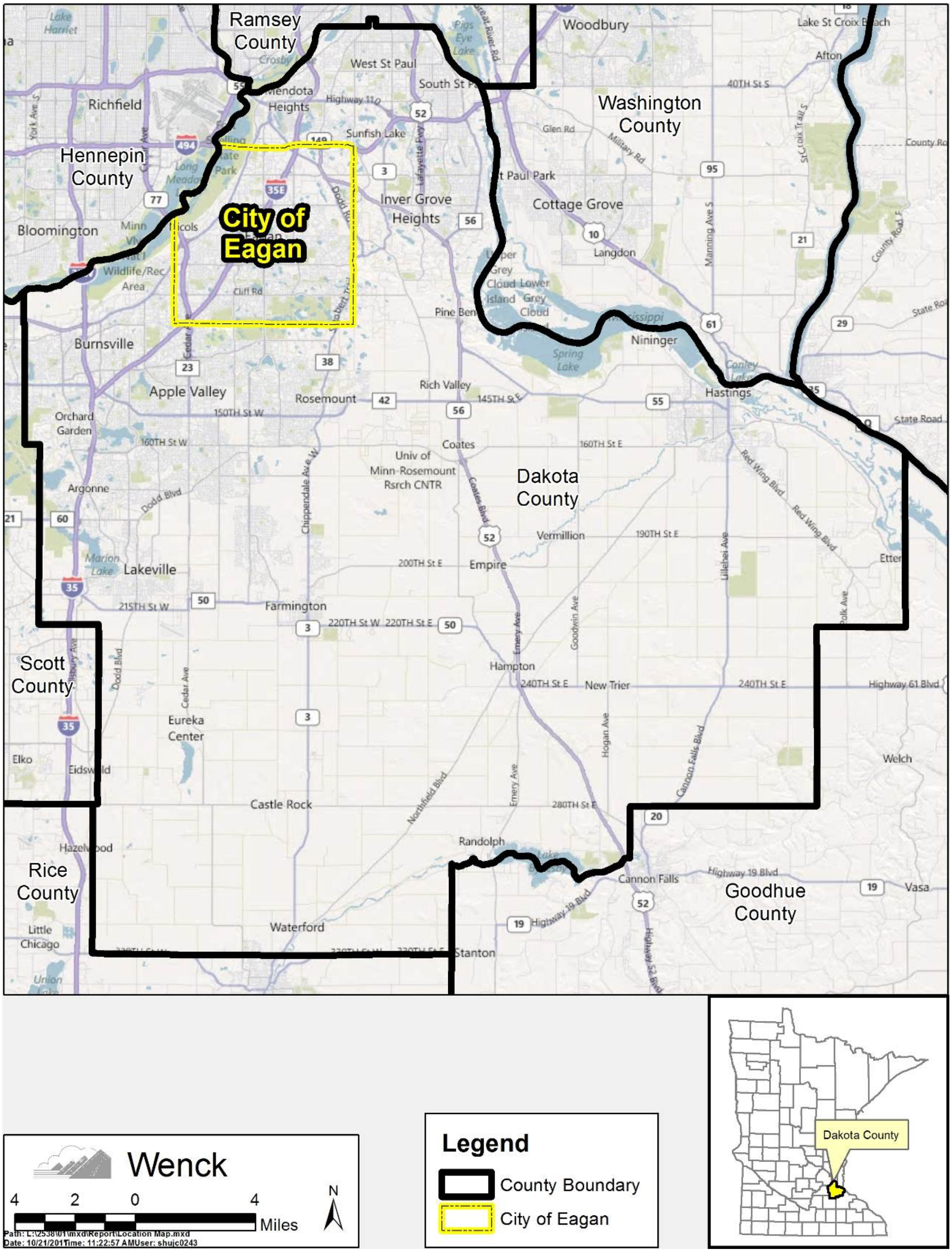

Figure 2.1. City of Eagan and Dakota County boundaries.

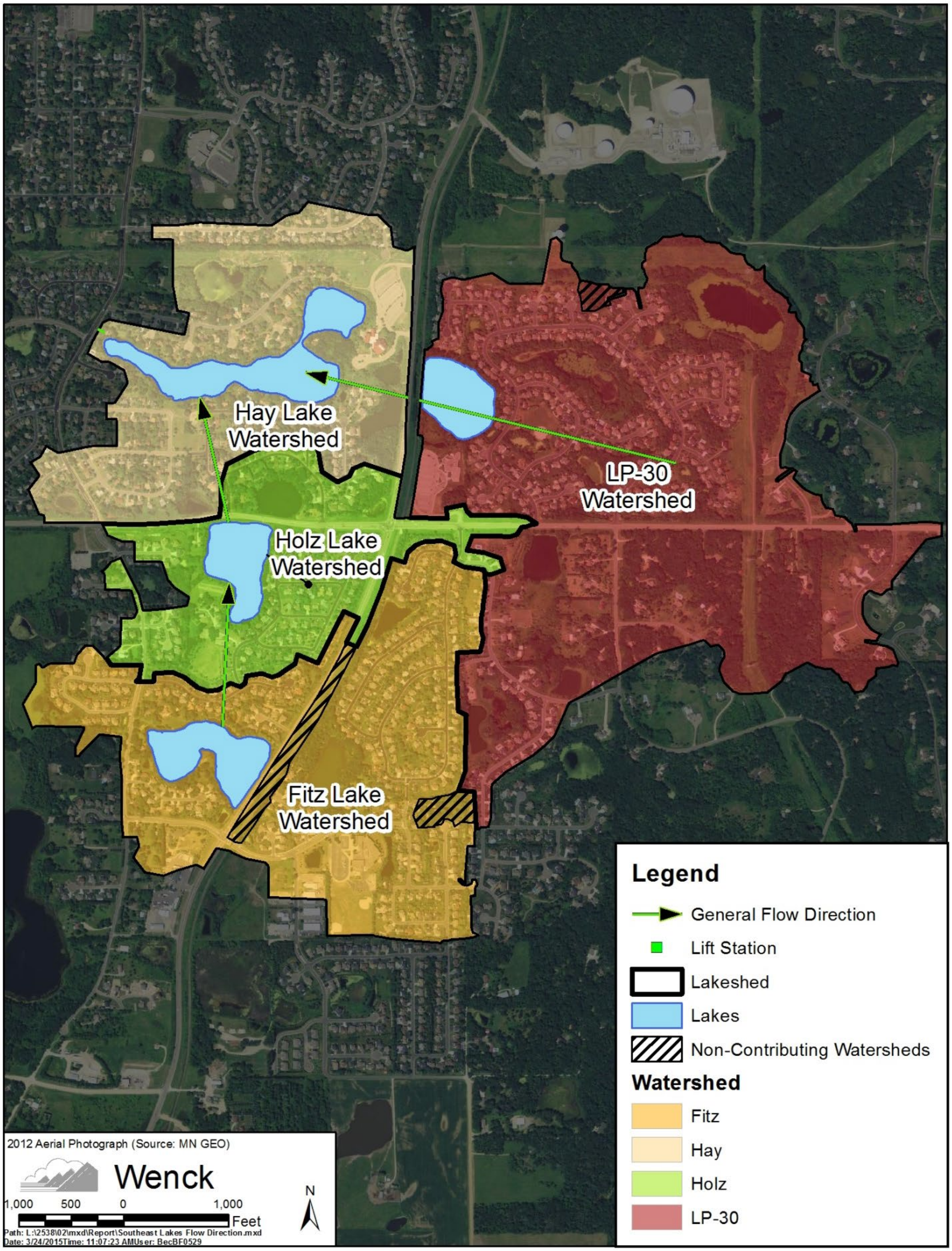

Figure 2.2. Southeast lakesheds and general flow direction.

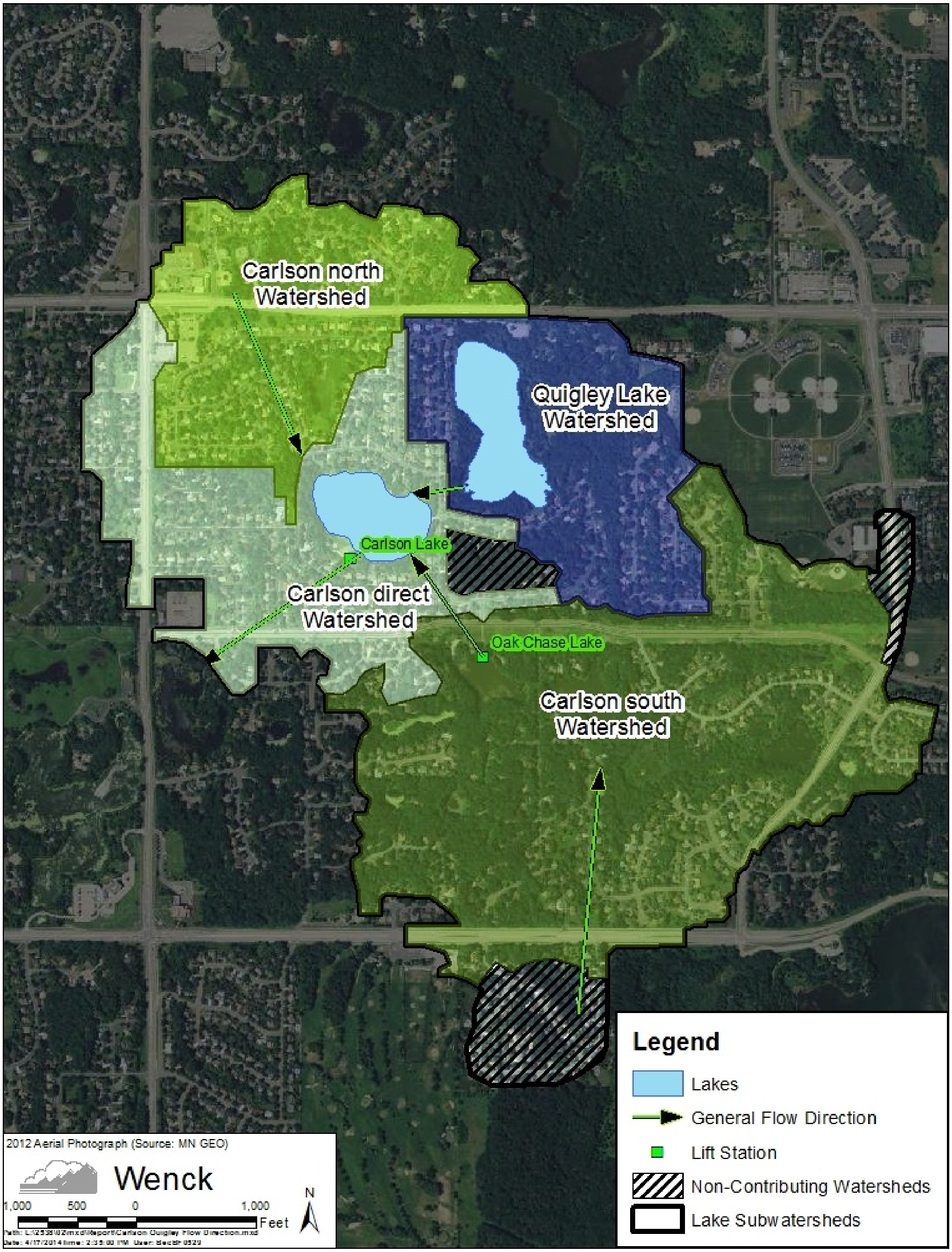

Figure 2.3. Carlson and Quigley subwatersheds and general flow direction.

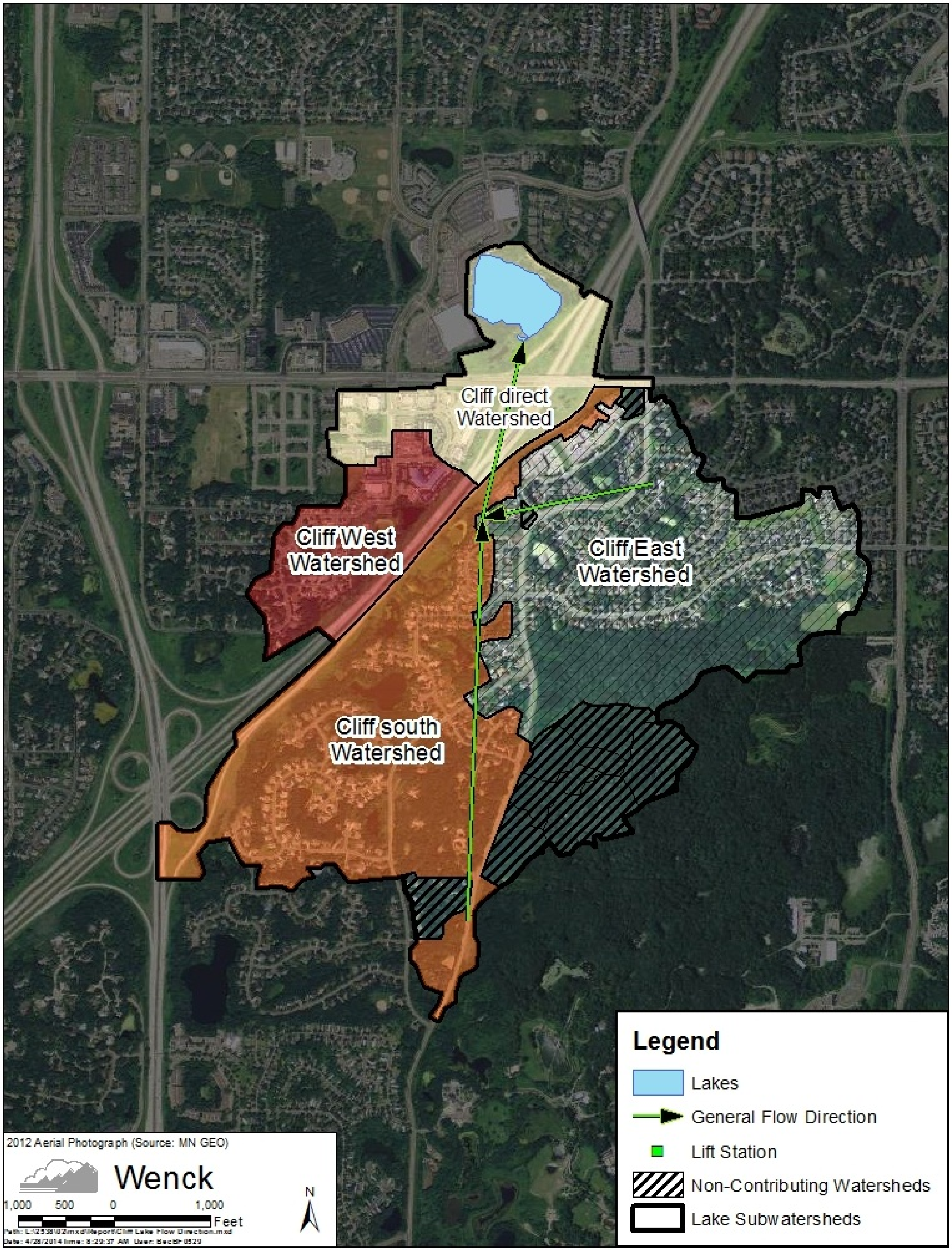

Figure 2.4. Cliff subwatersheds and general flow direction.

Figure 2.5. Cliff Lake outlet structure.

2.2.5 O'Leary and LeMay Lakes

O'Leary and LeMay lakes are in the northwest part of the city, with Interstate 35E bisecting the LeMay Lake watershed. The LeMay Lake watershed is the largest watershed of this study, with an approximate area of 1,279 acres. It drains the relatively small O'Leary watershed that is upstream, and which supplies only 3% of its total annual water yield. The LeMay watershed is also the most complex of this study. The O'Leary watershed gravity drains to the LeMay-Southeast watershed, which flows north to the Yankee lift station (Figure 2.7). The Yankee lift station then pumps water to a series of MnDOT ponds located near the intersection of Yankee Doodle Road and Interstate 35E. The final MnDOT stormwater pond in the series flows directly to LeMay Lake through a 36-inch stormwater pipe. The Knox lift station located in the northern region of the LeMay-Northeast watershed pumps stormwater south into a large pond, which drains to the Lexington lift station. The Lexington lift station subsequently pumps water from the LeMay-Northeast subwatershed to a MnDOT pond, which then drains directly to LeMay Lake.

O'Leary Lake drains approximately 51 acres to LeMay Lake, which is only a small portion of the LeMay Lake watershed (4%). LeMay Lake also receives stormwater from a large commercial and industrial area, including the Eagan Promenade Mall and a large industrial area to the north.

For purposes of applying water quality standards and making 303(d) assessments, the MPCA has determined O'Leary to be a wetland rather than a shallow lake.

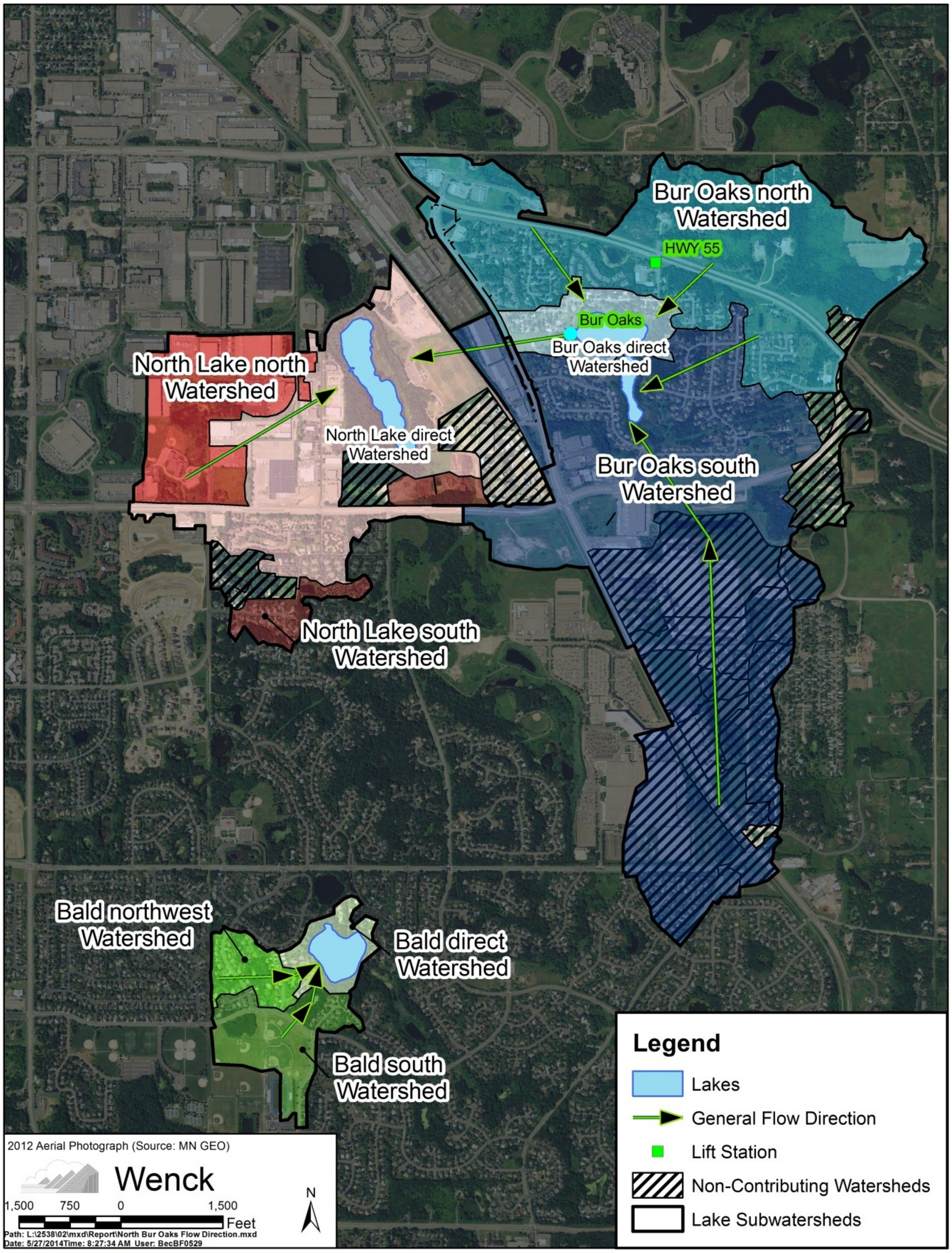

Figure 2.6. Bur Oaks and North lakes subwatersheds and general flow direction.

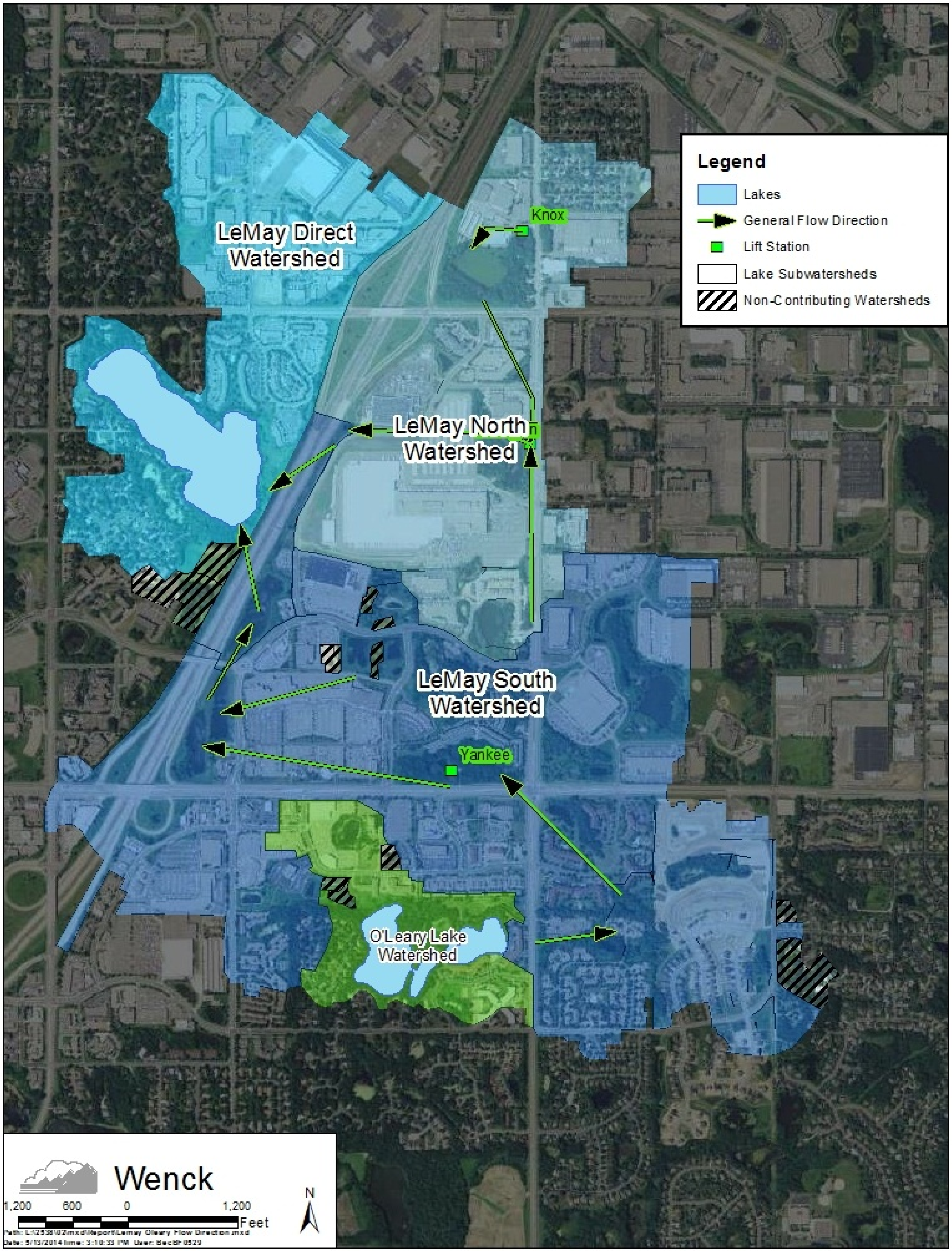

Figure 2.7. LeMay and O'Leary subwatersheds and general flow direction.

2.3 LAND USE

The City of Eagan provided land use information from its GIS parcel dataset, which was supplemented with Minnesota Department of Transportation (MnDOT) right-of-way (ROW) land use files. Watershed areas outside of the city were characterized using the 2010 Metropolitan Council land use coverage. Generally, land uses in the northern watersheds (LeMay, O'Leary, North, and Bur Oaks) and in the southern watersheds (Bald, Cliff, Carlson, Quigley, Hay, Holz, Fitz, and LP-30) are similar and shown in Figure 2.8.

The land use in the southern lakes area is predominantly residential (>45%) with the remaining area comprised of open area (parks) and rights-of-way (Table 2.1). The Cliff Lake watershed has large areas of impervious surfaces with a section of Interstate 35E and a commercial area on the northwest side of the lake. The remaining lakes' watersheds are mostly residential neighborhoods with a few parks.

Land use in the northern watersheds is predominantly retail and industrial (25% to 49%) areas with the remaining area comprised of residential parcels. Other than Bald Lake, these watersheds are characterized by large areas of impervious surfaces including commercial parking areas, warehouses, and malls. Both Bur Oaks and North Lake receive drainage from highly impervious industrial areas of the city. LeMay Lake receives drainage from dense commercial areas in the eastern watershed and highly impervious industrial areas to the north. Bald Lake has the most lightly used land use, with a large area of its watershed in park lands.

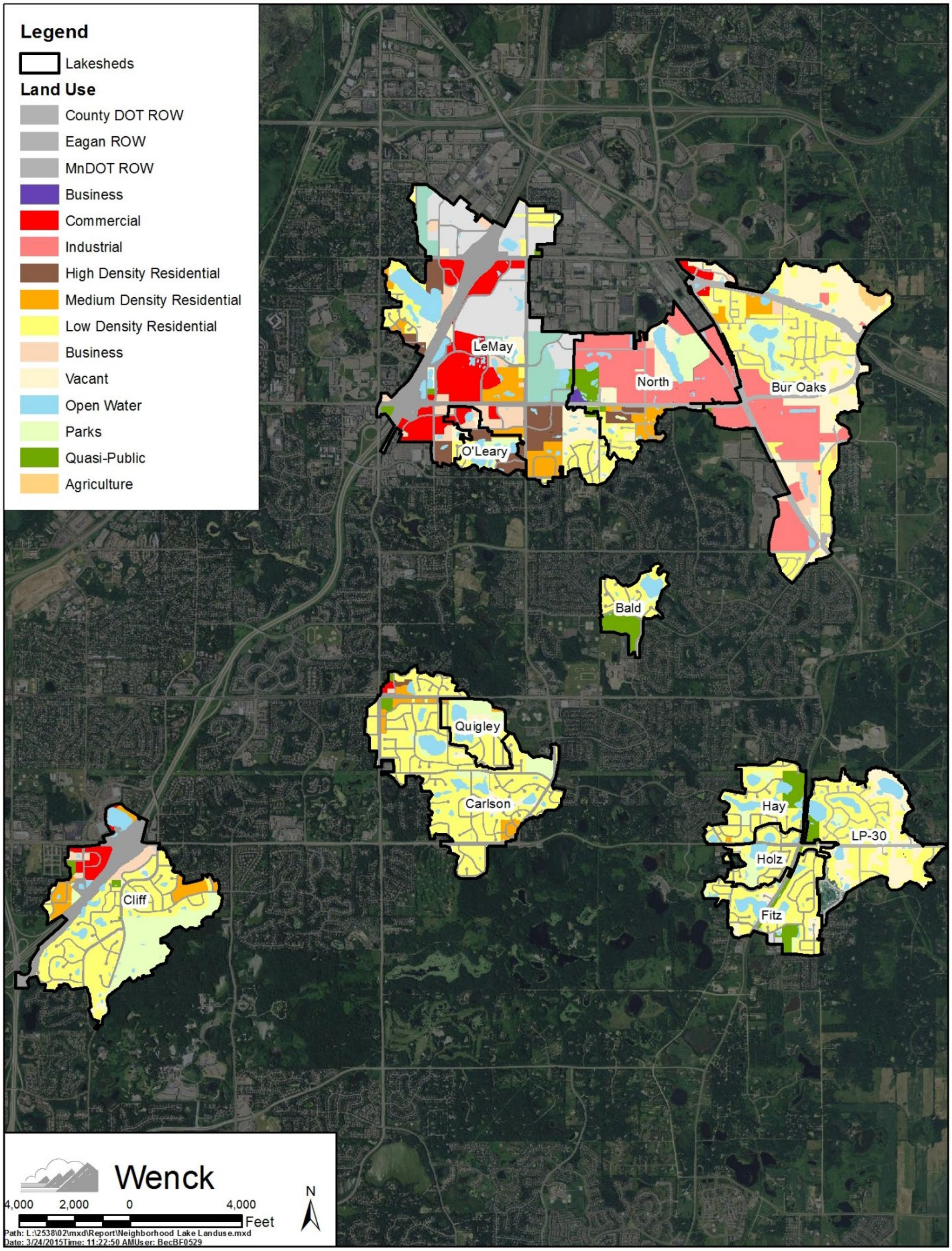

Figure 2.8. Land use within study watersheds.

Table 2.1. Land use percentage by type of use.

Lake	Area (Acres)	Right of Way	Residential	Water	Open Area	Retail/ Industrial	Agricultural
Bald	103	13%	46%	11%	30%	0%	0%
Bur Oaks	944	15%	52%	3%	4%	25%	2%
Carlson	664	20%	64%	8%	8%	1%	0%
Cliff	619	25%	43%	5%	19%	7%	0%
Fitz	210	17%	60%	11%	10%	2%	0%
Hay	809	15%	51%	18%	16%	0%	0%
Holz	318	24%	52%	12%	12%	0%	0%
LeMay	1,279	21%	27%	8%	2%	42%	0%
LP-30	325	0%	85%	10%	4%	0%	0%
North	1,396	13%	42%	4%	6%	33%	1%
O'Leary	88	7%	57%	21%	13%	2%	0
Quigley	105	10%	58%	15%	18%	0%	0%

[1] Watershed area includes upstream lakes.

2.4 SOILS AND GEOLOGY

Topography in the watersheds is dominated by steep and rolling hills with depressions that are filled with lakes and wetlands. These features are composed of glacial till and outwash from the advance and retreat of glacial lobes during the most recent ice age. Water tables throughout the watershed may be at or near the surface in depressional areas, and 10 ft. or deeper in the hills and higher elevations.

The Kingsley and Mahtomedi series are the most common soils types in the watersheds. Both are characterized by very deep, well drained, moderate to rapidly permeable soil layers. These soils were formed in loamy glacial till and sandy outwash on glacial moraines.

2.5 GROUNDWATER

The Dakota County Geologic Atlas describes the quaternary geology (the most recent geological period) of northern Dakota County as primarily sand and gravel with laterally discontinuous till, clay and silt layers that is typical of areas exhibiting glacial outwash. First encountered bedrock is observed at a depth between 350 to 800 feet below the surface in the study area.

Groundwater in the City of Eagan generally flows to the west towards the Minnesota River. However, groundwater in the eastern portion of the City of Eagan tends to flow east towards the Mississippi River. The break in groundwater flow direction generally follows surficial topography. There are isolated instances of thin discontinuous aquatard lenses that impede the vertical movement of recharge to regional groundwater. In the study area, these lenses were generally less than 40-ft below the surface and consist of clay till and silty-clay layers above bedrock.

Surface water bodies can interact with groundwater in a variety of ways dependent on the hydro-geologic connections, the relative elevations of the groundwater compared to the Ordinary High Water

Level (OHW) elevation, and the average depth and the maximum depth of each individual lake in the study area.

The groundwater elevation data for the study area were collected from the County Well Index (CWI). This information was used to infer the relationship between surface water features and groundwater. However, the static groundwater elevations reported on the CWI logs were observed at the time of drilling and may reflect seasonal highs, lows, or other temporal changes in groundwater elevations. Therefore, all inferences are interpreted to be a general condition. The interpretations may not describe the complete groundwater and surface water interaction, or how they may change during dry or wet periods.

Driller logs collected from the CWI indicate that material below the lake bottoms of the study area is moderately to highly conductive. Lake OHW elevations compared to groundwater elevations measured in nearby wells show that the lakes in the study area are generally losing and contribute to groundwater. OHW elevations are generally 50 to 100 feet higher than static groundwater elevations, with the exception of North, Bur Oaks, and Cliff lakes.

North and Bur Oaks Lakes

Groundwater elevations in more recently drilled wells near North and Bur Oaks lakes are approximately equal to their respective OHW elevations. This could reflect a seasonal high groundwater period where groundwater could influence North and Bur Oaks lakes (as a flow through lake or connected to groundwater lake). Well Driller logs also indicate that a 10- to 15-foot thick layer of clay is present a few feet below the lake bottoms. The clay layer may contribute to mounding effects, which explains higher groundwater levels in the area as compared to other nearby areas. As you move away from North and Bur Oaks lakes, the clay layer is not present, and groundwater elevations are approximately 30 to 50 feet below OHW elevations.

Cliff Lake

Cliff Lake is located in one of the aforementioned isolated instances of a thin discontinuous lens that impedes the vertical movement of recharge to regional groundwater. Cliff Lake has little connectivity to groundwater based on well driller logs that indicate soils to the east are clay and soils to the west are silty sands, which limit both vertical and horizontal movement of surficial recharge. Even though groundwater elevations near Cliff Lake are recorded as approximately equal to the OHW elevation, those elevations are not reflective of regional groundwater elevations. Surface hydrology plays a dominant role in Cliff Lake's water balance.

2.6 CLIMATOLOGICAL SUMMARY

Annual precipitation averaged 30.3 inches between 1990 and 2012 (Figure 2.9). Average annual snowfall is approximately 50 inches, with the most severe melt runoff conditions usually occurring in March and early April. Lakes in the Minneapolis-St. Paul metropolitan area average approximately 132 days of ice cover per year, with average freeze and thaw dates occurring the last week of November and the first week of April, respectively. The average date of the last below-freezing temperature in the spring is April 27, and the average date of the first below-freezing temperature in the fall is October 2, yielding an average growing season of 157 days.

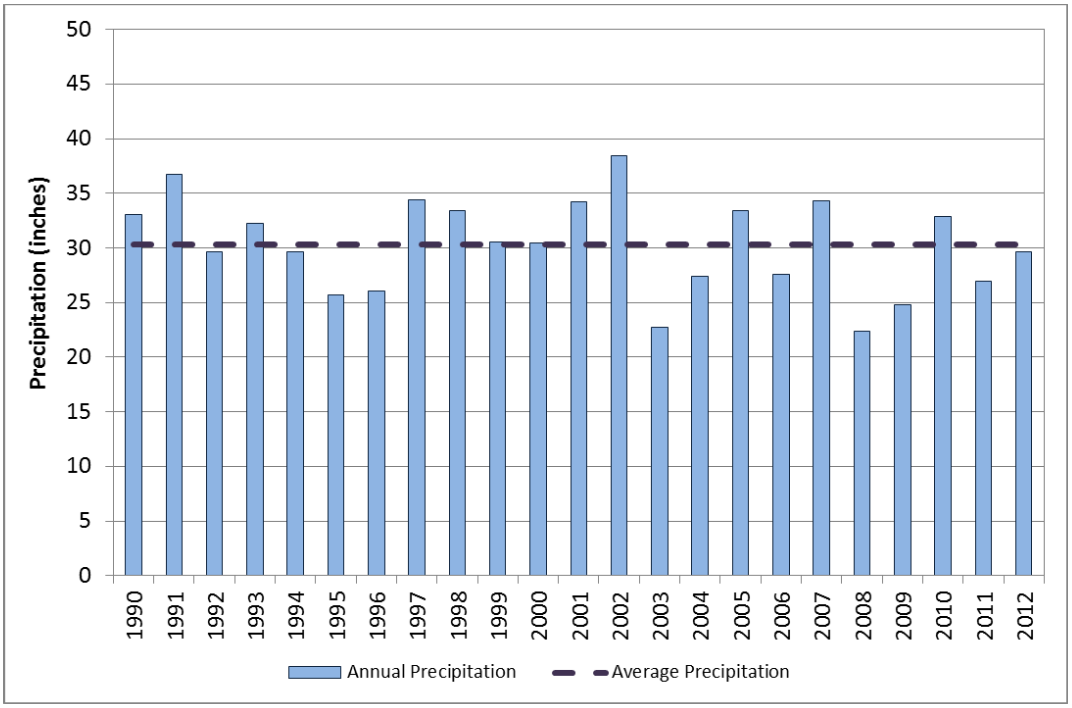

Figure 2.9. Annual and average precipitation recorded at the Minneapolis/St. Paul International Airport.

2.7 LAKE MORPHOMETRY

The majority (11 of 12 lakes) of the lakes in this study are small (9 to 32 acres) and shallow (maximum depth less than 15 feet; Table 2.2; Appendix B). The MPCA defines shallow lakes as enclosed basins with maximum depths less than 15 feet or where 80% or more of the surface area may support emerged or submerged aquatic vegetation (littoral zone). Carlson Lake is the only one that meets the criteria for deep lakes set by the MPCA (Table 2.2). However, Carlson Lake's maximum depth is only 19 feet and the littoral area is 74% of the lake. So, Carlson likely acts more like a shallow lake where the vegetation and fish play a large role in water quality. All of the lakes should support submerged aquatic vegetation over the majority of the lake area.

Residence time can be an important indicator of how sensitive a lake will be to changes in runoff water quality. Generally, lakes with small watersheds such as Bald, Quigley, or LP-30 have residence times greater than a year and lakes with large watersheds (>200 acres) have residence times less than a year. Lakes with the shorter residence times are more sensitive to changes in runoff water quality. Six of the lakes have residence times less than 0.5 years, suggesting they will be quite sensitive to stormwater water quality.

Table 2.2 Lake morphometry for all lakes in the study area.

Lake Name	Surface Area	Average Depth	Maximum Depth	Lake Volume	Residence Time	Littoral Area	Depth Class	Total Drainage Area[1]
Units	**acre**	**feet**	**feet**	**ac-ft**	**years**	**%**	**--**	**acre**
Bald	10	6	9	60	2.5	100%	Shallow	103
Bur Oaks	10.8	2.4	9	26	0.1	100%	Shallow	944
Carlson	12	8.4	19	100	0.5	74%	Deep	664
Cliff	11.8	2.8	7	33	0.2	100%	Shallow	619
Fitz	12.3	5.5	11	68	1.3	100%	Shallow	210
Hay	22	3.9	9	82	0.5	100%	Shallow	809
Holz	10	5.9	10	59	0.7	100%	Shallow	318
LeMay	32	5.3	16	168	0.3	99%	Shallow	1,279
LP-30	9	10.3	14	94	1.6	98%	Shallow	325
North	16	4.8	11	77	0.1	100%	Shallow	1,396
O'Leary	9.3	2.9	10	27	1.5	100%	Wetland[2]	88
Quigley	15	3.1	6	48	1.8	100%	Wetland[2]	105

[1] Areas include upstream drainage area

[2] Considered by MPCA a wetland not a lake for purposes of State of Minnesota water quality assessments and 303(d) list determinations.

2.8 WATER QUALITY

Water quality in Minnesota lakes is often evaluated using three associated parameters: total phosphorus, chlorophyll-a, and Secchi depth. Total phosphorus is typically the limiting nutrient in Minnesota's lakes, meaning that algal growth will increase with increases in phosphorus. However, there are cases where phosphorus is widely abundant and the lake becomes limited by nitrogen or light availability. Chlorophyll-a is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Since chlorophyll-*a* is a simple measurement, it is often used to evaluate algal abundance rather than expensive cell counts. Secchi depth is a physical measurement of water clarity, measured by lowering a black and white disk until it can no longer be seen from the surface. Increasing Secchi depths indicate less light refracting particulates in the water column and increasing water quality. Conversely, rising total phosphorus and chlorophyll-a concentrations point to decreasing water quality and thus lowering water clarity. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

Lake water quality samples were routinely collected by the City of Eagan at each of the 12 lakes throughout the growing season since 1991. Lake water quality varies depending on factors such as annual precipitation, annual temperature, biotic population dynamics, and other factors. However, annual summer averages from 2000 to 2012 (depending on annual data availability) were averaged to assess the general water quality of each lake (Table 2.3). Of the 12 lakes in this study Hay, LP-30, Bur Oaks, and North lakes typically have the best water quality while Fitz, Holz, and LeMay typically have the worst water quality.

Water quality data for each year are presented in Appendix C.

Table 2.3. Shallow and deep lake growing season averages for water quality parameters.

			In-Lake "Average" Condition (Calculated June - September)		
Lake Name	**Proposed Impairment (2014)**	**"Average" Condition Calculation Years**	**TP Concentration (µg/L)**	**Chl-*a* Concentration (µg/L)**	**Secchi Depth (m)**
Water Quality Standard for Shallow Lakes			**60.0**	**20.0**	**1.0**
Bald	No	2001-2010; 2012	75.0	26.9	1.2
Bur Oaks	No	2003-2010; 2012	41.9	6.9	0.7
Cliff	No	2002; 2005-2010; 2012	112.7	46.1	1.0
Fitz	Yes	2004-2009; 2012	105.0	57.2	0.6
Hay	No	2000-2004; 2005-2010; 2012	31.3	8.5	1.7
Holz	Yes	2001; 2003; 2005; 2007; 2009; 2012	72.5	24.8	1.5
LeMay	Yes	2000-2010; 2012	76.2	25.2	1.5
LP-30	No	2005; 2009; 2012	34.3	11.7	1.6
North	No	2003; 2005-2006; 2009; 2012	47.0	17.6	2.0
O'Leary	Wetland[1]	2005-2006; 2008; 2010; 2012	76.0	25.8	1.0
Quigley	Wetland[1]	2002; 2005-2007; 2010	74.8	45.8	0.9
Water Quality Standard for Deep Lakes			**40.0**	**14.0**	**1.4**
Carlson	Yes	2000-2010; 2012	49.6	32.7	1.4

[1] Considered by MPCA a wetland not a lake for purposes of State of Minnesota water quality assessments and 303(d) list determinations. Because wetlands do not have TP, Chl-a or Secchi standards, the standards for shallow lakes (which O'Leary and Quigley are close to morphometrically) were applied in this project as a voluntary target for improving water quality.

2.9 SHALLOW LAKE ECOLOGY

2.9.1 General Description

Shallow lakes are ecologically different from deep lakes. Compared to deep lakes, shallow lakes have a greater proportion of sediment area to lake volume, allowing potentially larger sediment contributions to nutrient loads and higher potential sediment resuspension that can decrease water clarity. Biological organisms also play a greater role in maintaining water quality. Rough fish, especially carp, can uproot submerged aquatic vegetation and stir up sediment. Submerged aquatic vegetation stabilizes the sediment, reducing the amount that can be resuspended and cloud water clarity. Submerged aquatic vegetation also provides refugia for zooplankton, a group of small crustaceans that consumes algae.

All of these interactions in shallow lakes occur within a theoretical paradigm of two alternative stable states: a clear water state and a turbid water state (Scheffer 2004). The clear water state is characterized by a robust and diverse submerged aquatic vegetation community, balanced fish community and large daphnia (zooplankton that are very effective at consuming algae). Alternatively, the turbid water state typically lacks submerged aquatic vegetation, is dominated by rough fish, and is characterized by both sediment resuspension and algal productivity. The state in which the lake persists depends on the biological community as well as the nutrient conditions in the lake. Therefore, lake management must focus on the biological community as well as the water quality of the lake.

The following five-step process for restoring shallow lakes that (Moss et al. 1996) was developed in Europe is also applicable here in the United States:

- Forward “switch” detection and removal
- External and internal nutrient control
- Biomanipulation (reverse “switch”)
- Plant establishment
- Stabilizing and managing restored system

The first step refers to identifying and eliminating those factors, also known as “switches,” that are driving the lake into a turbid water state. These can include high nutrient loads, invasive species such as carp and Curly-leaf pondweed, altered hydrology, and direct physical impacts such as plant removal. Once the switches have been eliminated, an acceptable nutrient load must be established. After the first two steps, the lake is likely to remain in the turbid water state even though conditions have improved, and it must be forced back into the clear lake state by manipulating its biology (also known as biomanipulation). Biomanipulation typically includes whole lake drawdown and fish removal. Once the submerged aquatic vegetation has been established, management will focus on stabilizing the lake in the clear lake state (steps 4 and 5).

2.10 FISHERIES AND AQUATIC VEGETATION

The biological conditions (fish, plants, zooplankton, and invertebrates) in shallow lakes play a critical role in maintaining water quality. The balance between top predators and their prey (panfish, minnows) can have a large effect on the size of the cladoceran population, an effective algae grazer. Likewise, the amount and type of vegetation can affect the fish and zooplankton balance, ultimately affecting the cladocerans population. Because all the lakes are highly dependent on biological conditions, fish and vegetation data were compiled for each of the assessment lakes (Table 2.4). Blue Water Science conducted vegetation surveys on each of the lakes in the summer of 2014 (Appendix D). The City of Eagan conducts periodic fish surveys on the lakes, however not all of the lakes were surveyed when this report was completed. All Minnesota DNR files were reviewed for this study. Compiled fish data are provided in Appendix E. Fish and vegetation conditions in the lakes are summarized in Table 2.4.

2.10.1 Fisheries

Fisheries play a direct role in controlling water clarity by affecting large zooplankton grazer abundance which can have a large influence on water clarity. An overabundance of zooplankton predators such as stunted panfish or fathead minnows can lead to increased algal blooms and a potential collapse of the submerged aquatic vegetation population.

<u>Common Carp and Rough Fish</u>

Rough fish (bullheads) and common carp can have negative effects on water quality in shallow lakes. Common carp are an invasive species that can be especially destructive in shallow lakes. Carp uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments and nutrients. These activities can lead to increased nutrients in the water column, ultimately resulting in increased nuisance algal blooms.

None of the lakes have observed or surveyed carp populations at this time. However, sizeable roughfish populations exist in several of the lakes, including Bur Oaks, Hay and LeMay lakes.

Fathead Minnows

Fathead minnows are particularly effective at grazing large zooplankton grazers, which can lead to increased algal populations. Bald, O'Leary and Quigley lakes have observed large fathead minnow populations.

2.10.2 Submerged Aquatic Vegetation

Aquatic plants are beneficial to lake ecosystems, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, and stabilization of sediments. However, in high abundance and density, they limit recreation activities, such as boating and swimming, and may reduce aesthetic values. Excess nutrients in lakes can lead to non-native, invasive aquatic plants taking over a lake. Some exotics can lead to special problems in lakes. For example, under the right conditions, Eurasian watermilfoil can reduce plant biodiversity in a lake when it grows in great densities and out-competes all the other plants. Ultimately, this can lead to a shift in the fish community because these high densities favor panfish over large game fish. Species such as Curly-leaf pondweed can cause very specific problems by changing the dynamics of internal phosphorus loading. Ultimately, there is a delicate balance within the aquatic plant community in any lake ecosystem.

All of the study lakes have submerged aquatic vegetation throughout, with coverage ranging from 40 to 100% of the lake area. As is typical of urban, nutrient-enriched shallow lakes, coontail is the dominant species in all. Coontail is a native species that is tolerant of poor water quality and grows very aggressively. It is not a rooted species and sometimes grows dense enough to mat at the surface.

Curly-leaf Pondweed

Curly-leaf pondweed is an invasive, like Eurasian watermilfoil, that can easily take over a lake's aquatic macrophyte community. It presents a unique problem because it is believed to affect significantly the in-lake availability of phosphorus, contributing to the eutrophication problem. Curly-leaf pondweed begins growing in late fall, continues growing under the ice, and dies back relatively early in summer, releasing nutrients into the water column as it decomposes, possibly contributing to algal blooms. Curly-leaf pondweed can also out-compete desirable native plant species.

All of the lakes except LP-30, O'Leary, and Quigley have Curly-leaf pondweed present. Although some of the lakes have Curly-leaf over much of the lake area, none of the lakes have dense growth at any of the locations at this time. Coverage ranges from 4% to 78% of the lake area and in most of the surveys only light growth was observed. Holz Lake is dominated by Curly-leaf pondweed in the early season.

Table 2.4. Fish and vegetation data for Eagan Lake.

Lake	Recent Fish Survey Month-Year	Carp Present?	Curly-leaf Pondweed Present? (% Occurrence)	Native Plant Coverage	City operated aeration system?	Fisheries Notes	Aquatic Vegetation Notes (no Eurasian watermilfoil was observed in any lake in the 2013 plant surveys)
Bald	(2015)	--	Yes (56%)	94%	Yes	Plentiful FHMs. Stocked BLG in 2010 but no aeration until 2012-13; survival may be limited. Stocked LMB young of the year in Sept 2012. Fish survey planned in 2015.	Dominant plant species is coontail; Curly-leaf pondweed established
Bur Oaks	Sep-2010	No	Yes (22%)	100%	Yes	Frequent winter kills occurred during the 1990s; the city now aerates the lake. NOP present, LMB absent in 2010 survey; stocked LMB young of the year in spring 2013. Winterkill 2013-14; restocked with LMB and BLG in spring 2014.	Dominant plant species coontail; Curly-leaf pondweed established; filamentous algae covers 48% of lake in August
Carlson	Jul-2012	No	Yes (16%)	42%	Yes	Modest stocking of walleye, bluegill, black crappie, and largemouth bass, and channel catfish.	Dominant plant species coontail and *Elodea;* Curly-leaf pondweed established
Cliff	Sep-2011 EF Sep-2013 TN	No	Yes (78%)	100%	Yes	BLG common, LMB present. Aerator operated when needed since 2008.	Dominant plant species is coontail; Curly-leaf pondweed established
Fitz	Sep-2013	No	Yes (32%)	80%	No	All BLB in 2013 survey, no other species caught.	Dominant plant species is coontail; Curly-leaf pondweed established
Hay	2014	No	Yes (16%)	97%	Yes	Serious winterkill 2013-14 when aeration system failed. Restocked in spring 2014 with BLG (by DNR).	Dominant plant species is coontail; Curly-leaf pondweed established; Heavy growth of native vegetation in summer
Holz	Sep-2011 EF Sep-2013 TN	No	Yes (53%)	40%	Yes	Frequent winter kills occurred during the 1990s. Now aerated, eliminating fish kills. Large LMB, crappies, and smaller BLG.	Dominant plant species is coontail; Curly-leaf pondweed established
LP-30	N/A	--	No	93%	No	--	Dominant plant species is coontail; No Curly-leaf pondweed established

Table 2.4 (continued). Fish and vegetation data for each assessed lake.

Lake	Recent Fish Survey	Carp Present?	Curly-leaf Pondweed Present? (% Occurrence)	Native Plant Coverage	City operated aeration system?	Fisheries Notes	Aquatic Vegetation Notes (no Eurasian watermilfoil was observed in any lake in the 2013 plant surveys)
LeMay	2014	No	Yes (59%)	67%	Yes	Survey planned for summer 2014. At least a partial kill winter 2013-14 when aerator failed twice and was off about 1 week each time. Otherwise, LMB, smaller BLC, medium BLG and HSF. Restocked spring 2014 with LMB, BLG.	Dominant plant species is coontail; Curly-leaf pondweed established
North	2012	No	Yes (4%)	58%	No	BLC and BLG common, HSF and LMB are present.	Dominant plant species is coontail; Curly-leaf pondweed established
O'Leary	N/A	--	No	100%	No	--	Dominant plant species is coontail; Curly-leaf pondweed established
Quigley	N/A	--	No	100%	No	--	Dominant plant species is coontail and white water lilies; Curly-leaf pondweed established

LMB= Large Mouth Bass,

BLB=Black Bullhead

BLC=Black Crappie

BLG=Bluegill

FHM=Fathead Minnows

HSF=Hybrid Sunfish

NOP=Northern Pike

EF=Electrofishing

TN=Trap Net

3.0 Phosphorus Source Assessment

3.1 NUTRIENTS IN PROPOSED IMPAIRED AND PROTECTION LAKES

A key component to developing a nutrient TMDL or lake management plan is to understand the sources contributing to the impairment. This section provides a brief description of the potential sources in the watershed contributing to excess nutrients in the lakes addressed in this TMDL. The latter sections of this report discuss the major pollutant sources that have been quantified using collected monitoring data and water quality modeling. The information presented here and in the upcoming sections together will provide information necessary to target pollutant load reductions.

3.2 NUTRIENT SOURCES AND LAKE RESPONSE

Following is a description of the nutrient sources and methods used to quantify each sources.

3.2.1 Watershed PONDNET Models

Watershed water and nutrient loading was estimated using a PONDNET (Walker, 1989) model developed for each lake watershed. PONDNET is a spreadsheet model based on routing of flow and TP through networks of wet detention ponds. Watershed runoff is estimated using a runoff coefficient while TP load is predicted using a land use specific runoff concentration (event mean concentration). TP removal is predicted using an empirical TP retention function. The City of Eagan originally developed a PONDNET model as a part of its nondegradation loading assessment to comply with MPCA's Municipal Separate Storm Sewer System (MS4) General Permit. The portions of this model that drain to each lake were updated with most current land use and watershed data and used to predict water yields and TP loading to each lake. The model operates on an annual time-step and was used to predict watershed yields/loads for a 12-year period (2000-2012).

The watershed model was validated using storm sewer flows through lift stations and pond water quality (Appendix F), where available. Model runoff coefficients were systematically reduced to provide the best fit possible for runoff volumes at seven lift stations. Average modeled discharge at the seven lift stations was within 11% of the recorded discharge (Appendix F). The watershed model included several upstream lakes as boundary conditions (i.e., model inputs). Flow from the model or lift station where monitoring data was available, was used along with lake water quality data to estimate loading from that part of the watershed. Lakes included in the model using monitoring data include Schwanz, Carlson, and Fish Lake.

Watershed water and phosphorus balances were developed for each of the lakes including loads from identified subwatersheds (Figures 3.1 through 3.3). Each of the watershed budgets includes upstream lakes as direct load to the downstream lake. These water and nutrient loads are directly input into the BATHTUB Model for lake response analysis.

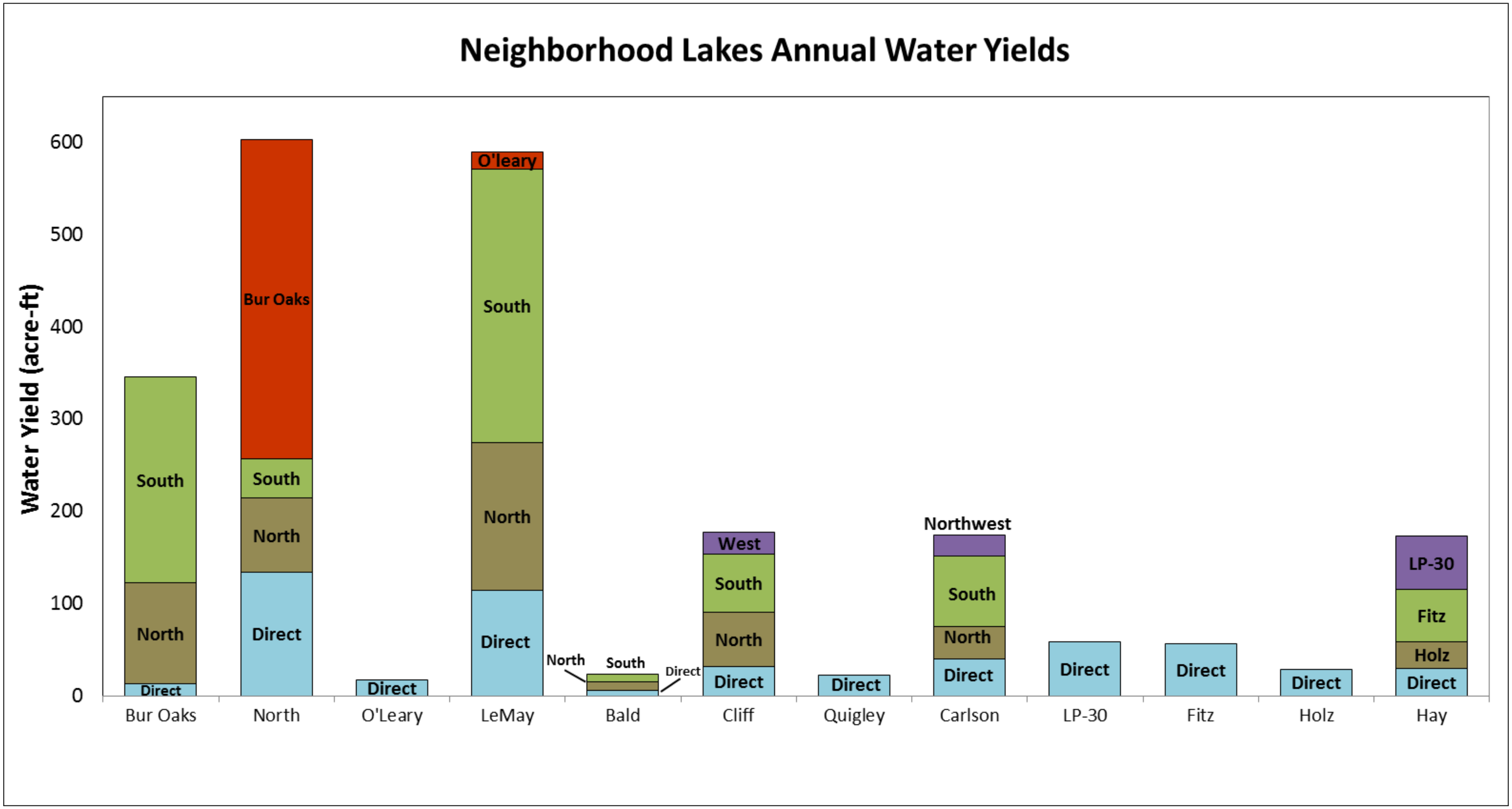

Figure 3.1. Average annual water yield subdivided by subwatersheds in each lake watershed.

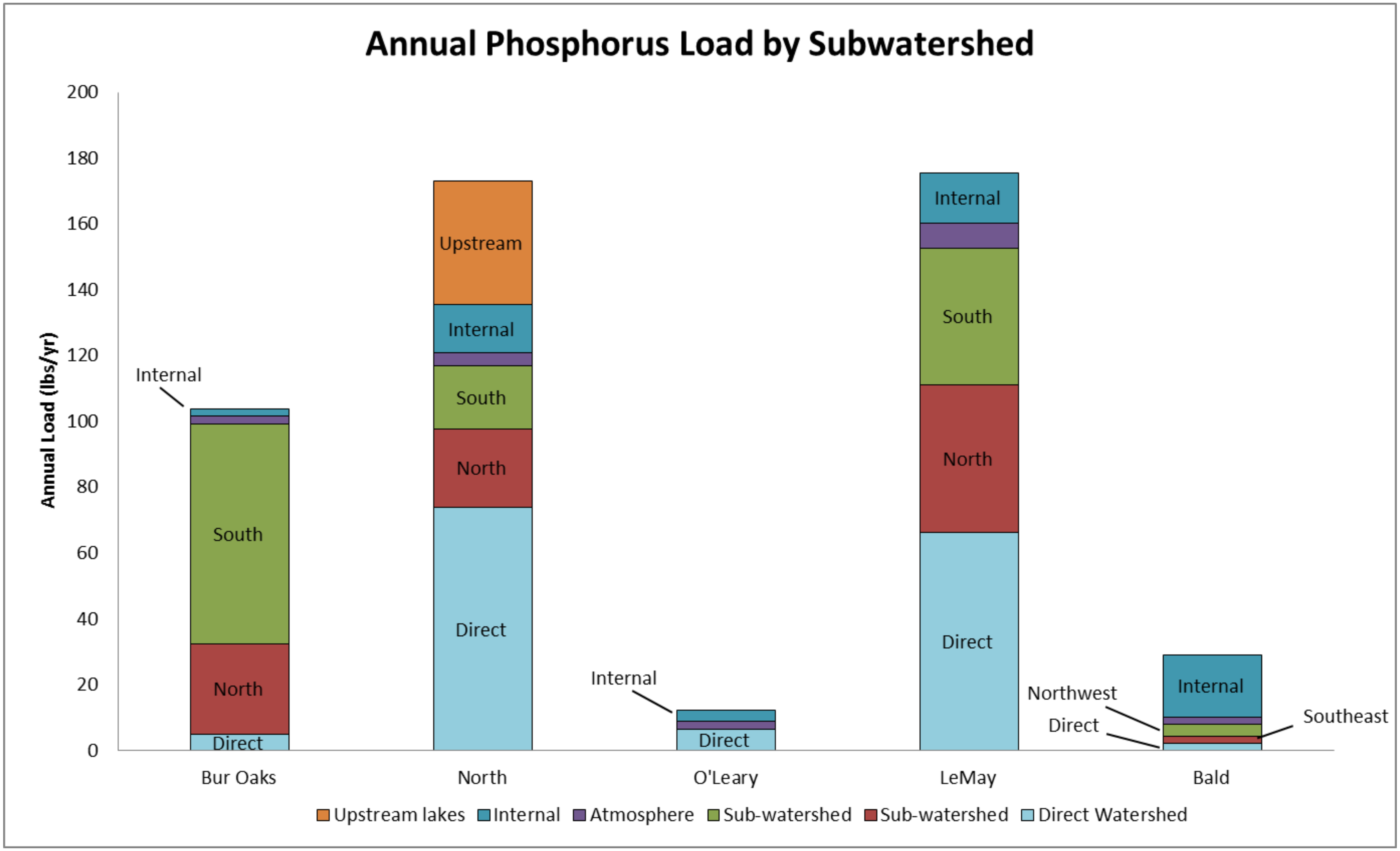

Figure 3.2. Annual watershed loads from watershed, internal, atmospheric, and upstream lake sources.

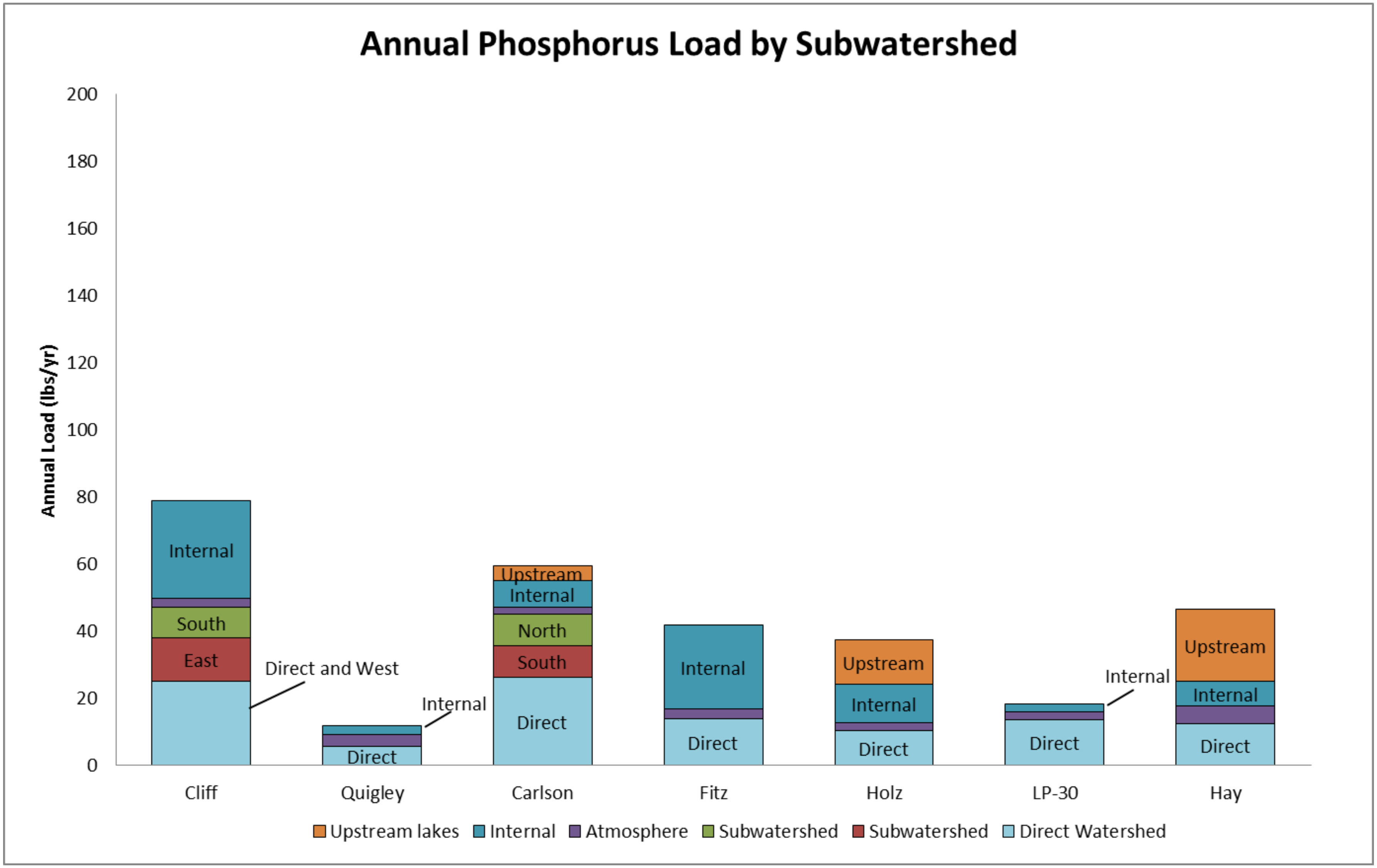

Figure 3.3. Annual watershed loads from watershed, internal, atmospheric, and upstream lake sources.

3.2.2 Upstream Lakes

Some of the lakes addressed in the TMDL have upstream lakes which are also addressed in the TMDL. Meeting water quality standards in the downstream lakes is contingent on water quality improvements in the proposed impaired upstream lakes. For these situations, outflow loads from the upstream lake were routed directly into the downstream lake and were estimated using monitored water quality.

3.2.3 Atmospheric Deposition

A study conducted for the MPCA, "Detailed Assessment of Phosphorus Sources to Minnesota Watersheds" (Barr Engineering, 2004), estimated the atmospheric inputs of phosphorus from deposition for different regions of Minnesota. The rates vary based on the precipitation received in a given year. Precipitation received during 2005-2011 was within that study's average range (25" to 38"). That study's annual atmospheric deposition rate of 26.8 kg/km^2 for average precipitation years was used to calculate annual atmospheric deposition load for these lakes.

3.2.4 Internal Loading

Internal phosphorus loading from lake sediments has been demonstrated to be an important part of the phosphorus budgets. Internal loading is typically the result of organic sediment releasing phosphorus to the water column. This often occurs when anoxic conditions are present, meaning that the water in and above the sediment is devoid of oxygen. However, studies have shown that internal loading can and does occur when the overlying water column is well oxygenated. For Carlson Lake, the only deep lake in this study, temperature and dissolved oxygen profiles were used to determine the volume of water under anoxic conditions throughout the summer growing season. This volume was then used to calculate an anoxic factor (Nürnberg 2004) normalized over the lake basin and reported as number of days.

Shallow lakes can often demonstrate short periods of anoxia due to instability of stratification, which can last a few days or even a few hours, that are often missed by periodic field measurements. Thus, the following equation was used to estimate the anoxic factor for all shallow lakes in this TMDL study (Nürnberg 2005):

$$AF_{shallow} = -35.4 + 44.2 \log (TP) + 0.95\ z/A^{0.5}$$

Where TP is the average summer phosphorus concentration of the lake, z is the mean depth (m) and A is the lake surface area (km^2).

To calculate total internal load for a lake, the anoxic factor (days) is multiplied by an estimated or measured phosphorus release rate ($mg/m^2/day$). Release rates were obtained by collecting sediment cores in the field and incubating them in the lab under oxic and/or anoxic conditions to measure phosphorus release over time (Table 3.1; Appendix G).

Table 3.1. Sediment release rates (aerobic and anaerobic), anoxic factors, and annual internal loads for each neighborhood lake.

Lake	Aerobic Release Rate ($mg/m^2/day$)	Anaerobic Release Rate ($mg/m^2/day$)	Average Oxic Factor (days)	Average Anoxic Factor (days)	Average Annual Internal Load (lbs/yr)
Bald	0.4	3.2	61	58.8	18.8
Bur Oaks	0.34	5.7	--	3.6	1.9
Carlson	0.56	4.7	35	55.8	9.4
Cliff	0.2	4.6	122	59.9[1]	31.6
Fitz	0.13	3.7	26.8	61.6[1]	26.8
Hay	0.15	1.2	--	31.4	7.4
Holz	0.17	2.3	61	55.9[1]	38.3
LP-30[2]	0.21	2.6	48	11	18.2
LeMay	0.27	3.4	61	15.8	19.9
North	0.12	6	--	17	14.6
O'Leary	0.13	2.4	61	17.1	4.1
Quigley	0.36	0.4	122	47.3[1]	8.5

[1] The shallow lake anoxic factor from Nurnberg 2005 were used for these lakes rather than field data because the field data likely underestimate the anoxic factor.

[2] Internal load estimates are based on sediment chemistry since release rates were not measured.

3.2.5 BATHTUB Model (Lake Response)

Once the nutrient budget for a lake has been developed, the lake's response to those nutrient loads must be established. Lake response to nutrient loading was modeled using BATHTUB and the extensive data set available for the proposed impaired lakes. BATHTUB is a series of empirical eutrophication models that predict the response to phosphorus inputs for morphologically complex lakes and reservoirs (Walker 1999). Several models (subroutines) are available for use within the BATHTUB model, and the Canfield-Bachmann model was used to predict the lake response to total phosphorus loads.

The Canfield-Bachmann model (Canfield and Bachmann 1981) estimates the lake phosphorus sedimentation rate, which is needed to predict the relationship between in-lake phosphorus concentrations and phosphorus load inputs. The phosphorus sedimentation rate is an estimate of net phosphorus loss from the water column through sedimentation to the lake bottom and is used in concert with lake-specific characteristics, such as annual phosphorus loading, mean depth, and hydraulic flushing rate, to predict in-lake phosphorus concentrations. These model predictions are compared to measured data to evaluate how well the model describes the lake system.

Once a model is well calibrated, the resulting relationship between phosphorus load and in-lake water quality is used to determine the assimilative capacity. Construction, calibration, and results of the BATHTUB model are presented in Appendix H.

4.0 Nutrient Budgets and TMDL Allocations

4.1 TMDL METHODOLOGY

The first step in developing an excess nutrient TMDL for lakes is to determine the total nutrient loading capacity or assimilative capacity. A key component for this determination is to estimate the current phosphorus loading by the sources for each lake. Following this estimation, BATHTUB is used to model responses of proposed impaired lakes to phosphorus loading and to determine loading capacities. The components of this process are described below.

To set the TMDL for each proposed impaired lake in the study, the nutrient inputs partitioned between sources in the lake response model is systematically reduced until the model predicted when each lake meets the current total phosphorus standard of 60 mg/L as a growing season mean for shallow lakes and 40 mg/L for deep lakes. Lake response model results are included in Appendix H.

To develop the appropriate loads under TMDL conditions, each load is evaluated sequentially to determine appropriate loads. Since atmospheric load is impossible to control, no reduction in this source is assumed for the TMDLs. Any upstream lakes are assumed to meet water quality standards, and the resultant reductions are applied to the lake being evaluated. If all of these reductions result in the lake meeting water quality standards, then the TMDL allocations are done. If more reductions are required, then the internal and external loads are evaluated simultaneously.

The capacity for watershed load reductions is considered first by looking at watershed loading rates and runoff concentrations compared to literature values. For example, some watershed phosphorus export rates are already so low that large reductions would be infeasible. Therefore, an internal load reduction is required to achieve water quality goals. In other cases, the situation is reversed and the internal load is already so low that only watershed reductions are required.

The general approach to internal load reductions is to evaluate the capacity for reducing the internal loading based on review of the existing sediment release rates and the lake morphometry. This is accomplished by reviewing the release rates versus literature values of healthy lakes. If the release rates are high, then they are reduced systematically until either a minimum of 1 mg/m^2/day is reached or the lakes meet TMDL requirements. In some extreme cases, the release rate has to be reduced below 1 mg/m^2/day to meet requirements. However, this is only done after all feasible watershed load reductions are included.

4.1.1 Load Allocation Methodology

The LA includes all non-permitted sources, including: atmospheric deposition, septic systems, discharge from upstream lakes, watershed loading from non-regulated areas, and internal loading. Some discharges from areas geographically located in a regulated MS4 that do not drain through a conveyance system (and therefore are not regulated sources) are also included in the LA (determined as described in the following section).

Table 4.1 summarizes the potential non-permitted nutrient sources in the Eagan Neighborhood Lakes watersheds.

Table 4.1. Potential non-permitted sources of phosphorus.

Non-Permitted Source	Source Description
Atmospheric Phosphorus Loading	Precipitation and dryfall (dust particles suspended by winds and later deposited).
Watershed Phosphorus Export	Variety in land use creating both rural and urban stormwater runoff that does not pass through a regulated MS4 conveyance system. There are no non-permitted runoff sources in these watersheds.
Internal Phosphorus Release	Under anoxic conditions, weak iron-phosphorus bonds break, releasing phosphorus in a highly available form for algal uptake. Carp and other rough fish present in lakes can lead to increased nutrients in the water column as they uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments. Over-abundance of aquatic plants can limit recreation activities and invasive aquatic species such as curly-leaf pondweed can change the dynamics of internal phosphorus loading. Historical impacts, such as WWTP effluent discharge, can also affect internal phosphorus loading.
Groundwater Contribution	Groundwater can be a source or sink for water in a lake and contains varying levels of phosphorus.

4.1.2 Wasteload Allocation Methodology

The WLA includes all permitted sources, including MS4 regulated stormwater and permitted point sources discharges. Table 4.2 summarizes the potential permitted sources for the Eagan Lakes.

Table 4.2. Potential permitted sources of phosphorus.

Permitted Source	Source Description	Phosphorus Loading Potential
Phase II Municipal Stormwater NPDES/SDS General Permit	Municipal Separate Storm Sewer Systems (MS4s)	Potential for runoff to transport grass clippings, leaves, car wash wastewater, and other phosphorus containing materials to surface water through a regulated MS4 conveyance system.
Construction Stormwater NPDES/SDS General Permit	Permits for any construction activities disturbing: 1) One acre or more of soil, 2) Less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre or 3) Less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources.	The Environmental Protection Agency (EPA) estimates a soil loss of 20 to 150 tons per acre per year from stormwater runoff at construction sites. Such sites vary in the number of acres they disturb.
Multi-sector Industrial Stormwater NPDES/SDS General Permit	Applies to facilities with Standard Industrial Classification Codes in ten categories of industrial activity with significant materials and activities exposed to stormwater.	Significant materials include any material handled, used, processed, or generated that when exposed to stormwater may leak, leach, or decompose and be carried offsite.

4.1.2.1 MS4s

There are four MS4s that are completely within or have a portion of their boundary in at least one of the proposed impaired lake watersheds (Table 4.3). Runoff from these MS4 entities that drains to proposed impaired lakes discussed in this report was assigned WLAs according to the following methodology. The current annual phosphorus load from the permitted sources was calculated by multiplying the percent area of each MS4 by the total annual watershed phosphorus load that reaches each lake. To calculate the WLAs, the required watershed reduction to meet water quality standards, as determined by the methodology described in Section 4.1, was applied to the calculated MS4 load. This approach assumes that an equal load reduction is required from all watershed areas.

Table 4.3. Permitted MS4s in each TMDL lakeshed.

MS4 Name		City of Eagan	City of Inver Grove Heights	MnDOT	Dakota County
MS4 ID Number		**MS400014**	**MS400096**	**MS400170**	**MS400132**
19-0066	Carlson	Yes	--	--	Yes
19-0077	Fitz	Yes	Yes	Yes[1]	--
19-0064	Holz	Yes	Yes	Yes[1]	--
19-0055	LeMay	Yes	--	Yes[1]	Yes

[1] MnDOT ROW areas used to calculate WLAs were 6 acres for Fitz, 7 acres for Holz, and 124 acres for LeMay.

To determine each MS4's WLA, their current loading was determined by multiplying the percent area of each MS4 by the total annual watershed phosphorus load that reaches each lake. The Right-of Way area used to calculate MnDOT's load was provided by MnDOT (Barbara Loida, pers. comm.). To determine MnDOT's WLA, the required watershed reduction to meet state water quality standards was applied to their load. If the load was less than 1 pound, no reduction was required for MnDOT. Rather, the City of Eagan claimed responsibility for that reduction.

4.1.2.2 Construction and Industrial Stormwater

Construction and industrial stormwater WLAs were established based on estimated percentage of land in the watershed that is currently under construction or permitted for industrial use. A recent permit review across Dakota County watershed showed minimal construction (<1% of watershed area) and industrial activities (<0.5% of the watershed area). To account for future growth, allocations in the TMDL were rounded up to 1% for construction stormwater and 0.5% for industrial stormwater.

The wasteload allocation for stormwater discharges from sites where there is construction activities reflects the number of construction sites > 1 acre expected to be active in the watershed at any one time, and the Best Management Practices (BMPs) and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local construction stormwater requirements must also be met.

The wasteload allocation for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES industrial stormwater permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains coverage under the appropriate NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local stormwater management requirements must also be met.

4.1.2.3 Other Permitted Sources

No other permitted sources (e.g., wastewater treatment facilities) are present in any of the study’s lake watersheds.

4.1.3 Margin of Safety

An explicit MOS has been included in this TMDL. Five percent of the load has been set aside to account for any uncertainty in the lake response models. The 5% MOS was considered reasonable for all of the modeled lakes due to the large quantity of watershed and in-lake monitoring data available.

4.1.4 Lake Response Variables

In addition to meeting phosphorus limits, chlorophyll-*a* and Secchi transparency standards must also be met. In developing the lake nutrient standards for Minnesota lakes (Minn. Rule 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (Heiskary and Wilson, 2005). Clear relationships were established between the causal factor total phosphorus and the response variables chlorophyll-*a* and Secchi transparency. Based on these relationships it is expected that by meeting the phosphorus target in each lake, the chlorophyll-*a* and Secchi standards will likewise be met.

4.1.5 Seasonal Variation

Seasonal variation is accounted for through the use of annual loads and developing targets for the summer period, where the frequency and severity of nuisance algal growth will be the greatest. Although the critical period is the summer, lakes are not sensitive to short-term changes in water quality. Rather, lakes respond to such long-term changes as variations in the annual load. Therefore, seasonal variation is accounted for in the annual loads. Additionally, by setting the TMDL to meet targets established for the most critical period (summer), the TMDL will inherently be protective of water quality during the other seasons.

4.1.6 Impact of Growth on Allocations

For all of the TMDLs, the following determination of the impact of growth on allocations applies.

4.1.6.1 Wastewater Sources

The MPCA, in coordination with the US EPA Region 5, has developed a streamlined process for setting or revising WLAs for new or expanding wastewater discharges to water bodies with an EPA approved TMDL (MPCA, 2012). This procedure will be used to update WLAs in approved TMDLs for new or expanding wastewater dischargers whose permitted effluent limits are at or below the in-stream target and will ensure that effluent concentrations will not exceed applicable water quality standards or surrogate measures. The process for modifying any and all WLAs will be handled by the MPCA, with input and involvement by the US EPA, once a permit request or reissuance is submitted. The overall process will use public notices to allow the public and US EPA to comment on permit changes based on the proposed WLA modification(s). Once any comments or concerns are addressed, and the MPCA determines that the new or expanded wastewater discharge is consistent with the applicable water quality standards, the permit will be issued and any updates to the TMDL WLA(s) will be made.

Current discharges can be expanded and new NPDES discharges can be added while maintaining water quality standards, provided permitted NPDES effluent concentrations remain below in-stream targets. Given this circumstance, a streamlined process for updating TMDL WLAs to incorporate new or expanding discharges will be employed. This process will apply to the non-stormwater facilities identified in this TMDL and any new wastewater or cooling water discharge in the watershed:

I. A new or expanding discharger will file with the MPCA permit program a permit modification request or an application for a permit reissuance. The permit application information will include documentation of the current and proposed future flow volumes and TSS loads.

II. The MPCA permit program will notify its TMDL program upon receipt of the request/application, and provide the appropriate information, including the proposed discharge volumes and the TSS loads.

III. TMDL program staff will provide the permit writer with information on the TMDL WLA to be published with the permit's public notice.

IV. The supporting documentation (fact sheet, statement of basis, effluent limits summary sheet) for the proposed permit will include information about the TSS discharge requirements, noting that for TSS, the effluent limit is below the in-stream TSS target and the increased discharge will maintain the turbidity water quality standard. The public will have the opportunity to provide comments on the new proposed permit, including the TSS discharge and its relationship to the TMDL.

V. The MPCA TMDL program will notify the EPA TMDL program of the proposed action at the start of the public comment period. The MPCA permit program will provide the permit language with attached fact sheet (or other appropriate supporting documentation) and new TSS information to the MPCA TMDL program and the EPA TMDL program.

VI. EPA will transmit any comments to the MPCA permits and TMDL programs during the public comment period, typically via e-mail. MPCA will consider any comments provided by EPA and by the public on the proposed permit action and WLA and respond accordingly; conferring with EPA if necessary.

VII. If, following the review of comments, MPCA determines the new or expanded TSS discharge, with a concentration below the in-stream target, is consistent with applicable water quality standards and the above analysis, MPCA will issue the permit with these conditions and send a copy of the final TSS information to the EPA TMDL program. MPCA's final permit action, which has been through a public notice period, will constitute an update of the WLA only.

VIII. EPA will document the update to the WLA in the administrative record for the TMDL. Through this process EPA will maintain an up-to-date record of the applicable WLA for permitted facilities in the watershed.

4.1.6.2 MS4 Allocation Load Transfer and Future Growth

Future transfer of watershed runoff loads in this TMDL may be necessary if any of the following scenarios occur within the project watershed boundaries:

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be given additional WLA to accommodate the growth.
2. One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
3. One or more non-regulated MS4s become regulated. If this has not been accounted for in the WLA, then a transfer must occur from the LA.
4. Expansion of a US Census Bureau Urban Area encompasses new regulated areas for existing permittees. An example is existing state highways that were outside an Urban Area at the time the TMDL was completed, but are now inside a newly expanded Urban Area. This will require either a WLA to WLA transfer or a LA to WLA transfer.
5. A new MS4 or other stormwater-related point source is identified and is covered under a NPDES permit. In this situation, a transfer must occur from the LA.

Load transfers will be based on methods consistent with those used in setting the allocations in this TMDL. In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer.

4.2 TMDL SUMMARY

The allowable TP load (TMDL) for each lake was divided among the WLA, LA, and the MOS as described in the preceding sections. The following tables summarize the existing and allowable TP loads, the TMDL allocations, and required reductions for each lake. TMDLs are based on data from the 10-year period 2003-2012. Any activities implemented during or after the mid-point of this time period, specifically 2008, that led to a reduction in TP loads to a lake may be considered progress toward meeting a WLA or LA. In these tables the total load reduction is the sum of the required WLA reductions plus the required LA reductions; this is not the same as the net difference between the existing and allowable total loads, however, because the WLA and LA reductions must accommodate the MOS.

The following rounding conventions were used:

- Values ≥100 reported in lbs/yr have been rounded to the nearest whole number.
- Values <100 reported in lbs/yr have been rounded to the nearest tenth of a pound.
- Values reported in lbs/day have been rounded to enough significant digits so that the value is greater than zero and all numbers in that column were held at the same number of significant digits. Though the daily values show multiple digits, it is not intended to imply great precision; this is done primarily to make the arithmetic accurate.

Tables 4.4 through 4.7 present the allocations for the proposed impaired lakes.

Table 4.4. TMDL allocations for Carlson Lake (Lake ID: 19-0066-00).

Allocation	Source	Existing TP Load		TP Allocations		Load Reduction	
		(lbs/yr)	(lbs/day)[1]	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	%
Waste-load	Construction and Industrial Stormwater	0.4	0.001	0.4	0.001	0.0	**0%**
	City of Eagan	41.8	0.114	30.3	0.083	11.5	**28%**
	Dakota County Right-of-Way	2.7	0.007	2.1	0.006	0.6	**22%**
Load	Upstream Lakes	4.6	0.013	3.7	0.010	0.9	**20%**
	Atmosphere	2.8	0.008	2.8	0.008	0.0	**0%**
	Internal Load	13.2	0.036	7.5	0.021	5.7	**43%**
	MOS	--	--	1.7	0.005	--	--
	TOTAL	**65.5**	**0.179**	**48.5**	**0.134**	**18.7**	**26%**

[1] Daily loads were calculated by dividing the annual load by 365.25 days accounting for leap years.

Table 4.5. TMDL allocations for Fitz Lake (Lake ID: 19-0077-00).

Allocation	Source	Existing TP Load		TP Allocations		Load Reduction	
		(lbs/yr)	(lbs/day)[1]	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	%
Waste-load	Construction and Industrial Stormwater	0.1	0.0004	0.1	0.0004	0.0	0%
	City of Eagan	12.6	0.0345	7.3	0.0200	5.3	42%
	City of Inver Grove Heights	0.6	0.0017	0.6	0.0017	0.0	0%
	MnDOT Right-of-Way	0.5	0.0013	0.5	0.0013	0.0	0%
Load	Atmosphere	2.9	0.0081	2.9	0.0081	0.0	0%
	Internal Load	26.8	0.0733	8.2	0.0224	18.6	69%
	MOS	--	--	0.4	0.0012	0.4	**--**
	TOTAL	**43.5**	**0.1193**	**20.0**	**0.0551**	**24.3**	**54%**

[1] Daily loads were calculated by dividing the annual load by 365.25 days accounting for leap years.

Table 4.6. TMDL allocations for Holz Lake (Lake ID: 19-0064-00).

Allocation	Source	Existing TP Load		TP Allocations		Load Reduction	
		(lbs/yr)	(lbs/day)[1]	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	%
Waste-load	Construction and Industrial Stormwater	1.0	0.0028	1.0	0.0028	0.0	0%
	City of Eagan	7.8	0.0214	6.8	0.0186	1.0	13%
	City of Inver Grove Heights	0.5	0.0013	0.5	0.0013	0.0	0%
	Dakota County Right-of-Way	0.6	0.0016	0.6	0.0016	0.0	0%
	MnDOT Right-of-Way	0.4	0.0011	0.4	0.0011	0.0	0%
Load	Upstream Lakes	13.3	0.0363	9.5	0.0260	3.8	29%
	Atmosphere	2.4	0.0065	2.4	0.0065	0.0	0%
	Internal Load	12.4	0.0339	8.2	0.0223	4.2	34%
	MOS	--	--	0.5	0.0013	--	--
	TOTAL	**38.4**	**0.1049**	**29.9**	**0.0815**	**9.0**	**22%**

[1] Daily loads were calculated by dividing the annual load by 365.25 days accounting for leap years.

Table 4.7. TMDL allocations for LeMay Lake (Lake ID: 19-0055-00).

Allocation	Source	Existing TP Load		TP Allocations		Load Reduction	
		(lbs/yr)	(lbs/day)^1	(lbs/yr)	(lbs/day)^1	(lbs/yr)	%
Waste-load	Industrial and Construction Stormwater	1.6	0.004	1.6	0.004	0.0	**0%**
	City of Eagan	131.5	0.360	95.9	0.263	35.6	**27%**
	Dakota County Right-of-Way	6.6	0.018	5.2	0.014	1.5	**21%**
	MnDOT Right-of-Way	16.3	0.045	12.7	0.035	3.6	**22%**
Load	Atmosphere	7.6	0.021	7.6	0.021	0.0	**0%**
	Internal Load	19.9	0.054	9.5	0.026	10.4	**52%**
	MOS	--	--	6.1	0.017	--	--
	TOTAL	**183.5**	**0.502**	**138.6**	**0.380**	**51.1**	**24%**

[1] Daily loads were calculated by dividing the annual load by 365.25 days accounting for leap years.

4.3 PROTECTION LAKES

Eight of the water bodies are not proposed to be on the impaired waters list because MPCA considers two to be wetlands (for purposes of State of Minnesota water quality assessments and 303(d) list determinations), several currently meet State water quality standards, and two lakes have high TP but do not exceed the response variables (chlorophyll-a and Secchi disk). However, understanding all of their nutrient budgets is critical to developing protection plans for these lakes. For those that did not require a reduction to meet water quality standards, a Margin of Safety was not included. Cliff and Bald lakes have recommended reductions to assure maintaining good water quality with allocations developed in the same manner as if they are proposed to be impaired. Both O'Leary and Quigley Lake were recently determined to be wetlands rather than shallow lakes. However, nutrient budgets were still developed for these water bodies in an effort to better understand their nutrient balance and appropriate management actions. These nutrient budgets are provided below.

4.3.1 Nutrient Loading Summary

Tables 4.8 through 4.14 present the nutrient loading summaries for the protection lakes.

Table 4.8. Nutrient budgets and recommended reductions for Bald Lake (Lake ID: 19-0061-00).

Source	Existing TP Load		Target TP Load		Load Reduction	
	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	%
Construction and Industrial Stormwater	0.1	0.0002	0.1	0.0002	0.0	**0%**
City of Eagan	7.9	0.0215	7.9	0.0215	0.0	**0%**
Atmosphere	2.4	0.0065	2.4	0.0065	0.0	**0%**
Internal Load	18.8	0.0514	9.7	0.0264	9.1	**49%[2]**
MOS	--	--	0.4	0.0011	--	**5%**
TOTAL	**29.2**	**0.0796**	**20.5**	**0.0557**	**9.1**	**30%**

[1] Daily loads were calculated by dividing the annual load by 365.25 days accounting for leap years.

[2] Meeting load reduction goals for Bald Lake without internal load reduction would be nearly impossible since internal loading is 64% of the total phosphorus budget.

Table 4.9. Nutrient budgets and recommended reductions for Bur Oaks Lake (Lake ID: 19-0259-00).

Source	Existing TP Load		Target TP Load		Load Reduction	
	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	%
Industrial and Construction Stormwater	0.7	0.002	0.7	0.002	0.0	**0%**
City of Eagan	42.3	0.116	42.3	0.116	0.0	**0%**
City of Inver Grove Heights	17.4	0.048	17.4	0.048	0.0	**0%**
Dakota County Right-of-Way	0.3	0.001	0.3	0.001	0.0	**0%**
MnDOT Right-of-Way	4.6	0.013	4.6	0.013	0.0	**0%**
Upstream Lakes	0.0	0.000	0.0	0.000	0.0	**0%**
Atmosphere	2.5	0.007	2.5	0.007	0.0	**0%**
Internal Load	7.2	0.020	1.9	0.005	5.3	**74%[2]**
MOS	--	--	--	--	--	--
TOTAL	**75.0**	**0.207**	**69.7**	**0.192**	**5.3**	**7%**

[1] Daily loads were calculated by dividing the annual load by 365.25 days accounting for leap years.

[2] Sediment anoxic release rates were relatively high (5.7 mg m^{-2} d^{-1}) in Bur Oaks Lake. For this reason internal load reductions were recommended to protect future water quality conditions.

Table 4.10. Nutrient budgets and recommended reductions for Cliff Lake (Lake ID: 19-0068-00).

Source	Existing TP Load		Target TP Load		Load Reduction Goal	
	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	%
Construction and Industrial Stormwater	0.4	0.001	0.4	0.001	0.0	**0%**
City of Eagan	29.8	0.081	15.8	0.043	14.0	**47%**
MnDOT Right-of-Way	5.0	0.014	2.8	0.008	2.2	**43%**
Atmosphere	2.8	0.008	2.8	0.008	0.0	**0%**
Internal Load	31.4	0.086	8.9	0.024	22.5	**71%**
MOS	--	--	1.0	0.003	--	**--**
TOTAL	**69.4**	**0.190**	**31.7**	**0.087**	**38.7**	**54%**

[1] Daily loads were calculated by dividing the annual load by 365.25 days accounting for leap years.

Table 4.11. Nutrient budgets and recommended reductions for Hay Lake (Lake ID: 19-0062-00).

Source	Existing TP Load		Target TP Load		Load Reduction	
	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	%
Construction and Industrial Stormwater	0.1	0.0003	0.1	0.0003	0	**0%**
City of Eagan	11.8	0.0324	11.8	0.0324	0	**0%**
MnDOT Right-of-Way	0.3	0.0007	0.3	0.0007	0	**0%**
Dakota County Right-of-Way	0.2	0.0005	0.2	0.0005	0	**0%**
Upstream Lakes	21.4	0.0587	21.4	0.0587	0	**0%**
Atmosphere	5.3	0.0144	5.3	0.0144	0	**0%**
Internal Load	7.4	0.0202	7.4	0.0202	0	**0%**
MOS	--	--	--	--	--	--
TOTAL	**46.5**	**0.1272**	**46.5**	**0.1272**	**0**	**0%**

[1] Daily loads were calculated by dividing the annual load by 365.25 days accounting for leap years

Table 4.12. Nutrient budgets and recommended reductions for LP-30 (Lake ID: 19-0053-00).

Source	Existing TP Load		Target TP Load		Load Reduction	
	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	%
Construction and Industrial Stormwater	0.1	0.0004	0.1	0.0004	0.0	**0%**
City of Eagan	0.8	0.0021	0.8	0.0021	0.0	**0%**
City of Inver Grove Heights	12.8	0.0351	12.8	0.0351	0.0	**0%**
Atmosphere	2.2	0.0062	2.2	0.0062	0.0	**0%**
Internal Load	2.5	0.0068	2.5	0.0068	0.0	**0%**
MOS	--	--	--	--	--	--
TOTAL	**18.4**	**0.0506**	**18.4**	**0.0506**	**0.0**	**0%**

[1] Daily loads were calculated by dividing the annual load by 365.25 days accounting for leap years.

Table 4.13. Nutrient budgets and recommended reductions for North Lake (Lake ID: 19-0136-00).

Source	Existing TP Load		Target TP Load		Load Reduction	
	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	%
Construction and Industrial Stormwater	1.2	0.003	1.2	0.003	0.0	**0%**
City of Eagan	110.0	0.301	110.0	0.301	0.0	**0%**
MnDOT Right-of-Way	1.2	0.003	1.2	0.003	0.0	**0%**
Dakota County Right-of-Way	4.7	0.013	4.7	0.013	0.0	**0%**
Upstream Lakes	25.6	0.070	25.6	0.070	0.0	**0%**
Atmosphere	3.8	0.010	3.8	0.010	0.0	**0%**
Internal Load	14.6	0.040	14.6	0.040	0.0	**0%**
MOS	--	--	--	--	--	**--**
TOTAL	**161.1**	**0.440**	**161.1**	**0.440**	**0.0**	**0%**

[1] Daily loads were calculated by dividing the annual load by 365.25 days accounting for leap years.

Table 4.14. Nutrient budgets and recommended reductions for O'Leary Lake (Lake ID: 19-0056-00).

Source	Existing TP Load		Target TP Load		Load Reduction Goal	
	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	%
Construction and Industrial Stormwater	0.1	0.0002	0.1	0.0002	0.0	**0%**
City Of Eagan	6.5	0.0179	4.5	0.0123	2.0	**31%**
MnDOT Right-of-Way	0.1	0.0002	0.1	0.0002	0.0	**0%**
Atmosphere	2.2	0.0061	2.2	0.0061	0.0	**0%**
Internal Load	4.1	0.0111	2.1	0.0057	2.0	**49%**
MOS	--	--	0.2	0.0007	--	**--**
TOTAL	**13.0**	**0.0355**	**9.2**	**0.0252**	**4.0**	**29%**

[1] Daily loads were calculated by dividing the annual load by 365.25 days accounting for leap years.

Table 4.15. Nutrient budgets and recommended reductions for Quigley Lake (Lake ID: 19-0155-00).

Source	Existing TP Load		Target TP Load		Load Reduction	
	(lbs/year)	(lbs/day)[1]	(lbs/yr)	(lbs/day)[1]	(lbs/yr)	%
Construction and Industrial Stormwater	0.06	0.0002	0.06	0.0002	0.00	**0%**
City Of Eagan	5.49	0.0150	3.41	0.0093	2.08	**38%**
Dakota County ROW	0.04	0.0001	0.04	0.0001	0.00	**0%**
Atmosphere	3.63	0.0100	3.63	0.0100	0.00	**0%**
Internal Load	8.52	0.0233	5.56	0.0152	2.96	**35%**
MOS	--	--	0.18	0.0005	--	--
TOTAL	**17.74**	**0.0486**	**12.88**	**0.0353**	**5.04**	**27%**

[1] Daily loads were calculated by dividing the annual load by 365.25 days accounting for leap years.

5.0 Implementation Plan

5.1 MANAGEMENT ACTIVITY SELECTION

The purpose of this plan is to identify water quality goals for the management of the neighborhood lakes and to identify projects necessary to reach those goals. It should be noted that the level of detail contained in this section is far greater than what is required for a TMDL report. This is because the approved Clean Water Partnership grant for this project included development of plans at this level and it is more efficient to include all of the information in a single report.

Potential projects to reduce nutrient loading were selected using the PONDNET model as a basis for pond and stormwater infrastructure performance for water quality. General feasibility of the projects was evaluated to determine if appropriate improvements are possible at the selected sites. Projects deemed feasible were carried forward to effectiveness evaluations and planning-level cost estimates.

5.2 ADAPTIVE MANAGEMENT

Implementation will be conducted using adaptive management principles (Figure 5.1). Adaptive management is essentially a phased approach where a strategy is identified and implemented in the first cycle. After implementation of that phase has been completed, progress toward meeting the goals is assessed. A new strategy is then formulated to continue making progress toward meeting the goals. These steps are continually repeated until established goals are met. This process allows for future technological advances that may alter the course of actions. Continued monitoring and “course corrections” responding to monitoring results are the most appropriate strategies for attaining the water quality goals of this management plan.

Adaptive management will be applied using the planning cycle for MS4s (Figure 5.1). To start, projects that are ready to go will be implemented, feasibility studies and designs will be developed where necessary and monitoring and outreach activities will continue. The next period will be used to continue implementing projects on the ground as well as monitoring to assess effectiveness of the selected practices.

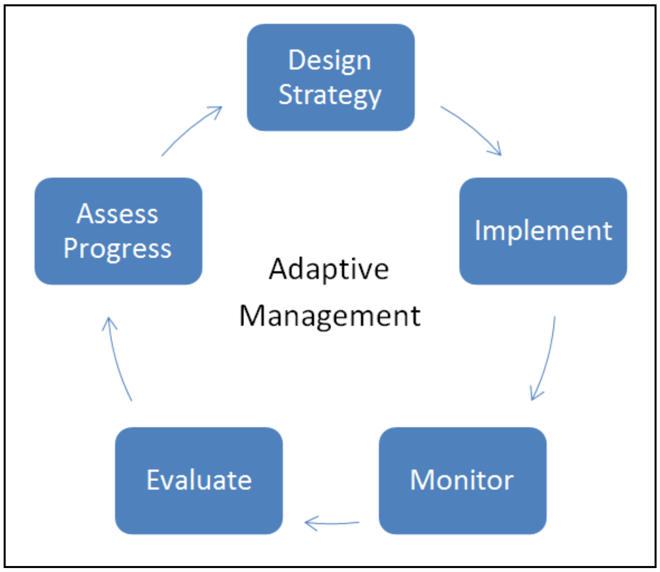

Figure 5.1. Adaptive management.

5.3 IMPLEMENTATION PLAN SUMMARY

Recommended management activities for each of the lakes include a mix of internal and external (watershed) nutrient reduction projects, fisheries management, aquatic vegetation management and shoreline management. Following is a summary of the potential management activities including associated costs. Costs were completed for an expected 30-year life cycle. It is important to note that some actions targeting external loading may not be applied toward a reduction to meet a WLA. Such non-WLA-creditable projects may include treatment within a water feature considered a water of the state. For clarification on a particular project proposers should contact the MPCA Stormwater Program.

5.3.1 Watershed Nutrient Management

A number of capital projects were identified to reduce watershed TP loading to the Neighborhood Lakes (Table 5.1; Figures 5.2 to 5.7). Projects also were assessed by estimating costs per pound TP removal over a 30-year period. These cost estimates provide comparisons among projects; however, there are other factors that may make a project attractive beyond just TP removal efficiency.

LeMay and O'Leary lakes

Land uses in the LeMay and O'Leary lakes subwatersheds are primarily commercial, industrial, and retail. The watershed load reduction goal for LeMay and O'Leary lakes is 32 lbs and 1.8 lbs, respectively. Four basins in the LeMay Lake subwatershed offer opportunities for projects to reduce the watershed load and meet the load reduction goal (Table 5.1; Figure 5.2). There is an opportunity for projects in the LeMay Lake direct watershed, which has a large industrial and commercial area to the north with currently little to no treatment. Another project opportunity is in the large retail area in the southwest corner of the LeMay Lake subwatershed, which offers opportunity for additional treatment. Five additional basins were identified for alum treatments.

Bald Lake

The Bald Lake subwatershed is comprised of residential and open space land uses. Because there is no watershed load reduction goal for Bald Lake, projects are considered measures for future protection from watershed loading (Table 5.1; Figure 5.3). Two basins were identified for alum treatments to protect from future watershed loading.

Bur Oaks and North lakes

Land uses in the Bur Oaks and North lakes subwatersheds are primarily industrial and residential. There is no watershed load reduction goal for both Bur Oaks and North lakes. Two basins in the Bur Oaks Lake subwatershed offer opportunities for projects to future protect the subwatershed as it continues to be developed (Table 5.2; Table 5.4). One pond in the Bur Oaks Lake subwatershed was identified for alum treatment. Three basins in the North Lake subwatershed offer opportunities for projects to future protect the subwatershed as it continues to be developed.

Carlson and Quigley lakes

Land use in the Carlson and Quigley lakes subwatersheds is primarily residential. The watershed load reduction goal for Carlson Lake is 12 lbs and for Quigley Lake is 2 lbs. Three watersheds in the Carlson Lake subwatershed offer opportunities for projects to reduce the watershed load and meet the load reduction goal. Since the watersheds for Carlson and Quigley lakes are primarily residential, neighborhood rain garden programs and increased street sweeping are opportunities to reduce watershed loads to help meet the load reduction goal (Table 5.1; Figure 5.5). Two additional basins were identified for alum treatments.

Cliff Lake

The Cliff Lake subwatershed is primarily residential land use. The watershed load reduction goal for Cliff Lake is 38 lbs. Two basins in the subwatershed offer opportunities for projects to reduce the watershed load and meet the load reduction goal (Table 5.1; Figure 5.6). A commercial area also offers opportunities for improvements. Two residential neighborhoods were identified as candidates for increased street sweeping to help reduce the watershed load to meet the load reduction goal. Five basins were identified for alum treatments.

Fitz, Holz and Hay lakes, and LP-30

Land use in the Fitz, Holz, Hay, and LP-30 subwatershed is primarily residential. The watershed load reduction goal for Fitz Lake is 5 lbs and for Holz Lake, it’s 1 lb. There is no watershed load reduction goal for Hay Lake and LP-30 because they are currently meeting water quality standards. Four watersheds offer opportunities for projects to reduce the watershed load to the lakes and meet the load reduction goals. Two neighborhoods are identified as areas with opportunities for a neighborhood rain garden program and increased street sweeping to reduce the watershed load to help meet the load reduction goal (Table 5.1; Figure 5.7).

Table 5.1. Capital projects to reduce TP loading to the Neighborhood Lakes.

Watershed ID	Project Description	Responsible Party	Average Annual Treatable Total Phosphorus Load (lbs)	Total Annual Phosphorus Load Reduction[2] (lbs)	Project Cost (30 Year Life Cycle)	Cost Efficiency[3] ($/lb)
LeMay Lake						
DP-3	Basin Expansion	City of Eagan	62.0	4.0	$ 452,000	$ 3,767
	Iron Enhanced Filtration System	City of Eagan		28.0	$ 270,000	$ 321
	Basin Expansion and Iron Enhanced Filtration System	City of Eagan		31.0	$ 667,000	$ 717
DP-4A, 4B, 26	Iron Enhanced Filtration System	City of Eagan	50.0	28.0	$ 1,285,000	$ 1,530
DP-5	Alum Treatment	City of Eagan	-	-	$ 8,000	-
DP-10	Alum Treatment	City of Eagan	-	-	$ 5,000	-
DP-12	Alum Treatment	City of Eagan	-	-	$ 30,000	-
DP-18.1	Alum Treatment	City of Eagan	-	-	$ 4,000	-
DP-27	Alum Treatment	City of Eagan	-	-	$ 75,000	-
DP-4.2	Iron Enhanced Filtration System	City of Eagan	13.0	10.0	$ 306,000	$ 1,020
DP-2.3	Basin Expansion and Iron Enhanced Filtration System	City of Eagan	10.0	6.0	$ 123,000	$ 683
DP-4A_2	Stormwater Reroute, Basin and Iron Enhanced Filtration System	City of Eagan	5.0	4.0	$ 364,000	$ 3,033
	Pervious Pavement and Underground Iron Enhanced Filtration System	City of Eagan		4.0	$ 686,000	$ 5,717
DP-2	Stormwater Reroute, Basin and Iron Enhanced Filtration System	City of Eagan	70.0	38.0	$ 1,500,000	$ 1,316
	Clarifier System	City of Eagan		44.0	$ 3,090,000	$ 2,341

Table 5.1 (continued). Capital projects to reduce TP loading to the Neighborhood Lakes

Watershed ID	Project Description	Responsible Party	Average Annual Treatable Total Phosphorus Load (lbs)	Total Annual Phosphorus Load Reduction[2] (lbs)	Project Cost (30 Year Life Cycle)	Cost Efficiency[3] ($/lb)
Bald Lake						
JP Residential	Rain garden Program[1]	City of Eagan; Residents	5.0	0.5	$ 112,000	$ 7,478
	Street Sweeping	City of Eagan		0.5	$ 83,000	$ 5,830
JP-20.1	Stormwater Reuse Irrigation System	City of Eagan	2.0	1.0	$ 409,000	$ 13,633
	Alum Treatment	City of Eagan		-	$ 1,200	-
JP-20.3	Alum Treatment	City of Eagan	-	-	$ 3,100	-
JP-20.5	Iron Enhanced Filtration System	City of Eagan	2.0	1.0	$ 91,000	$ 3,033
Bur Oaks Lake						
GP-2	Alum Treatment	City of Eagan	-	-	$ 14,400	-
GP-5	Iron Enhanced Filtration System	City of Eagan	48.0	18.0	$ 524,000	$ 970
GP-1.2	Basin Expansion	City of Eagan	82.0	16.0	$ 578,000	$ 1,204
	Iron Enhanced Filtration System	City of Eagan		14.0	$ 251,000	$ 598
	Basin Expansion and Iron Enhanced Filtration System	City of Eagan		38.0	$ 807,000	$ 708
North Lake						
EP-2.4_2	Iron Enhanced Filtration System	City of Eagan	12.0	7.0	$ 129,000	$ 614
EP-2.91	Basin Expansion	City of Eagan	0.8	0.3	$ 55,000	$ 5,510
EP-2.92	Basin Expansion	City of Eagan	0.9	0.4	$ 82,000	$ 6,674
Carlson Lake						
LP-42	Stormwater Reroute and Underground Filtration System	City of Eagan	11.0	6.0	$ 803,000	$ 4,461
LP-41	Alum Treatment	City of Eagan	-	-	$ 33,000	-
LP-44	Alum Treatment	City of Eagan	-	-	$ 17,000	
LP-53	Stormwater Reroute and Underground Filtration System	City of Eagan	10.0	7.0	$ 1,064,000	$ 5,067
	Stormwater Reroute and Iron Enhanced Filtration Basin	City of Eagan		7.0	$ 669,000	$ 3,186

Table 5.1 (continued). Capital projects to reduce TP loading to the Neighborhood Lakes.

Watershed ID	Project Description	Responsible Party	Average Annual Treatable Total Phosphorus Load (lbs)	Total Annual Phosphorus Load Reduction[2] (lbs)	Project Cost (30 Year Life Cycle)	Cost Efficiency[3] ($/lb)
Carlson Lake (continued)						
LP-42	Rain garden Program[1]	City of Eagan; Residents	19.0	1.0	$ 304,000	$ 10,133
	Street Sweeping	City of Eagan		1.0	$ 242,000	$ 8,067
LP-70	Iron Enhanced Filtration System	City of Eagan	11.0	6.0	$ 167,000	$ 928
LP-44	Rain garden Program[1]	City of Eagan; Residents	8.0	0.5	$ 120,000	$ 8,487
	Street Sweeping	City of Eagan		0.5	$ 87,000	$ 5,957
Quigley Lake						
LP-43	Rain garden Program[1]	City of Eagan; Residents	10.0	0.6	$ 144,000	$ 7,776
	Street Sweeping	City of Eagan		0.6	$ 94,000	$ 5,342
Cliff Lake						
AP-16	Alum Treatment	City of Eagan	-	-	$ 7,000	-
AP-16.1	Alum Treatment	City of Eagan	-	-	$ 14,000	-
AP-17	Alum Treatment	City of Eagan	-	-	$ 22,000	-
AP-30	Alum Treatment	City of Eagan	-	-	$ 11,000	-
AP-33B	Alum Treatment	City of Eagan	-	-	$4,000	-
AP-42	Basin Expansion and Iron Enhanced Filtration System	City of Eagan	33.0	22.0	$ 269,000	$ 408
AP-42	Commercial BMPs	City of Eagan	4.0	2.0	$ 134,000	$ 2,239
AP-44	Iron Enhanced Filtration System	City of Eagan	8.0	6.0	$ 218,000	$ 1,211

Table 5.1 (continued). Capital projects to reduce TP loading to the Neighborhood Lakes.

Watershed ID	Project Description	Responsible Party	Average Annual Treatable Total Phosphorus Load (lbs)	Total Annual Phosphorus Load Reduction[2] (lbs)	Project Cost (30 Year Life Cycle)	Cost Efficiency[3] ($/lb)
Fitz Lake						
LP-26.3	Stormwater Reroute, Basin Expansion and Iron Enhanced Filtration System	City of Eagan	10.0	8.0	$ 320,000	$ 1,333
LP-26.4	Iron Enhanced Filtration System	City of Eagan	0.5	0.3	$ 76,000	$ 8,444
LP-26.5	Iron Enhanced Filtration System	City of Eagan	3.0	2.0	$ 77,000	$ 1,283
Holz Lake						
LP-28	Tree Boxes	City of Eagan	2.0	1.0	$ 65,000	$ 2,167
	Rain gardens	City of Eagan; Residents	3.0	1.0	$ 219,000	$ 7,300
	Street Sweeping		5.0	0.5	$ 73,000	$ 4,867
Hay Lake						
LP-31	Rain garden Program[1]	City of Eagan; Residents	9.0	2.0	$ 388,000	$ 6,467
	Street Sweeping			0.5	$ 117,000	$ 7,800

[1] Estimated load reduction and project costs are based on participation of 15% of the residences in the identified project area.

[2] The estimated treatable total phosphorus load routed through the proposed BMP. In most cases it is the entire subwatershed load. However a few cases only allow treatment of a fraction of the watershed load.

[3] Cost efficiency is the 30-year life cycle project cost divided by the 30 year total phosphorus load reduction.

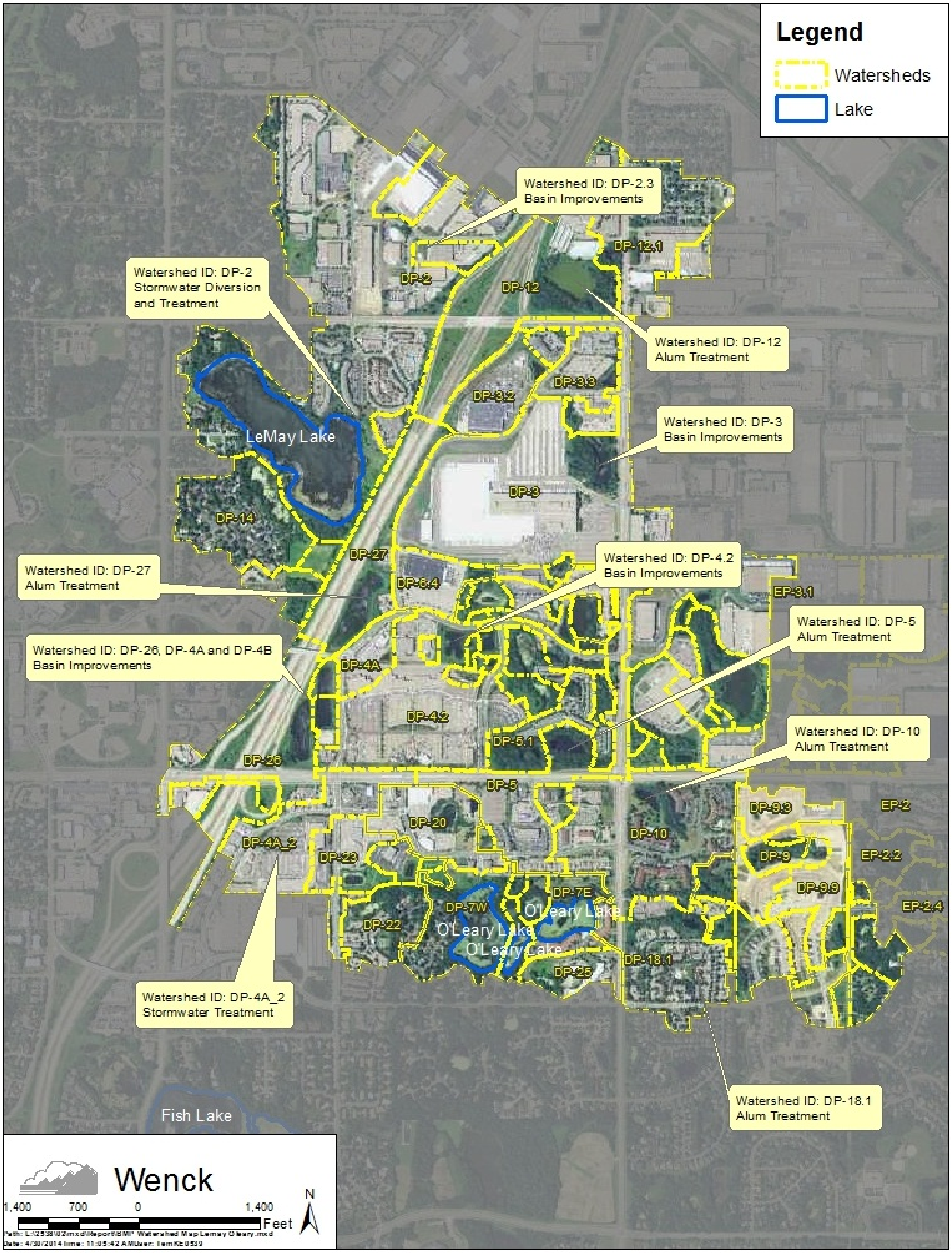

Figure 5.2. Potential LeMay Lake and O'Leary Lake projects.

Figure 5.3. Potential Bald Lake projects.

Figure 5.4. Potential Bur Oaks Lake and North Lake projects.

Watershed ID: LP-44
Alum Treatment

Watershed ID: LP-42 and LP-44
NeighborhoodRain Gardens

Watershed ID: LP-43
Neighborhood Rain Gardens

Watershed ID: LP-42
Stormwater Reroute
and Underground
Filtration System

Watershed ID: LP-53
Stormwater Reroute
and Underground
Filtration System

Watershed ID: LP-70
Basin Improvements

Watershed ID: LP-41
Alum Treatment

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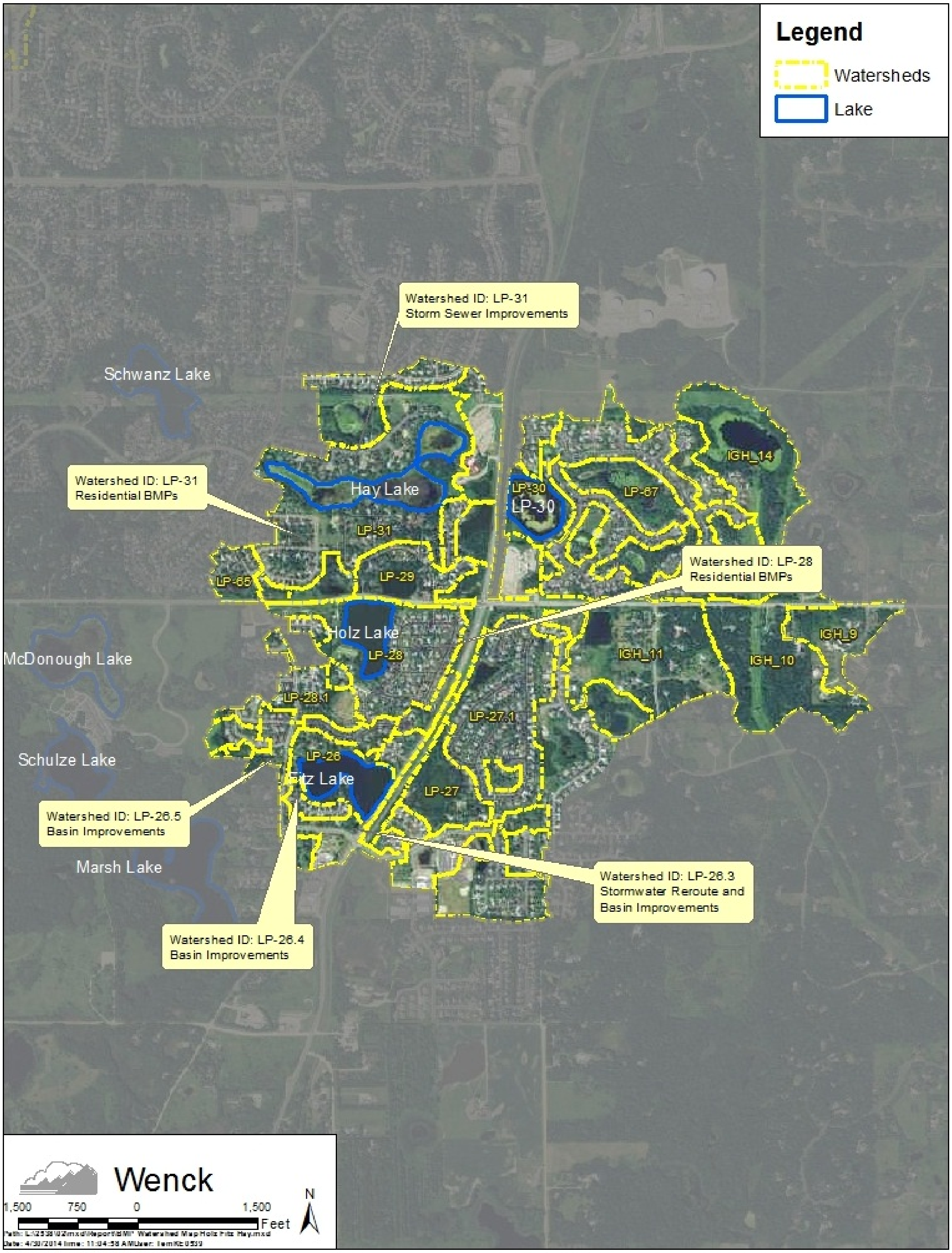
Figure 5.5. Potential Carlson Lake and Quigley Lake projects.

Figure 5.6. Potential Cliff Lake projects.



Watershed ID: LP-31
Storm Sewer Improvements

Watershed ID: LP-31
Residential BMPs

Watershed ID: LP-28
Residential BMPs

Watershed ID: LP-26.5
Basin Improvements

Watershed ID: LP-26.3
Stormwater Reroute and
Basin Improvements

Watershed ID: LP-26.4
Basin Improvements

Figure 5.7. Potential Fitz Lake, Holz Lake, Hay Lake, and LP-30 projects.

5.4 IN-LAKE MANAGEMENT

5.4.1 Internal Nutrient Load Control

Four Lakes--Bald, Bur Oaks, Fitz, and LeMay--were identified as having internal P loading large enough to recommend alum applications as viable options for lake phosphorus management. Over half of each of these lakes' TP budgets is from internal phosphorus loading. Although LeMay Lake only receives 13% of total TP budget from internal sources, the large reductions necessary to achieve state water quality standards are difficult to meet with only watershed projects.

Two calculations are necessary to determine the amount of alum needed to reduce internal loading effectively. First, the dosing area (m^2) needs to be determined. For Bald and LeMay lakes, the maximum area influenced by anoxic overlying water was selected as the most effective area to be treated with alum. This area was assumed to be the greatest source of phosphate release. For Fitz and Bur Oaks lakes, alum would be applied to areas deeper than 5 feet.

Sediment cores from each lake were collected and analyzed for redox-bound phosphorus (redox-p) to estimate the amount of alum needed to adsorb redox-sensitive phosphorus. Sediment redox-p concentrations were then converted to an aluminum-to-phosphorus ratio large enough to adsorb 90% of the available sediment redox-p ($Al:P_{90\%}$) using an empirical relationship developed by James and Bischoff (in prep). The alum dose per area (m^2) was calculated by multiplying $Al:P_{90\%}$ ratio by the redox-p in the uppermost 10 cm of each lake.

The unit area alum dose (Al g/m^2) can then be multiplied by the dosing area to determine the mass of aluminum needed. For these cost estimates, a buffered alum solution was included as a conservative assurance because it is currently unknown whether alum applications in LeMay, Bald, Bur Oaks, or Fitz lakes would cause pH to decrease temporarily to unacceptable levels. Buffered alum solutions generally include aluminum sulfate and sodium aluminate, which cost an estimated $2.00 and $5.00 per gallon, respectively. An assumed 2:1 aluminum sulfate-to-sodium aluminate ratio would be used in the Bald, Bur Oaks, LeMay, and Fitz lake treatments.

Assuming the aforementioned, the cost for each initial alum treatment is outlined in Table 5.2. Although alum is a proven method for substantially reducing internal loading from lake sediments, such treatments can degrade over time. The combination of sedimentation and alum structural changes may require an additional treatment during its estimated 30-year life cycle. Thus, a second but reduced alum application is included in each cost estimate to ensure long-term limits of phosphorus release from sediments.

None of the lakes proposed for alum treatments currently have public boat access. A joint effort between the contractor and City would be needed for alum equipment to access each lake.

Other lakes that may benefit from internal load reduction are listed in Table 5.3, but none are recommended as candidates in near term for alum dosing. Alum dosing is not a priority in these lakes because they either have relatively small potential internal load reductions or are not considered impaired.

Table 5.2. Cost estimates for alum treatments in Bald, Bur Oaks, Fitz, and LeMay.

Lake	Average Annual Internal Total Phosphorus Load (lbs)	Total Annual Phosphorus Load Reduction (lbs)	Initial Alum Application Cost	Project Cost (30 Year Life Cycle)	Cost Efficiency[1] ($/lb)
Bald	18.8	9.1	$ 158,400	$ 187,000	$ 567
Bur Oaks	7.0	5.0	$ 122,100	$ 145,800	$ 972
Fitz	26.8	19.0	$ 139,400	$ 163,900	$ 288
LeMay	19.9	10.4	$ 101,000	$ 122,000	$ 387

Table 5.3. Lakes with potential internal load reduction.

Lake	Annual Internal Total Phosphorus Load (lbs)	Potential Internal Load Reduction (lbs)
Carlson	13.2	5.7
Cliff	31.6	22.5
Holz	12.4	4.2
O'Leary	4.1	2.0
Quigley	8.5	2.9

5.4.2 Fisheries Management and Monitoring

Fisheries management is critical in maintaining clear water conditions in shallow lakes. Ideally, the fish community is balanced between top predators and panfish populations, lacks stunting in the panfish community, and has low numbers of fathead minnows and rough fish. The lakes also lack carp populations or if carp are present, they are managed to maintain low densities of carp. Following is a description of fish management activities to be considered for these shallow lakes in Eagan. See also Table 5.4.

5.4.2.1 Fathead Minnow Management

City staff noted three of the lakes (Bald, O'Leary, and Quigley) at some point in the past had high numbers of fathead minnows, which can negatively affect water quality in shallow lakes by exerting heavy grazing pressure on large zooplankton. Large zooplankton help support clear water through efficient grazing of algal populations. There are a number of ways to manage fathead minnows in shallow lakes, including stocking top predators (e.g., walleye, bass, and northern pike). However, these three lakes are not considered long-term habitat for fish such as walleye because they lack suitable spawning areas and tend to winter kill. The city's aeration program may contribute to fathead minnow survival secondarily to its intended purpose of supporting game fish populations. It is also possible but not reliable that winterkills will reduce fathead minnow populations in some years.

5.4.2.2 Bullhead and Roughfish Management

Bullheads and carp contribute to poor water clarity by stirring up sediments and uprooting submerged aquatic vegetation. None of the lakes are known to have carp populations, and ideally their introduction will continue to be prevented. Also, Fitz Lake's sizeable bullhead population would be reduced or managed. Options include physical removal using seine nets, chemical removal using rotenone, or stocking top predators such as channel catfish or walleye.

5.4.2.3 Fish Monitoring

Regular monitoring of the fish community by the Minnesota DNR and/or the city will continue to provide information to evaluate any changes that may need to be addressed, including fishery balance, rough fish (especially carp), and decline in numbers or biomass. Ideally each lake will be surveyed once every five years, according to DNR standard protocol.

5.4.2.4 Invasive Species Prevention

Invasive species such as carp, zebra and Quagga mussels, rusty crayfish, New Zealand Mud snail, Chinese and Banded Mystery Snail, , and spiny water fleas can have significant negative effects on the biological communities in lakes. Prevention is much less expensive than control in the long term, so education about these species, how they spread, and what individual lake users can do is critical in preventing their introduction to the lakes.

Table 5.4. Fisheries management activities for the Neighborhood Lakes.

Lake	Management Action	Responsible Party	Fisheries Condition	Current Management	Estimated Annual Cost
Bald	Fisheries Survey	City of Eagan	No data.	Annual aeration as needed; Stocked bluegills in 2010, LMB in 2012	In-Kind
	Fathead Minnow Management	City of Eagan; MnDNR	Potentially large population of fathead minnows	Maintain population of LMB as predators.	$2,000 as needed.
Bur Oaks	Fish stocking as needed to maintain balance.	City of Eagan; MnDNR	Relatively balanced fishery although panfish may be small in size.	Annual aeration as needed; Stocked LMB & BLG in 2014 after winterkill due to aerator problems.	$2,000 as needed.
Carlson	Fish stocking as needed to maintain balance.	City of Eagan; MnDNR	Fish count low in 2012 with small panfish population that is small in size.	Modest stocking of walleye, bluegill, black crappie, and largemouth bass, and channel catfish.	$2,000 as needed.
Cliff	Top predator stocking such as largemouth bass or northern pike.	City of Eagan; MnDNR	Large number of small panfish. Good number of largemouth bass.	Annual aeration as needed.	$4,000 now. $2,000 as needed.
Fitz	Bullhead Management or top predator stocking.	City of Eagan; MnDNR	Lacks panfish population. Dominated by bullheads.	Sampling to determine if BLB survived 2013-14 winter.	$5,000
Hay	Fish stocking as needed to maintain balance.	City of Eagan; MnDNR	Small overall fish population with some bullheads.	Annual aeration as needed; DNR restocked BLG after winterkill in 2013-14.	$2,000 as needed.
Holz	Top predator stocking such as largemouth bass or northern pike.	City of Eagan; MnDNR	Large number of small panfish. Good number of largemouth bass.	Annual aeration as needed.	$4,000 now. $2,000 as needed.
LeMay	Top predator stocking such as largemouth bass or northern pike.	City of Eagan; MnDNR	Large number of small panfish. Some bullheads.	Annual aeration as needed; Restocked LMB and BLG in 2014 after 2013-14 winterkill.	$4,000 now. $2,000 as needed.
LP-30	Fish survey in 2014.	City of Eagan	No data.	Discuss options with IGH.	In-Kind
North	Fish stocking as needed to maintain balance.	City of Eagan	Small number of fish. Panfish are small in size.	Run lift station as needed/possible in low oxygen conditions.	$2,000 as needed.
O'Leary	Fathead Minnow Management	City of Eagan; MnDNR	Potentially large population of fathead minnows	None.	$5,000
Quigley	Fathead Minnow Management	City of Eagan; MnDNR	Potentially large population of fathead minnows	None.	$5,000

Table 5.4 (continued). Fisheries management activities for the Neighborhood Lakes.

Lake	Management Action	Responsible Party	Fisheries Condition	Current Management	Estimated Annual Cost
All Lakes	Invasive Species Prevention – Education and Signage	City of Eagan; MnDNR	Carp have not been identified in any of these lakes. No other invasive species that affect fisheries has been identified.	Education	$3,000

5.4.3 Aquatic Vegetation Management and Monitoring

Submerged aquatic vegetation is critical in maintaining the clear water state in the shallow lakes of this study. Most of the lakes have stable plant populations, but are dominated by one or two species including coontail. While this condition supports clear water, it doesn't support the breadth of wildlife and fish that would be expected with submerged vegetation. Managing a shallow urban lake for plant diversity is poorly understood, however, and most efforts use mechanical removal or herbicides. The management goal of these lakes ideally is to maintain current populations, manage invasive species such as Curly-leaf pondweed, and increase diversity where possible through nutrient and water level management and via changes in sediment chemistry ultimately (Table 5.5).

5.4.3.1 Diversity Management

Almost all of the lakes are dominated by coontail, which is typical of nutrient enriched, urban lakes with relatively stable water elevations. Even though it is a native species, coontail can dominate a lake by extensively matting the surface. Coontail management is currently poorly understood, and the only effective tools are physical removal and herbicide treatments. None of the lakes currently have coontail at chronic, extensive levels. Increasing plant diversity in these lakes is likely tied to nutrient management and changes in sediment chemistry. In the short term, nutrient management is the best approach for aquatic vegetation diversity in these lakes.

Most of the lakes are robustly covered in native vegetation that supports the clear lake state. In comparison, plant surveys indicate Holz Lake only has 40% coverage in vegetation.

5.4.3.2 Curly-leaf Pondweed Control

Curly-leaf pondweed is a non-native plant that can have negative impacts on lake water quality and recreation if the population reaches extensive levels (high density, breaks the surface). It establishes under the ice, giving it a competitive advantage over native vegetation after spring temperatures warm. When Curly-leaf pondweed dies in midsummer, the plant's TP is released into the water.

Many studies and projects throughout the country over the years have focused on Curly-leaf pondweed and its effective management. However, both are poorly understood. At a minimum, any attempts to control this plant would begin with relatively simple monitoring of its extent and density in early season. Further determinations of what, if any, actions to take and when are not as simple, however. As with other lake plants, typical controls include chemical treatment and physical removal, but iron added to sediment and lake drawdowns before winter have also been done. All of the lakes except LP-30, O'Leary and Quigley have Curly-leaf pondweed. Only Holz Lake appears to have high densities in the early season. Routine monitoring of all of the study lakes will help the city increase its understanding of the extent of Curly-leaf pondweed.

5.4.4 Assess and Manage Filamentous Algae

Bur Oaks Lake and LP-30 have filamentous algae blooms that form mats on the surface throughout the summer. Filamentous algae start their life cycle on the sediments and are typically driven by internal phosphorus release.

Filamentous algae may be monitored and assessed, but there is no quantitative distinction of when a filamentous algae bloom is a nuisance, and most shallow lakes have filamentous algae, especially in very shallow areas. A basic point intercept evaluation of mat coverage may provide a repeatable assessment strategy. However, simple observations throughout the year are often adequate for determining the extent of lake filamentous algae.

Filamentous algae can be quite difficult to control, with very few options for limiting the growth. Algae management efforts that focus on internal phosphorus release from the sediments, from where the majority of nutrients for filamentous algae come, may be the most effective strategy in the long term. Physical removal of algae mats is an option; however, this would be an ongoing activity that would require an annual budget for city staff time to coordinate and implement. Based on local evidence, alum additions to these lakes will reduce filamentous algae blooms.

5.4.4.1 Invasive Species Prevention

The prevention of invasive species is critical to maintaining a healthy biological community in the lakes. Invasive species such as Eurasian water milfoil, hydrilla, flowering rush, and purple loosestrife can reduce the diversity of the plant community and choke out native species. Prevention is much less expensive than control in the long term, so education about these species, how they spread, and what individual lake users can do is critical in preventing their introduction.

Table 5.5. Submerged aquatic vegetation management activities for the neighborhood lakes.

Lake	Management Action	Responsible Party	Vegetation Condition	Estimated Cost
Bald	Monitor and Control Curly-leaf pondweed when necessary	City of Eagan	Curly-leaf pondweed established	$4,000 annually
Bur Oaks	Monitor and Control Curly-leaf pondweed when necessary	City of Eagan	Curly-leaf pondweed established; filamentous algae covers 48% of lake in August	$4,000 annually
	Filamentous algae monitoring and control	City of Eagan		$145,800 alum treatment
Carlson	Monitor and Control Curly-leaf pondweed when necessary	City of Eagan	Curly-leaf pondweed established	$4,000 annually
Cliff	Monitor and Control Curly-leaf pondweed when necessary	City of Eagan	Curly-leaf pondweed established	$4,000 annually
Fitz	Monitor and Control Curly-leaf pondweed when necessary	City of Eagan	Curly-leaf pondweed established	$4,000 annually
Hay	Monitor and Control Curly-leaf pondweed when necessary	City of Eagan	Curly-leaf pondweed established; Heavy growth of native vegetation in summer	$4,000 annually
	Filamentous algae monitoring and control	City of Eagan		$4,000 annually
Holz	Monitor and Control Curly-leaf pondweed when necessary ; selective treatment when necessary	City of Eagan	Curly-leaf pondweed established; dominant in early season; Harvesting conducted historically but not in recent years. Only 40% coverage of lake in vegetation	$4,000 annually; $7,000 annually for control
LeMay	Monitor and Control Curly-leaf pondweed when necessary	City of Eagan	Curly-leaf pondweed established	$4,000 annually
LP-30	Filamentous algae monitoring and control	City of Eagan	Filamentous algae covers 27% of lake in August	$36,200 alum treatment
North	Monitor and Control Curly-leaf pondweed when necessary	City of Eagan	Curly-leaf pondweed established	$4,000 annually
O'Leary	Monitor	City of Eagan		$4,000 annually
Quigley	Monitor	City of Eagan	Heavy growth of native vegetation in summer	$4,000 annually
All Lakes	Invasive Species Prevention – Education and Signage; Prevention of Eurasian water milfoil, Curly-leaf pondweed, hydrilla, purple loosestrife, and flowering rush	City of Eagan	None of these species are currently present in the lakes except for flowering rush in Holz Lake.	$2,000 annually

5.5 EDUCATION AND OUTREACH

Public information and education is a top priority of Eagan's water quality program. It plays an essential role in protecting aquatic habitat and recreational values by increasing awareness about reducing pollutants at their sources through changes in behavior. The program has three primary objectives:

1. Recognition of the direct connection between the stormwater drainage system and many of the lakes and wetlands in the community;
2. Importance of keeping vegetative materials, fertilizers, and chemical wastes away from streets and driveways where they can enter the stormwater system; and
3. Awareness of restrictions on lawn fertilizers containing phosphorus.

5.6 WATER QUALITY MONITORING

The city routinely monitors the neighborhood lakes for water quality, including TP, chlorophyll-*a* and Secchi depth as well as field parameters such as dissolved oxygen and temperature. This monitoring will continue in the future.

5.7 WATERSHED BMP DESCRIPTIONS

BMP projects were evaluated in each lake subwatershed to identify opportunities that reduce watershed total phosphorus load. The projects presented in the following sections are based on an initial review of the existing infrastructure and contour information made available by the city. For each project identified, an approximate watershed load, BMP load reduction, and preliminary 30-year life cycle cost will be identified. For all of these projects, costs do not include easement or land acquisition. Detailed project cost estimates are provided in Appendix I. It is important to note that these projects represent a list of potential projects that can be implemented to meet phosphorus load reduction goals. It is important to note that some actions targeting external loading may not be applied toward a reduction to meet a WLA. Such projects may include treatment within a water feature considered a water of the state. For clarification on a particular project proposers should contact the MPCA Stormwater Program. Also, as more information is gathered, some of the projects may be determined infeasible due to site restrictions, lack of easements, or other unforeseen conditions. The City of Eagan intends to use this study to inform implementation of their stormwater program.

5.7.1 LeMay and O'Leary Lakes

5.7.1.1 Basin DP-3 Improvements

Basin DP-3 receives stormwater from a large commercial and industrial area with opportunity for expansion and outlet modifications to improve total phosphorus removal. Approximately 24% of the LeMay Lake subwatershed is routed through Basin DP-3 and the estimated existing total annual phosphorus load discharging the basin is approximately 62 lbs. Basin DP-3 was evaluated for an iron enhanced filtration system with outlet modification, basin expansion, and combination of expansion and filtration system. The basin improvements were assessed by evaluating current site constraints and load reduction potential. An iron enhanced filtration system could be integrated into the existing outlet system and treat runoff from the 0.75 inch, 24-hour precipitation event. The basin also has potential for an estimated additional 2.6 acre-feet by excavating the adjacent land on the northeast shoreline. The estimated annual load reduction and 30-year life cycle cost for three project alternatives are listed below. The project layout based on the feasibility and preliminary designs are shown in Figure 5.8.

Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 28 lbs
Estimated 30-year Life Cycle Cost: $270,000

Basin Expansion
Estimated Annual Load Reduction: 4 lbs
Estimated 30-year Life Cycle Cost: $452,000

Basin Expansion and Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 31 lbs
Estimated 30-year Life Cycle Cost: $667,000

Figure 5.8. Basin improvement projects for DP-3.

5.7.1.2 Basins DP-4A, DP-4B and DP-26 Improvements

Basins DP-4A, DP-4B and DP-26 receive stormwater from approximately 56% of the LeMay Lake subwatershed that consists of industrial, commercial, retail and residential land uses. The estimated existing total annual phosphorus load discharging basin DP-26 is approximately 50 lbs. Basins DP-4A, DP-4B and DP-26 were evaluated for an iron enhanced filtration system with outlet modification, and the basin improvements were assessed by evaluating current site constraints and load reduction potential. An iron enhanced filtration system could be integrated into the existing outlet system and treat runoff from the 1.0 inch, 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. The project layout based on the feasibility and preliminary design is shown in Figure 5.9.

Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 28 lbs
Estimated 30-year Life Cycle Cost: $1,285,000

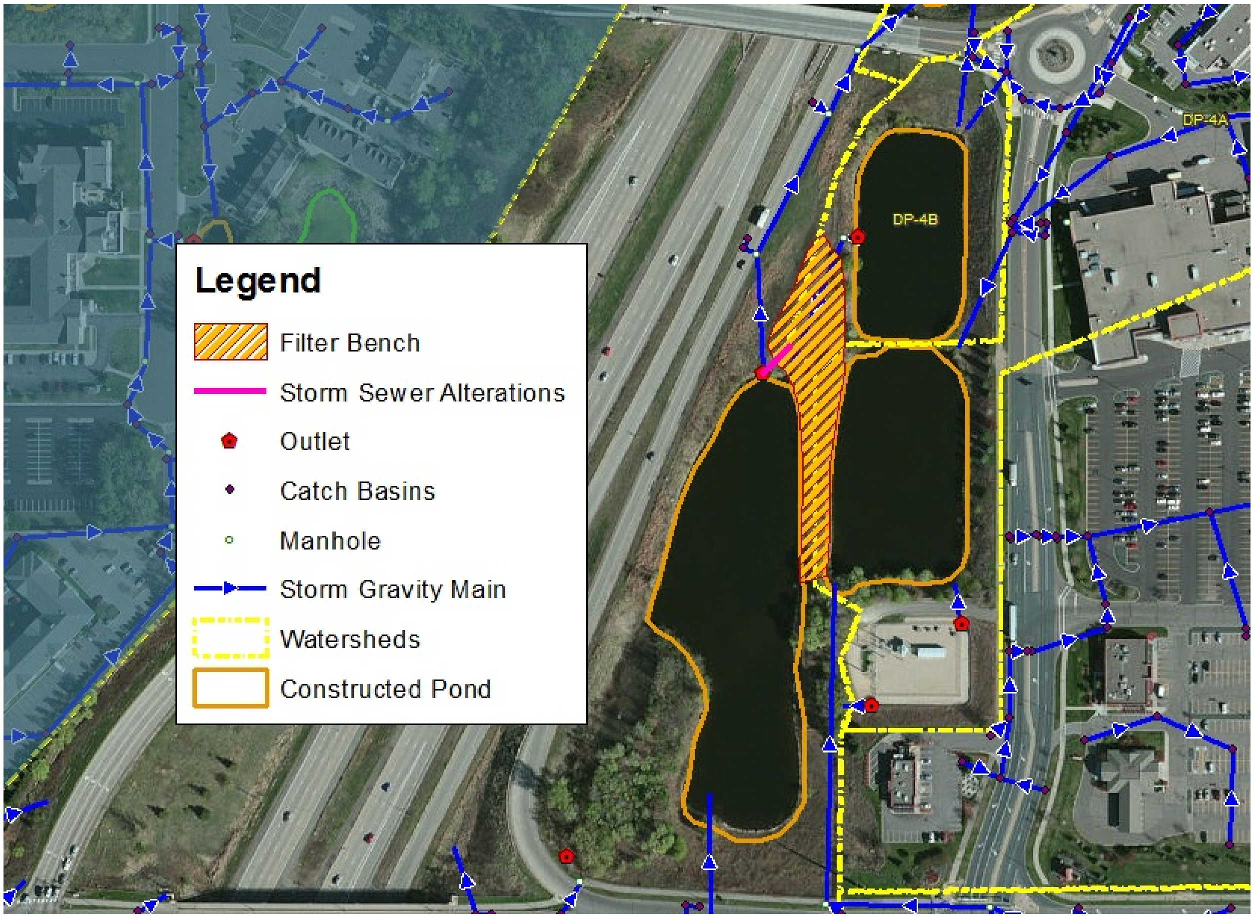


Figure 5.9. Basin improvement project for Basins DP-4A, DP-4B, DP-26.

5.7.1.3 Basin DP-4.2 Improvements

Basin DP-4.2 receives stormwater from approximately 5% of the LeMay Lake subwatershed that consists of retail and commercial land use. The estimated existing total annual phosphorus load discharging basin DP-4.2 is approximately 13 lbs. Basin DP-4.2 was evaluated for an iron enhanced filtration system with outlet modification, and the basin improvements were assessed by evaluating current site constraints and load reduction potential. An iron enhanced filtration system could be integrated into the existing outlet system and treat runoff from the 2.0 inch 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. The project layout based on the feasibility and preliminary design is shown in Figure 5.10.

Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 10 lbs
Estimated 30-year Life Cycle Cost: $306,000

Figure 5.10. Basin improvement project for Basin DP-4.2.

5.7.1.4 Stormwater Reroute and Basin DP-2.3 Improvements

There is an opportunity to reroute stormwater to Basin DP-2.3 and increase the watershed that is treated to approximately 20 acres, which is approximately 2% of the LeMay Lake subwatershed. The primary land use of the watershed that would be routed to basin DP-2.3 consists of industrial and commercial land use. The estimated total potential annual phosphorus load that can be treated at basin DP-2.3 is approximately 10 lbs. Basin DP-2.3 was evaluated for an expansion and an iron enhanced filtration system with outlet modification, and the basin improvements were assessed by evaluating current site constraints and load reduction potential. The basin could be expanded to 0.9 acre-feet of storage with an iron enhanced filtration system integrated into the existing outlet system. The basin improvements were sized to treat runoff from the 1.0 inch 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. The project layout based on the feasibility and preliminary design is shown in Figure 5.11

Basin Expansion and Iron Enhanced Filtration System
Estimated Annual Load Reduction: 6 lbs
Estimated 30-year Life Cycle Cost: $123,000

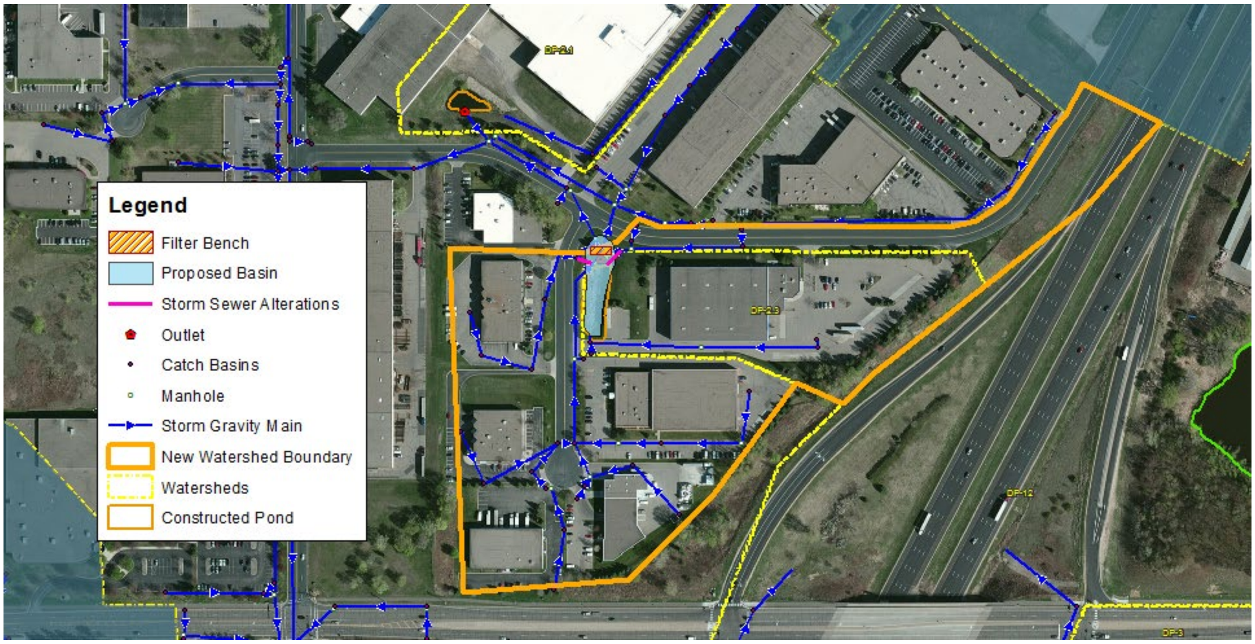


Figure 5.11. Basin improvement project for Basin DP-2.3.

5.7.1.5 Stormwater Improvements to Watershed DP-4A_2

The land use in subwatershed DP-4A_2 is primarily retail and commercial, and the runoff is untreated before it discharges to basin DP-4A. There is opportunity to treat approximately 8 acres of impervious commercial and retail area to improve treatment to stormwater runoff. The estimated potential annual total phosphorus load that can be treated from the 8 acres is approximately 5 lbs. Two project alternatives were evaluated to improve treatment within the subwatershed. The first potential project is to route the 8 acres to a proposed basin designed to meet NURP criteria with a permanent pool equivalent to the runoff from the 2.5 inch, 24-hour precipitation event. The basin can include an iron enhanced filtration system as an outlet to provide additional total phosphorus load reduction. Based on an initial review, the iron enhanced filtration system was sized to treat runoff from the 2.5 inch, 24-hour precipitation event.

The second alternative option to treat the runoff from the 8 acres is to utilize two underground storage areas with iron enhanced filtration systems. Pervious pavement above the underground storage areas provides access for the stormwater runoff to enter the underground storage areas where it can be filtered. The underground storage areas are sized to store and filter the runoff from the 2.5 inch, 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the projects are listed below. The stormwater reroute with basin project alternative based on the feasibility and preliminary design is shown in Figure 5.12. The underground storage and filtration system with pervious pavement project alternative based on the feasibility and preliminary design is shown in Figure 5.13.

Stormwater Reroute with Basin and Iron Enhanced Filtration System
Estimated Annual Load Reduction: 4 lbs
Estimated 30-year Life Cycle Cost: $364,000

Pervious Pavement and Underground Iron Enhanced Filtration System

Estimated Annual Load Reduction: 4 lbs
Estimated 30-year Life Cycle Cost: $686,000

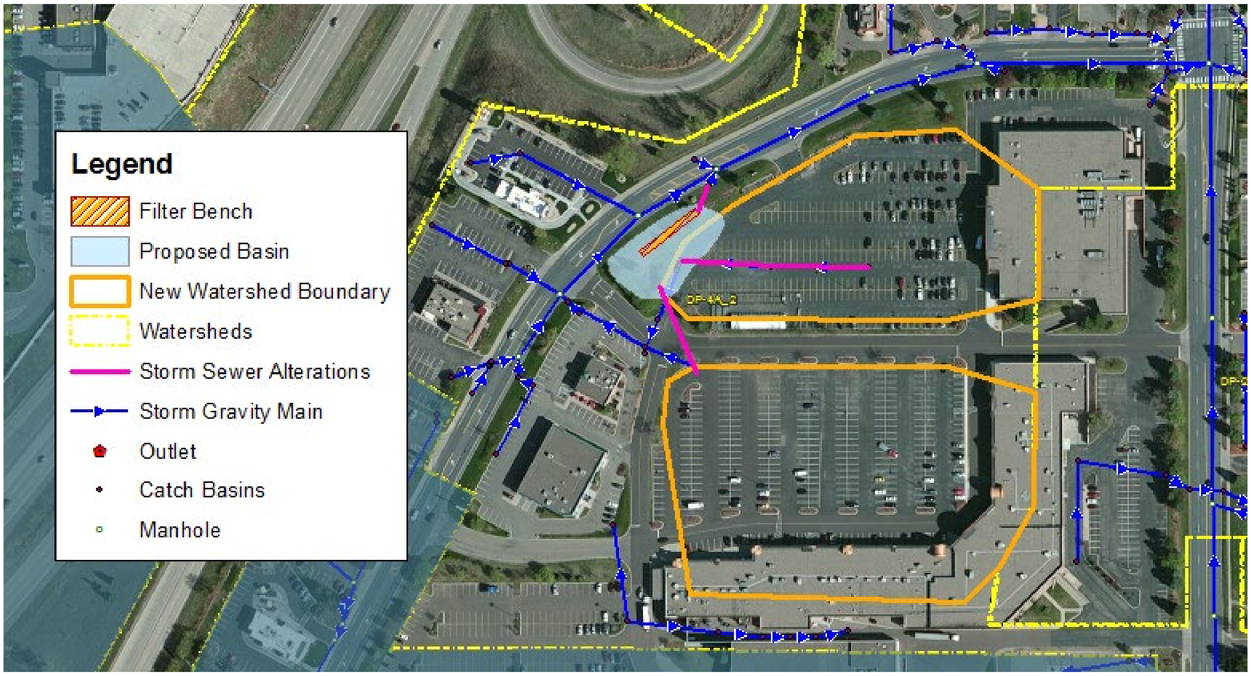


Figure 5.12. Stormwater Reroute with Basin Project Alternative for Watershed DP-4A_2.

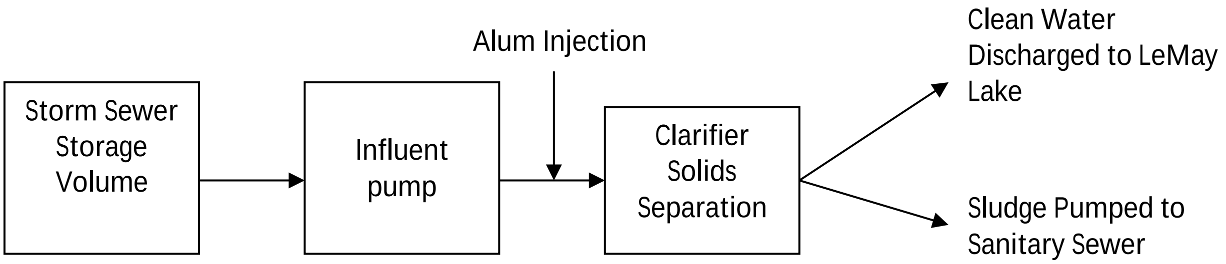
Figure 5.13. Underground storage and filtration system with pervious pavement project alternative for Watershed DP-4A_2.

5.7.1.6 Stormwater Improvements to Watershed DP-2

Land uses in the DP-2 subwatershed are primarily retail, commercial, and industrial with some high density residential. The runoff from the watershed is mostly untreated and is routed through a 48-inch and 54-inch diameter pipe before it discharges to LeMay Lake via a 72-inch pipe. The trunk storm sewer system that drains the subwatershed is deep, reaching approximately 20 feet below the surface. Two alternative solutions were developed for the DP-2 subwatershed that consider using the existing pipe system as temporary storage, replacing the manhole structure immediately upstream of the lake, and retrofitting with a low flow bypass diversion weir. The estimated existing total annual runoff phosphorus load from the rerouted watershed is approximately 70 lbs.

The first option is to gravity drain low flows from the diversion structure in two 36-inch diameter pipes to an above ground iron enhanced filtration system along the east side of LeMay Lake. The iron enhanced filter system is sized to provide treatment to the 1-inch, 24-hour rainfall event.

The second alternative is to gravity drain low flows from the diversion structure to a lift station that feeds an above ground clarifier. Alum is injected into the stormwater prior to entering the clarifier. Alum floc is settled to the bottom of the clarifier which is connected to the sanitary sewer. The general process flow diagram is shown below.



The estimated annual load reduction and 30-year life cycle cost for the projects are listed below. The stormwater diversion with filtration basin project alternative is shown in Figure 5.14. The stormwater treatment by clarifier project alternative is shown in Figure 5.15.

Stormwater Reroute and Iron Enhanced Filtration Basin
Estimated Annual Load Reduction: 38 lbs
Estimated 30-year Life Cycle Cost: $1,500,000

Stormwater Reroute and Clarifier System
Estimated Annual Load Reduction: 44 lbs
Estimated 30-year Life Cycle Cost: $3,090,000

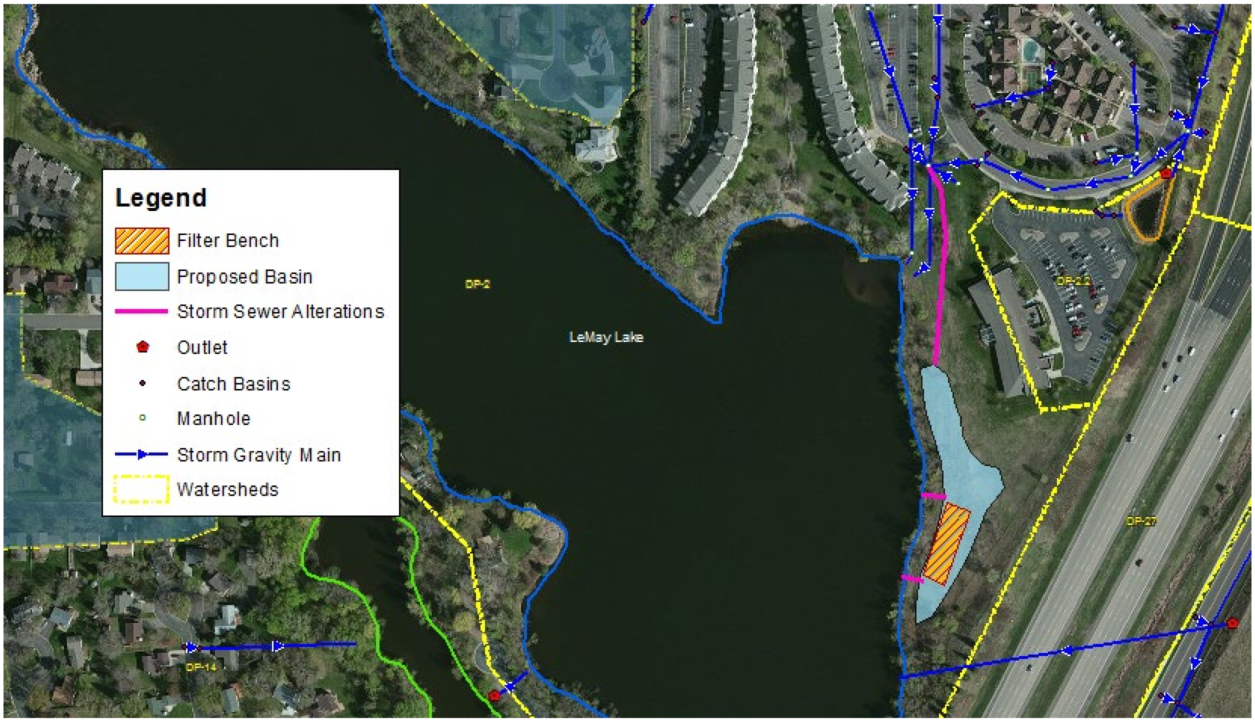


Figure 5.14. Stormwater reroute with iron enhanced filtration basin project alternative for Watershed DP-2.

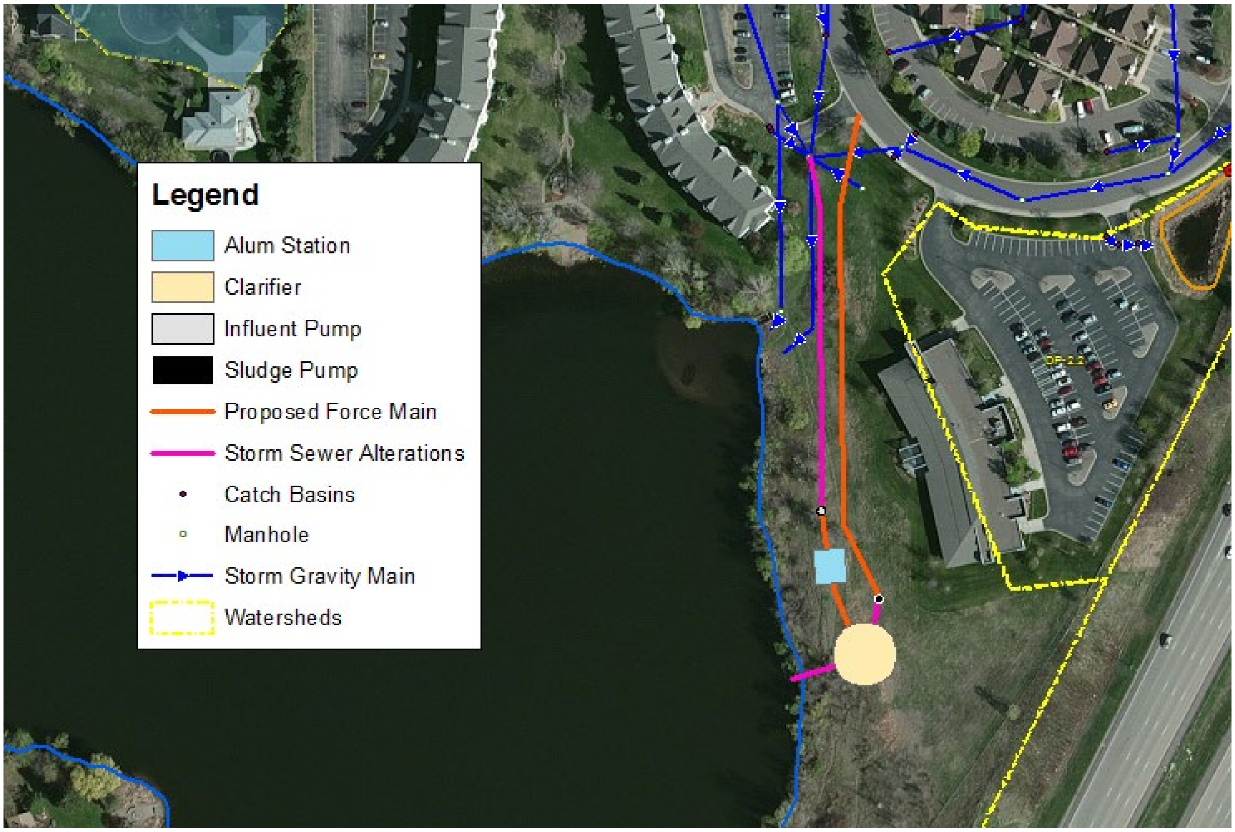


Figure 5.15. Stormwater reroute with treatment by clarifier project alternative for Watershed DP-2.

5.7.2 Bald Lake

5.7.2.1 Bald Lake Residential Rain Garden and Street Sweeping Programs

The Bald Lake watershed consists of residential neighborhoods. Approximately 19 acres discharge runoff to residential streets prior to entering the storm sewer system. Annually an estimated 5 lbs of potential total phosphorus load comes from this area. A neighborhood rain garden program could target treatment of low flow events and provide future protection from total phosphorus loading. Approximately 90 residences were identified as potential candidates in a neighborhood rain garden program, which was evaluated by estimating the number of participating residences in the contributing watershed to determine the load reduction potential. The rain gardens were assumed to treat the 1-inch, 24-hour precipitation event for a contributing runoff area of 0.2 acres. Table 5.6 details the estimated load reduction and cost for the rain garden program. Figure 5.16 details the scope of the rain garden program.

An alternative to reduce the watershed load to Bald Lake is to increase the frequency of sweeping approximately 2.2 curb miles of residential streets. The annual total phosphorus load reduction, estimated as described by Law et al. (2008), with a 30-year life cycle cost is listed below. Figure 5.17 also details the scope of the street sweeping program.

Table 5.6. Bald Lake residential rain garden program.

Percent of Participating Residences	Number of Participating Residences	Estimated Load Reduction (lbs)	Estimated 30-year Life Cycle Cost
10%	9	0.3	$ 72,000
15%	14	0.5	$ 112,000
20%	18	0.6	$ 144,000
25%	23	0.8	$ 184,000
50%	45	1.6	$ 360,000

Street Sweeping Program
Estimated Curb Miles: 2.2 Miles
Street Sweeping Frequency: (MAR-1, APR-2, MAY-2, SEP-1, OCT-2, NOV-2)
Estimated Annual Load Reduction: 0.5 lbs
Estimated 30-year Life Cycle Cost: $83,000

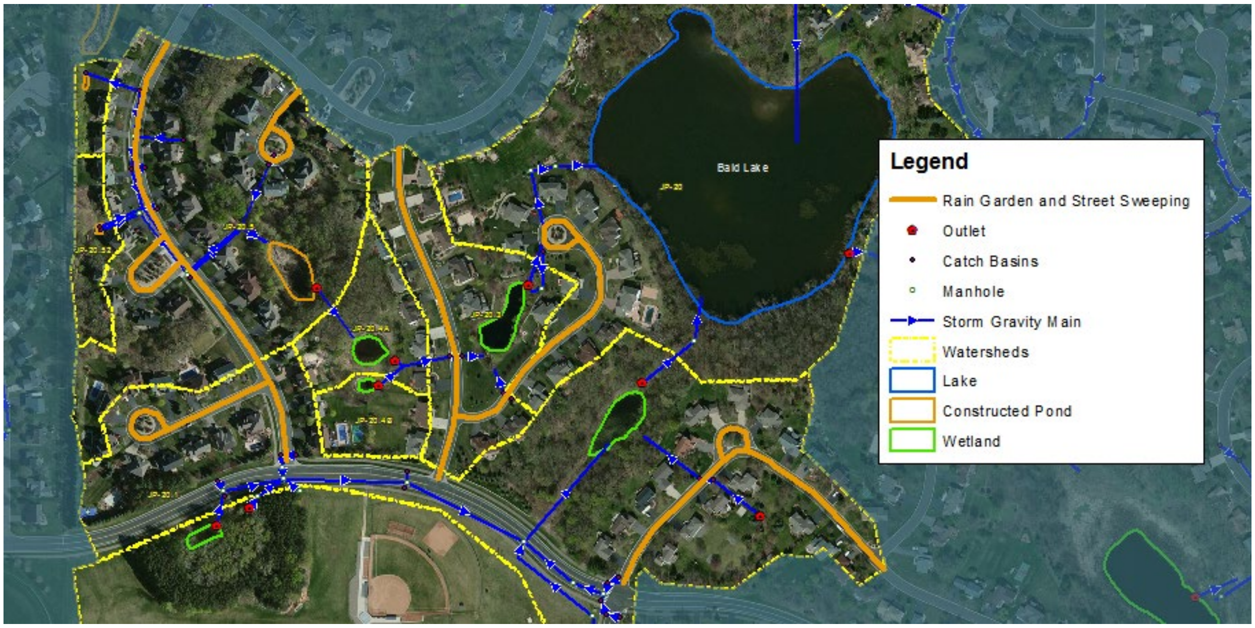


Figure 5.16. Neighborhood rain garden program and street sweeping programs for the Bald Lake neighborhoods.

5.7.2.2 JP-20.1 and JP-20.2 Stormwater Reuse irrigation System

There is opportunity to reuse stormwater runoff to irrigate a recreational area in the JP-20.1 and JP-20.2 watersheds. Land uses in these areas are primarily open space and residential. A stormwater reuse project would collect runoff from approximately 28 acres to irrigate an area of 1.25 acres. The system can be designed to irrigate a depth of 1 inch per week for 26 weeks. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. See Appendix I for more information on the project cost estimate. The stormwater reuse project based on the feasibility and preliminary design is shown in Figure 5.17.

Stormwater Reuse irrigation System
Estimated Annual Load Reduction: 1 lb
Estimated 30-year Life Cycle Cost: $409,000

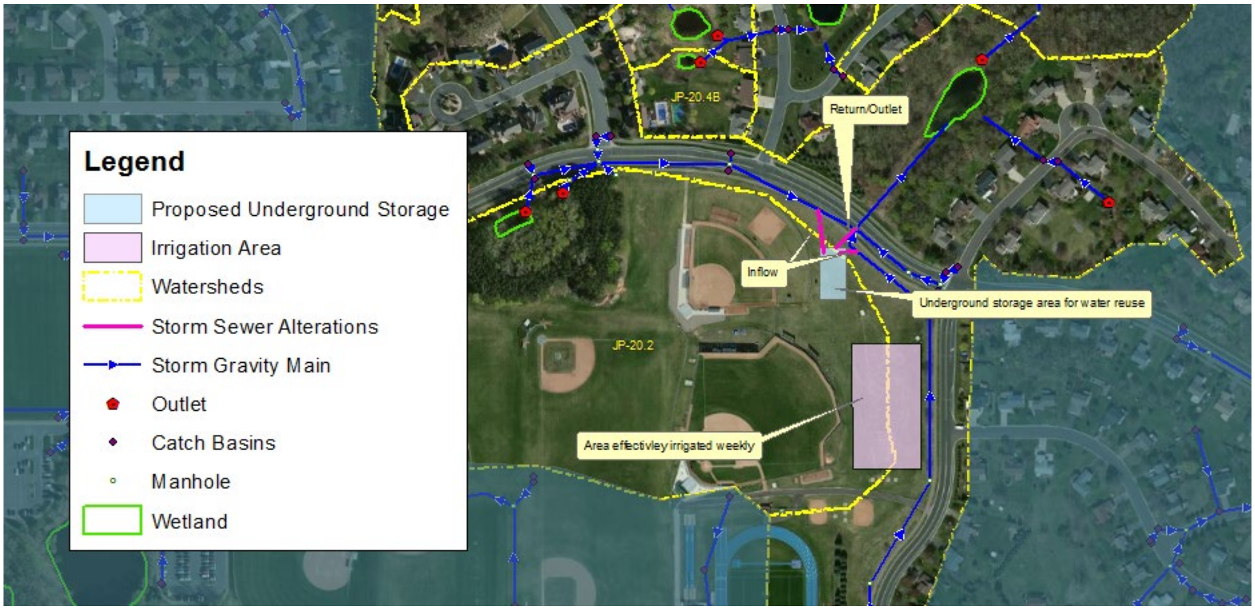


Figure 5.17. Stormwater irrigation reuse project for Watersheds JP-20.1 and JP-20.2.

5.7.2.3 Basin JP-20.5 Improvements

Basin JP-20.5 receives stormwater from approximately 15% of the Bald Lake subwatershed, which consists of residential neighborhoods. The basin’s estimated existing total annual phosphorus load is approximately 2 lbs. Basin JP-20.5 was evaluated for an iron enhanced filtration system with outlet modification, and the basin improvements were assessed by evaluating current site constraints and load reduction potential. An iron enhanced filtration system could be integrated into the existing outlet system and would treat runoff from the 1- inch, 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. The project layout based on the feasibility and preliminary design is shown in Figure 5.18.

Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 1 lbs
Estimated 30-year Life Cycle Cost: $91,000

Figure 5.18. Basin improvement project for Basin JP-20.5.

5.7.3 Bur Oaks and North Lakes

5.7.3.1 Basin GP-1.2 Improvements

Basin GP-1.2 receives stormwater runoff from industrial, commercial, residential, and open spaces platted for future industrial and commercial land use. Approximately 50% of the Bur Oaks Lake subwatershed is routed through Basin GP-1.2 and the estimated existing total annual phosphorus load discharging the basin is approximately 82 lbs. Basin GP-1.2 was evaluated for an iron enhanced filtration system with outlet modification, basin expansion, and combination of expansion and filtration system. The basin improvements were assessed by evaluating current site constraints and load reduction potential. An iron enhanced filtration system could be integrated into the existing outlet system and treat runoff from the 0.25-inch, 24-hour precipitation event. The basin also has potential for an estimated additional 7.2 acre-feet of dead storage by excavating the adjacent land and dredging the existing permanent pool. An iron enhanced filtration system could be combined with the basin expansion and have the potential to treat runoff from the 0.5-inch 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the three project alternatives are listed below. The project layout based on the feasibility and preliminary design is shown in Figure 5.19.

Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 14 lbs
Estimated 30-year Life Cycle Cost: $251,000

Basin Expansion
Estimated Annual Load Reduction: 16 lbs
Estimated 30-year Life Cycle Cost: $578,000

Basin Expansion and Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 38 lbs
Estimated 30-year Life Cycle Cost: $807,000

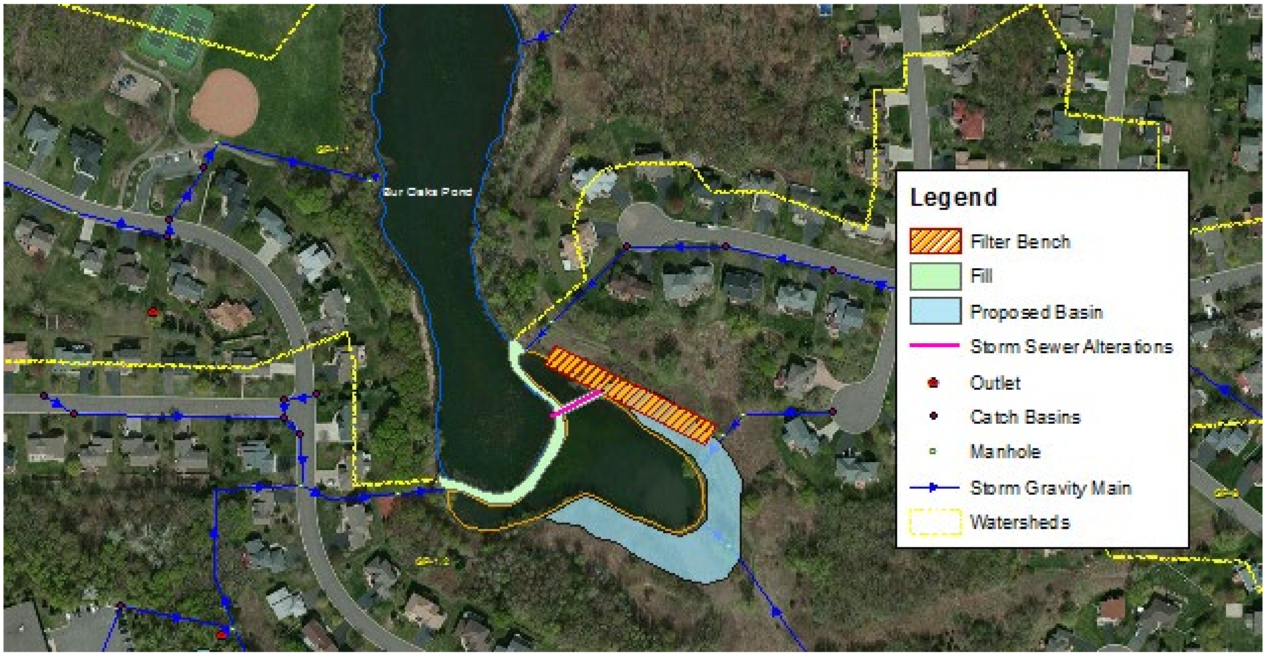


Figure 5.19. Basin improvement projects for Basin GP-1.2.

5.7.3.2 Basin EP-2.4_2 Improvements

Basin EP-2.4_2 receives stormwater from approximately 6% of the North Lake subwatershed, which consists of industrial and commercial land uses. The existing total annual phosphorus load discharging basin EP-2.4_2 is approximately 12 lbs. Basin EP-2.4_2 was evaluated for an iron enhanced filtration system with outlet modification, and the basin improvements were assessed by evaluating current site constraints and load reduction potential. An iron enhanced filtration system could be integrated into the existing outlet system and treat runoff from the 1- inch, 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. The project layout based on the feasibility and preliminary design is shown in Figure 5.20.

Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 7 lbs
Estimated 30-year Life Cycle Cost: $129,000

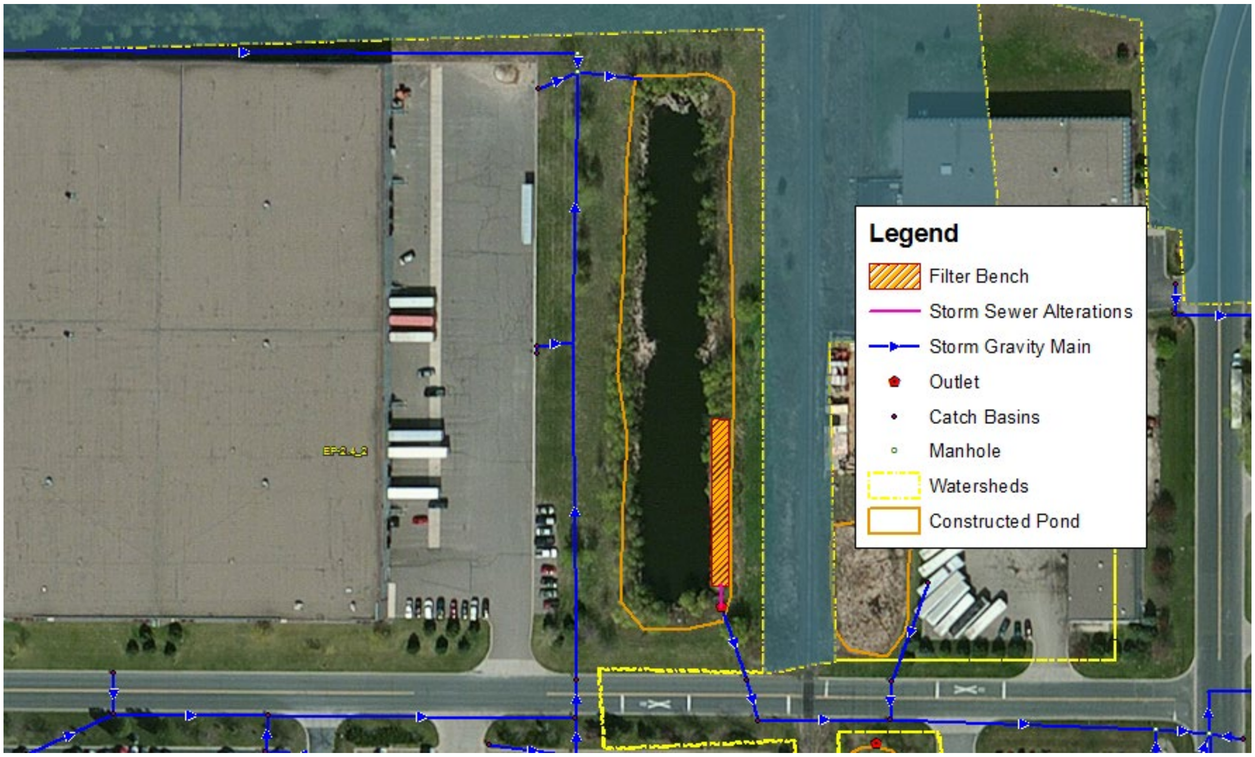


Figure 5.20. Basin improvement project for Basin EP-2.4_2.

5.7.3.3 Basin EP-2.91 Improvements

Basin EP-2.91 receives stormwater from less than 1% of the North Lake subwatershed, which consists of industrial land uses. The existing total annual phosphorus load discharging basin EP-2.91 is approximately 0.8 lbs. Basin EP-2.91 was evaluated for a basin expansion. Based on an initial review, the basin has potential for an estimated additional 0.3 acre-feet of dead storage by excavating the adjacent land and dredging the existing permanent pool. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. The project layout based on the feasibility and preliminary design is shown in Figure 5.21.

Basin Expansion
Estimated Annual Load Reduction: 0.3 lbs
Estimated 30-year Life Cycle Cost: $55,000

Figure 5.21. Basin improvement project for Basin EP-2.91.

5.7.3.4 Basin EP-2.92 Improvements

Basin EP-2.92 receives stormwater from less than 1% of the North Lake subwatershed, which consists of industrial land use. The existing total annual phosphorus load discharging basin EP-2.92 is approximately 0.9 lbs. Basin EP-2.92 was evaluated for a basin expansion. Based on an initial review, the basin has potential for an estimated additional 0.9 acre-feet of dead storage by excavating the adjacent land and dredging the existing permanent pool. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. The project layout based on the feasibility and preliminary design is shown in Figure 5.22.

Basin Expansion
Estimated Annual Load Reduction: 0.4 lbs
Estimated 30-year Life Cycle Cost: $82,000

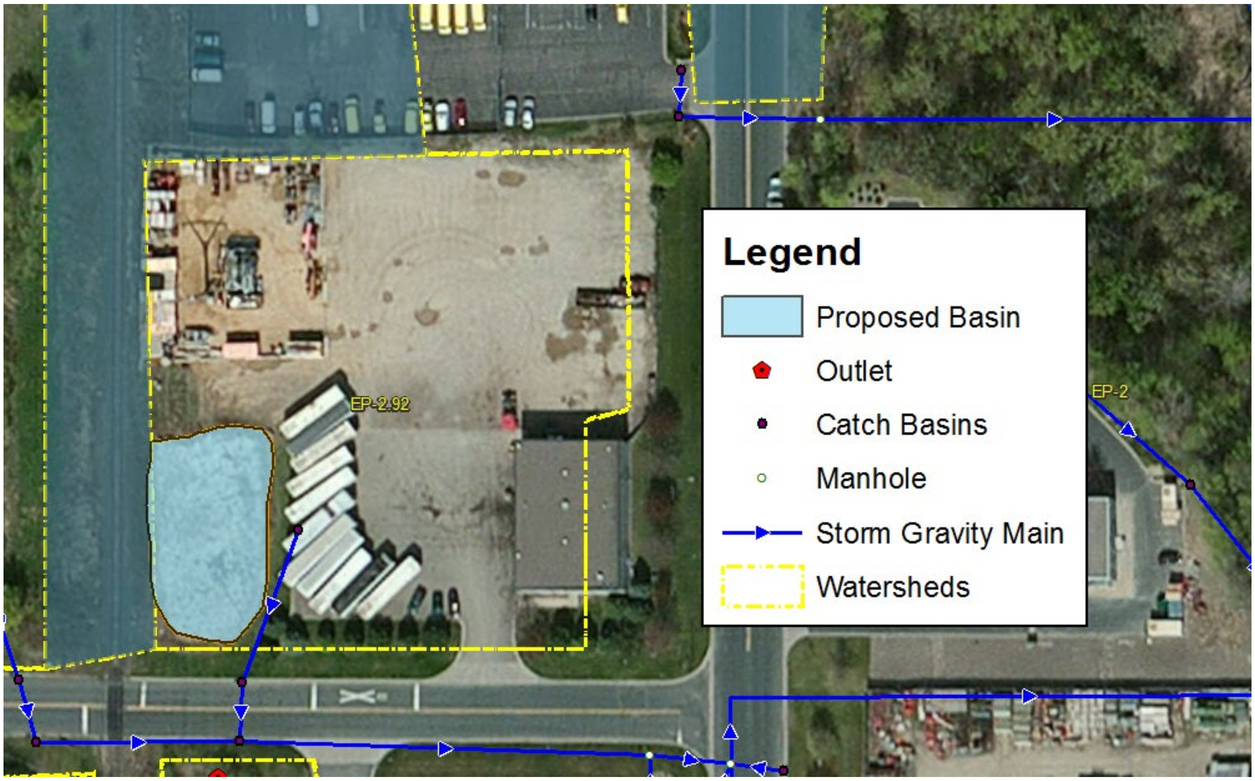


Figure 5.22. Basin improvement project for Basin EP-2.92.

5.7.4 Carlson Lake and Quigley Lake

5.7.4.1 LP-42 Stormwater Reroute and Underground Filtration System.

The Carlson Lake Direct watershed LP-42 primarily receives stormwater from residential area. There is opportunity to reroute approximately 90 acres of the LP-42 watershed to an underground filtration system for treatment prior to discharging into Carlson Lake. This reroute would treat approximately 16% of the Carlson Lake subwatershed that currently receives no treatment. The estimated existing total annual runoff phosphorus load from the rerouted watershed is approximately 11 lbs. The LP-42 watershed reroute was evaluated for an underground filtration system capable of treating runoff from the 1-inch, 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. The project layout based on the feasibility and preliminary designs are shown in Figure 5.23.

Stormwater Reroute and Underground Filtration System
Estimated Annual Load Reduction: 6 lbs
Estimated 30-year Life Cycle Cost: $803,000

Figure 5.23. Stormwater reroute with an underground filtration system.

5.7.4.2 LP-53 Stormwater Reroute and Iron Enhanced Filtration System.

Basin LP-53 receives stormwater runoff from a large residential area with opportunity to reroute the basin discharge into an underground filtration system. Approximately 47% of the Carlson Lake subwatershed is routed through Basin LP-53, and the estimated existing total annual phosphorus load discharging the basin is approximately 10 lbs. Basin LP-53 was evaluated for an underground iron enhanced filtration system and a surface iron enhanced filtration system capable of treating runoff from the 2.5-inch, 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the projects are listed below. The project layout based on the feasibility and preliminary designs are shown in Figure 5.24.

Stormwater Reroute and Underground Iron Enhanced Filtration System
Estimated Annual Load Reduction: 7 lbs
Estimated 30-year Life Cycle Cost: $1,064,000

Stormwater Reroute and Iron Enhanced Filtration Basin
Estimated Annual Load Reduction: 7 lbs
Estimated 30-year Life Cycle Cost: $669,000

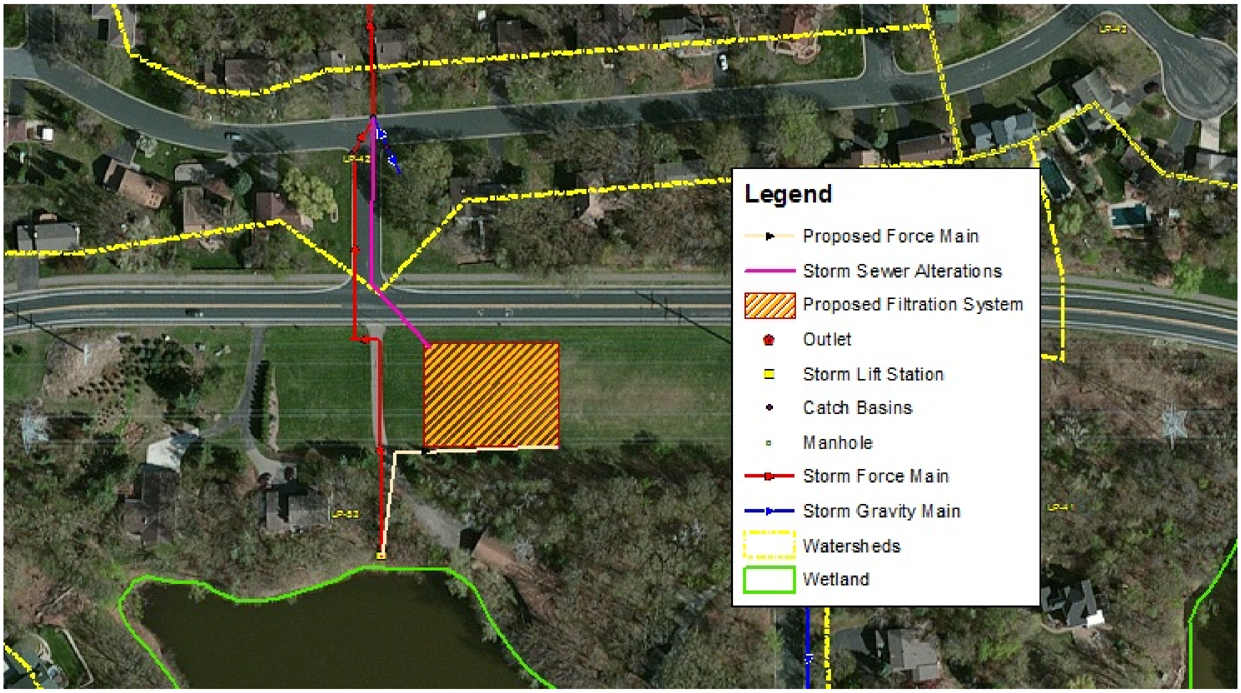


Figure 5.24. Stormwater reroute with underground and basin iron enhanced filtration system project alternatives for Watershed LP-53.

5.7.4.3 Basin LP-70 Improvements.

Basin LP-70 receives stormwater from residential and open area with opportunity for outlet modifications to improve total phosphorus removal. Approximately 26% of the Carlson Lake subwatershed is routed through Basin LP-70, and the estimated existing total annual phosphorus load discharging the basin is approximately 11 lbs. An iron enhanced filtration system could be integrated into the existing outlet system and treat runoff from the 0.1-inch, 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. The project layout based on the feasibility and preliminary designs are shown in Figure 5.25.

Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 6 lbs
Estimated 30-year Life Cycle Cost: $167,000

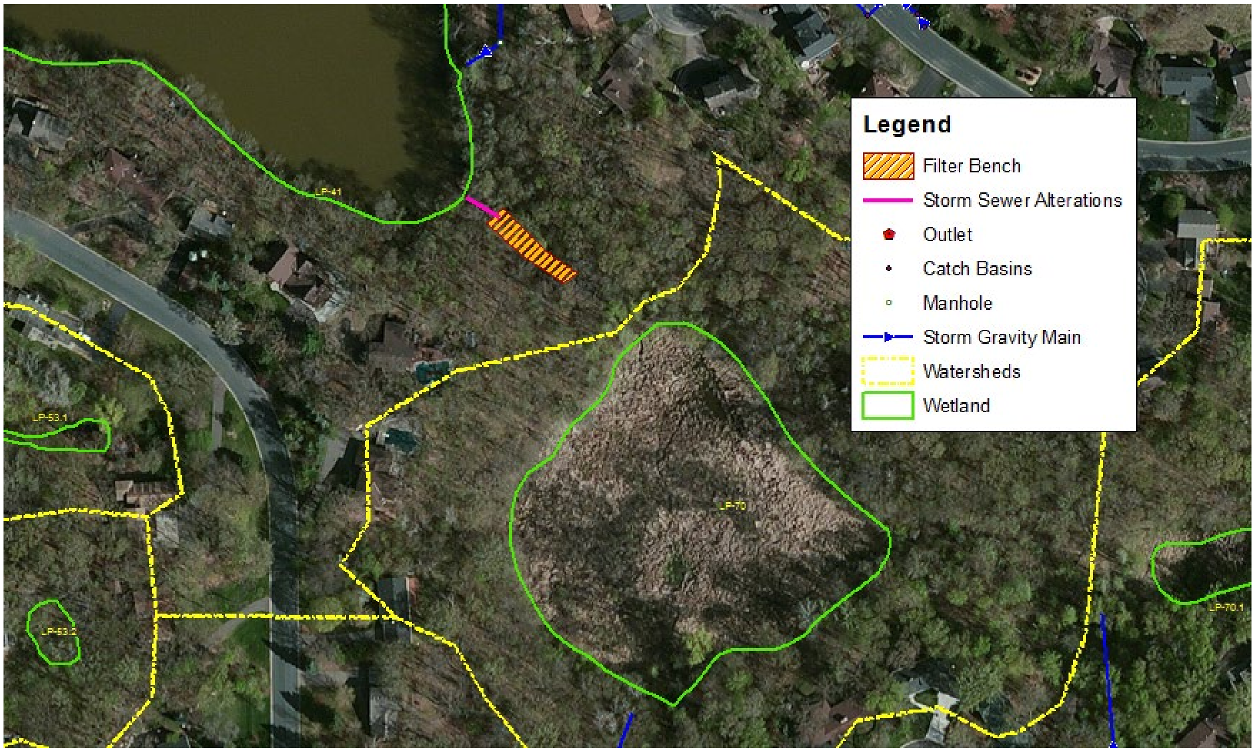


Figure 5.25. Basin improvement project for LP-70.

5.7.4.4 Watershed LP-42 Residential Rain Garden and Street Sweeping Programs

The watershed LP-42 is primarily residential neighborhoods. There are approximately 78 acres which stormwater runoff discharges to the residential streets prior to entering the storm sewer system. The estimated existing potential annual total phosphorus load from the 78 acres is 19 lbs. An opportunity for a neighborhood rain garden program exists to treat low flow events and decrease the watershed load. Approximately 250 residences were identified as potential candidates in a neighborhood rain garden program, which was evaluated by estimating the number of participating residences in the contributing watershed to determine the load reduction potential. The rain gardens were assumed to treat the 1-inch, 24-hour precipitation event for a contributing runoff area of 0.2 acres. Table 5.7 details the estimated load reduction and cost for the rain garden program. Figure 5.26 details the scope of the rain garden program.

An alternative to treat the watershed load to Carlson Lake is to increase the frequency of sweeping of approximately 6.4-curb miles of residential streets. The annual total phosphorus load reduction, estimated based on Law et al. (2008) and a 30-year life cycle cost is listed below. Figure 5.27 details the scope of the street sweeping program.

Table 5.7. Watershed LP-42 residential rain garden program.

Percent of Participating Residences	Number of Participating Residences	Estimated Load Reduction (lbs)	Estimated 30-year Life Cycle Cost
10%	25	0.9	$ 200,000
15%	38	1.3	$ 304,000
20%	50	1.7	$ 400,000
25%	63	2.2	$ 504,000
50%	125	4.4	$ 1,000,000

Street Sweeping Program
Estimated Curb Miles: 6.4 Miles
Street Sweeping Frequency: (MAR-1, APR-2, MAY-2, SEP-1, OCT-2, NOV-2)
Estimated Annual Load Reduction: 1 lb
Estimated 30-year Life Cycle Cost: $242,000

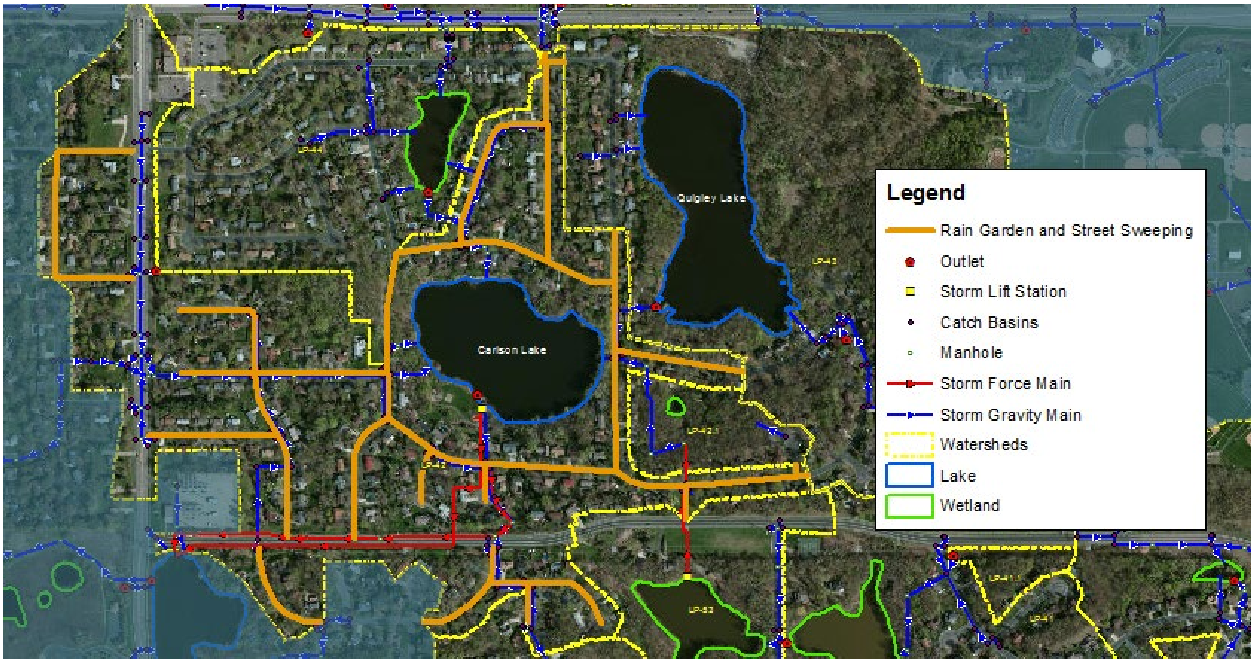


Figure 5.26. Residential rain garden and street sweeping programs for the LP-42 neighborhoods.

5.7.4.5 Watershed LP-44 Residential Rain gardens and Street Sweeping Programs

The watershed LP-44 is primarily residential neighborhoods. There are approximately 35 acres that discharge runoff to residential streets prior to entering the storm sewer system. The estimated existing potential annual total phosphorus load from this area is 8 lbs. An opportunity for a neighborhood rain garden program exists to treat low flow events and decrease the watershed load. Approximately 100 residences were identified as potential candidates in a neighborhood rain garden program, which was evaluated by estimating the number of participating residences in the contributing watershed to determine the load reduction potential. The rain gardens were assumed to treat the 1-inch, 24-hour precipitation event for a contributing runoff area of 0.2 acres. Table 5.8 details the estimated load reduction and cost for the rain garden program. Figure 5.27 details the scope of the rain garden program.

An alternative to reduce the watershed load to Carlson Lake is to increase sweeping of approximately 2.3 curb miles of residential streets. The estimated annual load reduction and 30-year life cycle cost for the street sweeping program is listed below. Figure 5.27 details the scope of the street sweeping program.

Table 5.8. Watershed LP-44 Residential Rain garden Program.

Percent of Participating Residences	**Number of Participating Residences**	Estimated Load Reduction (lbs)	**Estimated 30-year Life Cycle Cost**
10%	10	0.3	$ 80,000
15%	15	0.5	$ 120,000
20%	20	0.6	$ 160,000
25%	25	0.8	$ 200,000
50%	50	1.6	$ 400,000

Street Sweeping Program

Estimated Curb Miles: 2.3 miles
Street Sweeping Frequency: (MAR-1, APR-2, MAY-2, SEP-1, OCT-2, NOV-2)
Estimated Annual Load Reduction: 0.5 lbs
Estimated 30-year Life Cycle Cost: $87,000

Figure 5.27. Neighborhood rain garden and street sweeping programs for the LP-44 neighborhoods.

5.7.4.6 Watershed LP-43 Residential Rain gardens and Street Sweeping Programs

The watershed LP-43 is primarily residential neighborhoods. Limited opportunities exist for regional treatment of the stormwater runoff. There are approximately 35 acres which stormwater runoff discharges to the residential streets prior to entering the storm sewer system. The estimated existing potential annual total phosphorus load from the 35 acres is 8 lbs. An opportunity for a neighborhood rain garden program exists to treat low flow events and decrease the watershed load. Approximately 112 residences were identified as potential candidates in a neighborhood rain garden program. The rain garden program was evaluated by estimating the number of participating residences in the contributing watershed to determine the load reduction potential. The rain gardens were assumed to treat the 1 inch 24-hour precipitation event for a contributing runoff area of 0.2 acres. Table 5.9 details the estimated load reduction and cost for the rain garden program. Figure 5.28 details the scope of the rain garden program.

An alternative option to treat the watershed load is to implement an increased frequency street sweeping program. The LP-43 watershed has approximately 2.5 curb miles of residential streets that could have a benefit on reducing the watershed load to Carlson Lake. The estimated annual load reduction and 30-year life cycle cost for the street sweeping program is listed below. Figure 5.28 details the scope of the street sweeping program.

Table 5.9. Watershed LP-43 residential rain garden program.

Percent of Participating Residences	Number of Participating Residences	Estimated Load Reduction (lbs)	Estimated 30-year Life Cycle Cost
10%	12	0.4	$ 96,000
15%	18	0.6	$ 144,000
20%	24	0.8	$ 192,000
25%	30	1.0	$ 240,000
50%	60	2.1	$ 480,000

Street Sweeping Program

Estimated Curb Miles: 2.5 Miles

Street Sweeping Frequency: (MAR-1, APR-2, MAY-2, SEP-1, OCT-2, NOV-2)

Estimated Annual Load Reduction: 0.5 lbs

Estimated 30-year Life Cycle Cost: $94,000

Figure 5.28. Neighborhood rain garden and street sweeping program for the LP-43 Watershed.

5.7.5 Cliff Lake Watershed Nutrient Management

5.7.5.1 Basin AP-42 Improvements

Basin AP-42, which is located on MnDOT ROW, receives stormwater from approximately 63% of the Cliff Lake subwatershed which consists of residential neighborhoods. The estimated existing total annual phosphorus load discharging basin AP-42 is approximately 33 lbs. An iron enhanced filtration system with outlet modification, and the basin improvements was assessed by evaluating current site constraints and load reduction potential. The iron enhanced filtration system could be integrated with the existing outlet system and treat runoff from the 1.5 inch 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. Because the basin resides in MnDOT right-of-way, basin improvements in the AP-42 watershed must first be approved by MnDOT. The project layout based on the feasibility and preliminary design is shown in Figure 5.29.

Basin Expansion and Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 22 lbs
Estimated 30-year Life Cycle Cost: $269,000

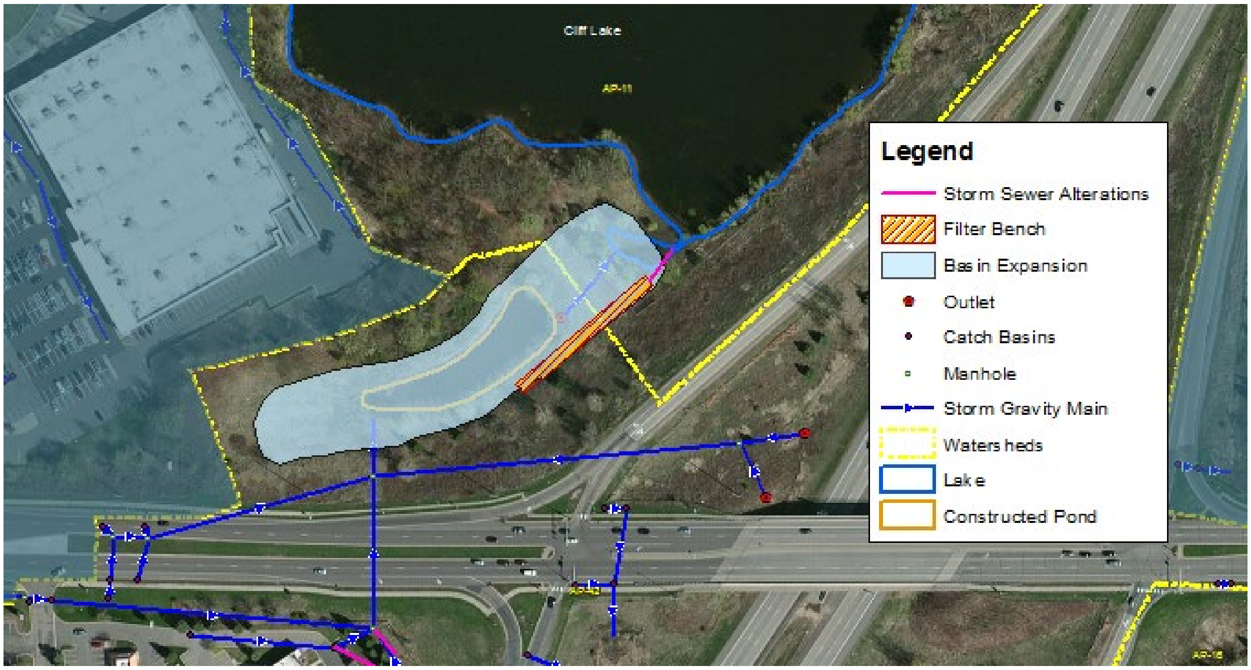


Figure 5.29. Basin improvement projects for AP-42.

5.7.5.2 Basin AP-44 Improvements

Basin AP-44 receives stormwater from approximately 10% of the Cliff Lake watershed. The AP-44 subwatershed consists of primarily commercial and residential land uses. Based on a review of the existing storm sewer information provided by the city, it was determined that most of the commercial impervious surfaces were directly connected. Using the city PondNet model it is estimated that the existing basin is 35% efficient at removing total phosphorus. Being that there is no existing infiltration or filtration mechanism it is assumed that most of the dissolved fraction of the total phosphorus number is not treated. The estimated existing total annual phosphorus load discharging basin AP-44 is approximately 8 lbs.

In order to address the treatment of a higher percentage of the particulate phosphorus and the dissolved phosphorus, an iron enhanced filtration system with a modification to the existing outlet, and the basin improvements were assessed. Based on a review of the existing storm sewer information it is feasible to integrate an iron enhanced filtration system with the existing outlet of the basin. For this feasibility analysis it is estimated that the water quality volume that can be treated by modifying the existing outlet is the volume of water associated with the 2.5 inch 24-hour precipitation event. The estimated efficiency after making the proposed modifications is 79.8% (an increase of 44% efficiency).

The estimated annual load reduction and 30-year life cycle cost for the project is listed below. Costs do not include easement or land acquisition. See Appendix I for more information on the project cost estimate. The project layout based on the feasibility and preliminary design is shown in Figure 5.30.

Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 6 lbs
Estimated 30-year Life Cycle Cost: $218,000

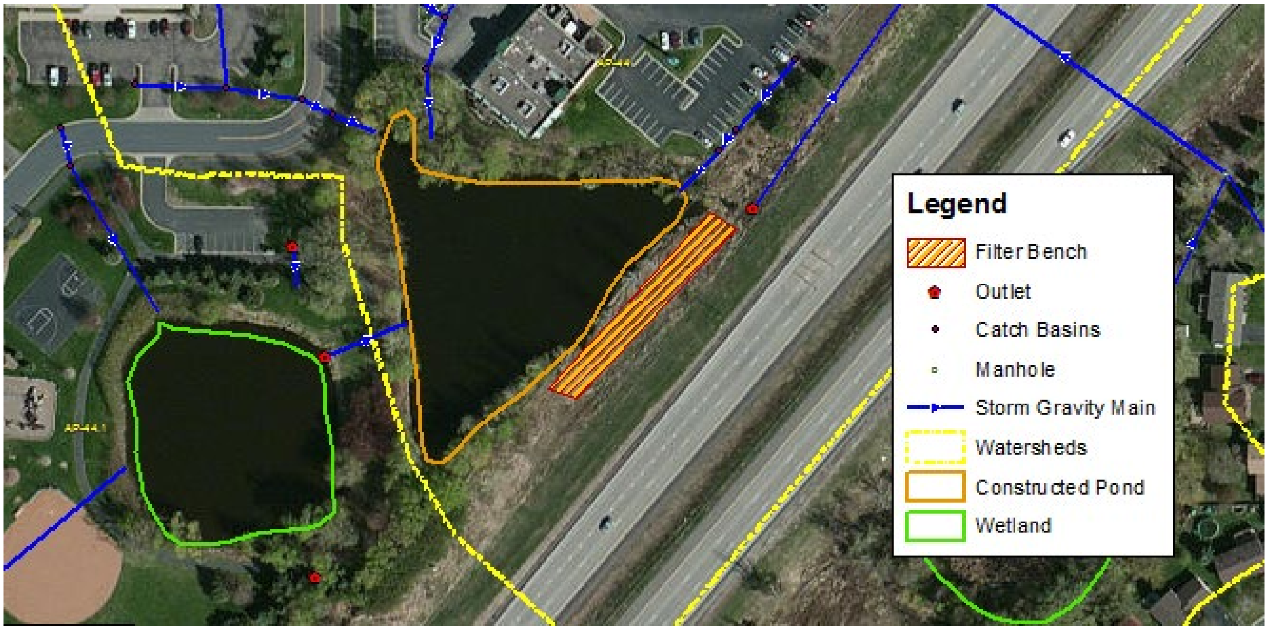


Figure 5.30. Basin improvement projects for AP-44.

5.7.5.3 AP-42 Commercial BMPs

There exists an opportunity to treat runoff from impervious surfaces off of the commercial area parking lots East of 35W and south of Cliff Road in subwatershed AP-42. The estimated total annual load from the impervious surfaces accounts for approximately 1% of the total water shed area. Green spaces in and around the parking lots offer opportunity to incorporate depressed areas for rain gardens. The estimated existing total annual phosphorus load discharging off the impervious areas is approximately 4 lbs. Rain gardens could be installed in select locations to treat runoff up to the 2 inch 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. Costs do not include easement or land acquisition. The project layout based on the feasibility and preliminary design is shown in Figure 5.31.

Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 2 lbs
Estimated 30-year Life Cycle Cost: $134,000

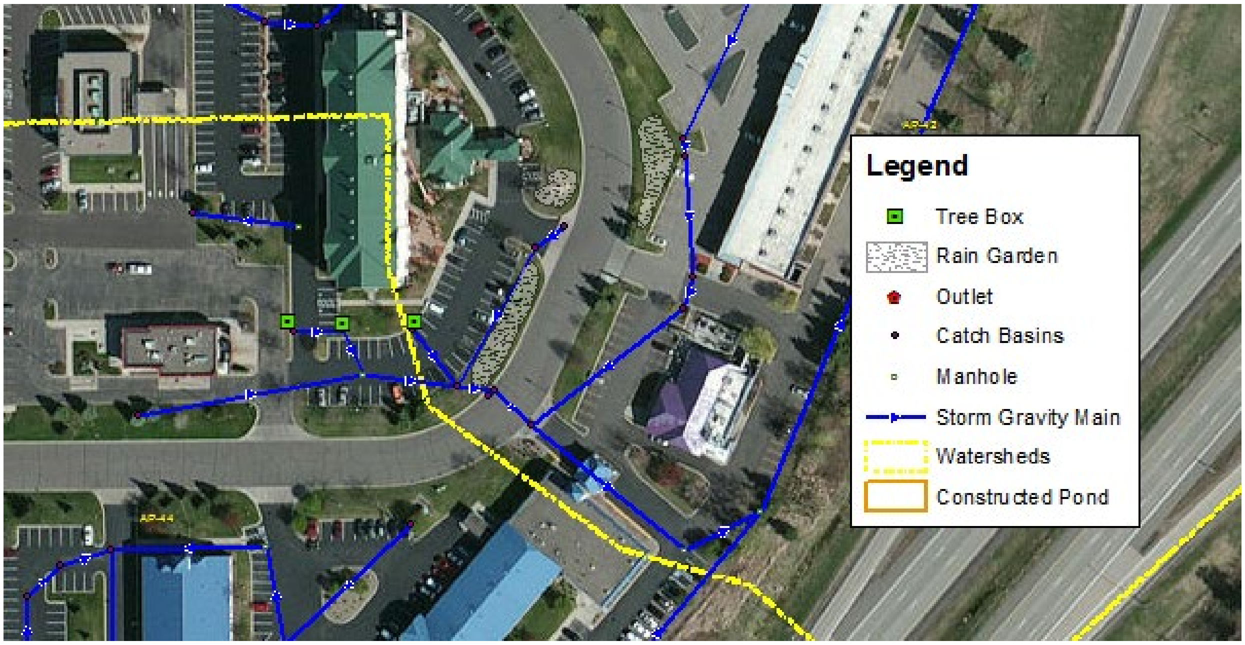


Figure 5.31. Commercial area BMP projects for Watershed AP-42.

5.7.6 Fitz Lake, Holz Lake, Hay Lake, and LP-30 Watershed Nutrient Management

5.7.6.1 Basin LP-26.3 Improvements and Stormwater Reroute from LP 27 and 27.1

Stormwater entering Fitz Lake from basin LP-26.3, 27.1, and 27 accounts for approximately 67% of the Fitz Lake subwatershed. The land use in these subwatersheds is predominantly residential neighborhoods. The estimated average total annual phosphorus loading to Fitz Lake from these basins is approximately 10 lbs per year. LP-27 and 27.1 contribute to approximately 8 lbs per year of the total load. The storm sewer pipe from LP 27.1 and 27 flow into a single manhole before discharging to the lake. An opportunity exists to modify this structure with a low flow bypass structure. The bypass structure would bypass low flows into basin LP-26.3. High flows would continue to flow directly to the lake. In addition to the bypass, LP-26.3 was evaluated for an iron enhanced filtration system with outlet modification. The basin improvements were assessed by evaluating current site constraints and load reduction potential. The iron enhanced filtration system could be integrated into the existing outlet system and treat runoff from the 2.5 inch 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. Costs do not include easement or land acquisition. The project layout based on the feasibility and preliminary design is shown in Figure 5.32.

Stormwater Reroute, Basin Expansion and Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 8 lbs
Estimated 30-year Life Cycle Cost: $320,000

Figure 5.32. Stormwater Reroute and Basin improvement projects for LP-26.3.

5.7.6.2 Basin LP-26.4 Improvements

Basin LP-26.4 receives stormwater from approximately 2% of the Fitz Lake subwatershed which consists of residential neighborhoods. This basin offers an opportunity for future protection by the addition of an iron enhanced filtration system and outlet modification to improve total phosphorus removal. The estimated existing total annual phosphorus load discharging basin LP-26.4 is approximately 0.5 lbs. Basin LP-26.4 was evaluated for an iron enhanced filtration system with outlet modification, and the basin improvements were assessed by evaluating current site constraints and load reduction potential. An iron enhanced filtration system could be integrated into the existing outlet system and treat runoff from the 2.75 inch 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. Costs do not include easement or land acquisition. The project layout based on the feasibility and preliminary design is shown in Figure 5.33.

Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 0.3 lbs
Estimated 30-year Life Cycle Cost: $76,000

Figure 5.33. Basin improvement project for LP-26.4.

5.7.6.3 Basin LP-26.5 Improvements

Basin LP-26.5 receives stormwater from approximately 4% of the Fitz Lake subwatershed which consists of residential neighborhoods. This basin offers an opportunity for future protection by the addition of an iron enhanced filtration system and outlet modification to improve total phosphorus removal. The estimated existing total annual phosphorus load discharging basin LP-26.5 is approximately 3 lbs. Basin LP-26.5 was evaluated for an iron enhanced filtration system with outlet modification, and the basin improvements were assessed by evaluating current site constraints and load reduction potential. An iron enhanced filtration system could be integrated into the existing outlet system and treat runoff from the 1.25 inch 24-hour precipitation event. The estimated annual load reduction and 30-year life cycle cost for the project is listed below. Costs do not include easement or land acquisition. The project layout based on the feasibility and preliminary design is shown in Figure 5.34.

Iron Enhanced Filtration System with Outlet Modification
Estimated Annual Load Reduction: 2 lbs
Estimated 30-year Life Cycle Cost: $77,000

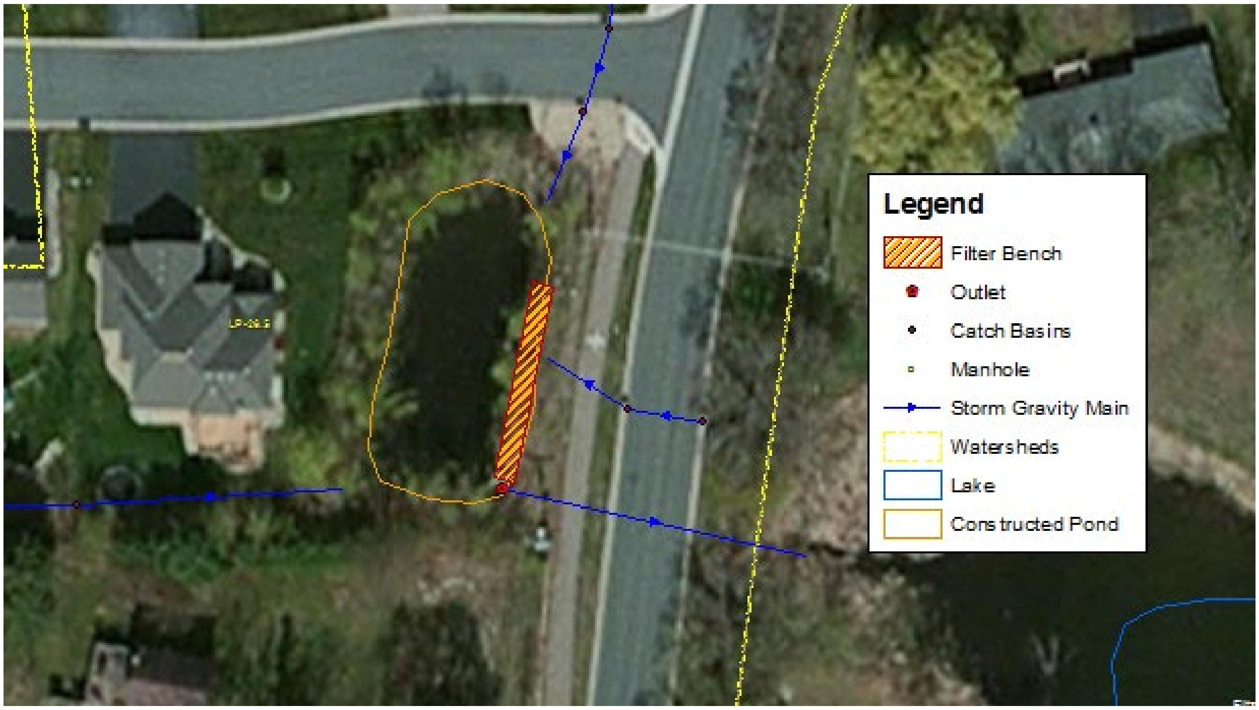


Figure 5.34. Basin improvement project for LP-26.4.

5.7.6.4 LP-28 Residential Rain Gardens, Street Sweeping Programs, and Other Improvements

The LP-28 watershed consists of residential neighborhoods. There are approximately 23 acres which stormwater runoff discharges to the residential streets prior to entering the storm sewer system. The estimated existing potential annual total phosphorus load from the 23 acres is 5 lbs. Two BMP options were evaluated for load reductions in the subwatershed. The first BMP option evaluated is neighborhood rain gardens to treat low flow events. Approximately 7 locations were identified as potential candidates in a neighborhood rain garden program. The locations were identified as potential candidates due to available land and proximity to the existing storm sewer system. The rain gardens were assumed to treat the 1 inch 24-hour precipitation event. Where rain gardens were not feasible, tree boxes were considered. Tree boxes work in line with the existing storm sewer network and treat low flows. Figure 5.35 details the areas.

An alternative option to treat the watershed load is to implement an increased frequency street sweeping program. The LP-28 subwatershed has approximately 1.9 curb miles of residential streets that could have a benefit on reducing the watershed load to Holz Lake. The annual total phosphorus load reduction was estimated by the efficiency of street sweeping as described by Law et al. (2008). The estimated annual load reduction and 30-year life cycle cost for the street sweeping program is listed below. Figure 5.35 details the scope of the street sweeping program.

Rain gardens

Estimated Annual Load Reduction: 1 lbs
Estimated 30-year Life Cycle Cost: $65,000

Tree Boxes
Estimated Annual Load Reduction: 1 lbs
Estimated 30-year Life Cycle Cost: $219,000

Street Sweeping Program
Estimated Curb Miles: 1.9 Miles
Street Sweeping Frequency: (MAR-1, APR-2, MAY-2, SEP-1, OCT-2, NOV-2)
Estimated Annual Load Reduction: 0.5 lbs
Estimated 30-year Life Cycle Cost: $73,000

Figure 5.35. Residential BMPs and street sweeping program for the LP-28 Watershed.

5.7.6.5 LP-31 Residential Rain Gardens and Street Sweeping Programs

The LP-31 watershed consists of residential neighborhoods. There are approximately 45 acres which stormwater runoff discharges to the residential streets prior to entering the storm sewer system. The estimated existing potential annual total phosphorus load from the 45 acres is 9 lbs. An opportunity for a neighborhood rain garden program exists to treat low flow events and decrease the watershed load. Approximately 100 residences were identified as potential candidates in a neighborhood rain garden program. The rain garden program was evaluated by estimating the number of participating residences in the contributing watershed to determine the load reduction potential. The rain gardens were assumed to treat the 1 inch 24-hour precipitation event for a contributing runoff area of 0.2 acres. Table

5.10 details the estimated load reduction and cost for the rain garden program. Figure 5.36 details the scope of the rain garden program.

An alternative option to treat the watershed load is to implement an increased frequency street sweeping program. The LP-31 subwatershed has approximately 3.0 curb miles of residential streets that could have a benefit on reducing the watershed load to Hay Lake. The annual total phosphorus load reduction was estimated by the efficiency of street sweeping as described by Law et al. (2008). The estimated annual load reduction and 30-year life cycle cost for the street sweeping program is listed below. Figure 5.36 details the scope of the street sweeping program.

Table 5.10. Watershed LP-31 Residential Rain garden Program.

Percent of Participating Residences	Number of Participating Residences	Estimated Load Reduction (lbs)	Estimated 30-year Life Cycle Cost
10%	10	0.3	$ 80,000
15%	15	0.5	$ 120,000
20%	20	0.6	$ 160,000
25%	25	0.8	$ 200,000
50%	50	1.5	$ 400,000

Street Sweeping Program
Estimated Curb Miles: 3.0 Miles
Street Sweeping Frequency: (MAR-1, APR-2, MAY-2, SEP-1, OCT-2, NOV-2)
Estimated Annual Load Reduction: 0.5 lbs
Estimated 30-year Life Cycle Cost: $117,000

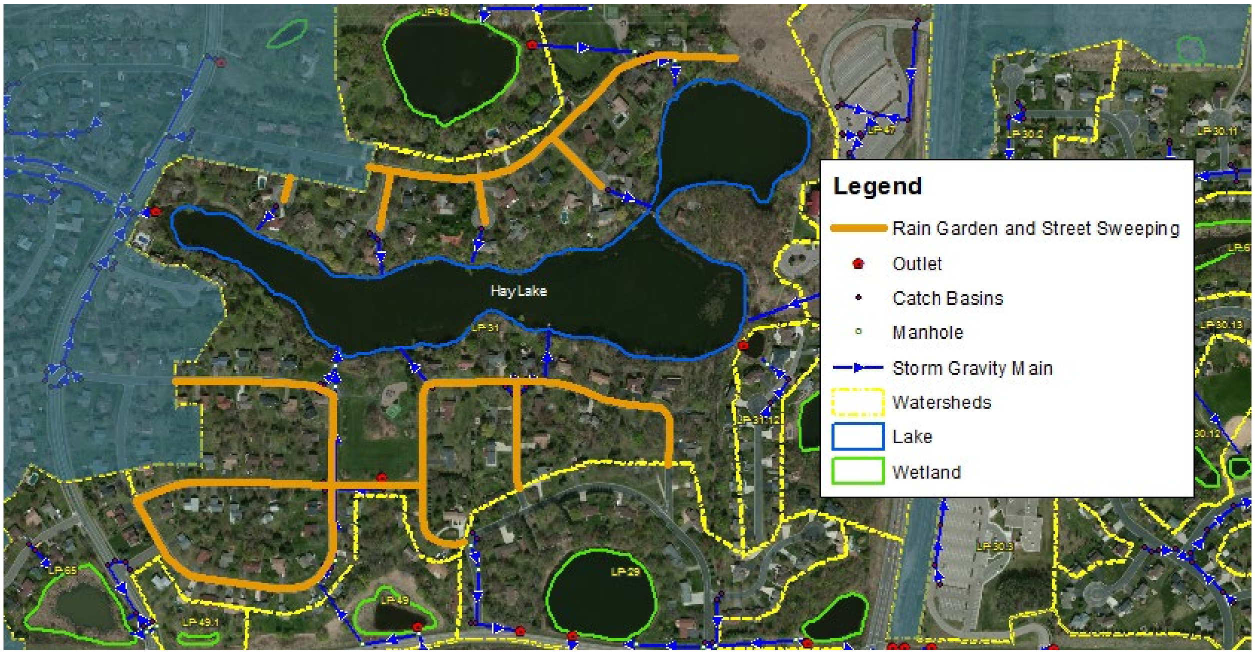


Figure 5.36. Neighborhood rain garden and street sweeping programs for the LP-31 Watershed.

6.0 Reasonable Assurance

6.1 INTRODUCTION

When establishing a TMDL, the responsible party(ies) must reasonably assure the ability to reach and maintain water quality endpoints. Several factors contribute to reasonable assurances, including acknowledging a thorough knowledge of the overall effectiveness of the BMPs and the ability to implement the BMPs. This TMDL establishes aggressive goals for the reduction of nutrients to four lakes in Eagan.

The City of Eagan comprises over 99% of the watershed area draining to these lakes and is the primary LGU responsible for implementing the TMDL with the remaining areas in Inver Grove Heights or are maintained by the County and MnDOT. Many of the goals outlined in this TMDL study are consistent with the primary goal of the City of Eagan's Water Quality and Wetland Management Plan (WQWMP, City of Eagan 2007), which is to manage surface water resources using scientifically-based, common sense approaches that meet or exceed regulatory requirements. The WQWMP prioritizes developing and implementing strategies to bring any impaired waters into compliance with appropriate water quality standards and thereby establish the basis for removing such waters from the 303(d) List. The plan provides the watershed management framework for addressing water quality issues. In addition, the stakeholder process associated with this TMDL effort has generated commitment and support from the local citizens affected by this TMDL and will help ensure that this TMDL project is carried successfully through implementation.

The City of Eagan also works closely with MnDOT, Dakota County, and Inver Grove Heights to implement projects aimed at improving and protecting local water resources. In fact, the City of Eagan agreed to take on small WLA reductions from these parties to ensure that the projects are completed efficiently. These partnerships provide the basis for working together to ensure that the load reductions will be achieved.

Various sources of technical assistance and funding may be used to execute the Implementation Plan, including (but not limited to) the following local, state and federal sources:

- Local government assistance and funding
- Funds earmarked for TMDL implementation from the Clean Water Fund.
- Federal Section 319 Grants for watershed improvements

Finally, it is reasonable to expect that existing regulatory programs such NDPES will continue to control discharges from industrial, municipal, and construction sources.

6.2 REGULATORY APPROACHES

NPDES Phase II MS4 stormwater permits are in place for the cities draining to the Neighborhood Lakes addressed in this study. Under the stormwater program, permit holders such as the city are required to develop and implement a Stormwater Pollution Prevention Plan (SWPPP; MPCA, 2013). The SWPPP must cover six minimum control measures:

- Public education and outreach;
- Public participation/involvement;
- Illicit discharge, detection and elimination;
- Construction site runoff control;
- Post-construction site runoff controls;
- Pollution prevention/good housekeeping

The permit holder must identify BMPs and measurable goals associated with each minimum control measure.

The MPCA's MS4 general permit requires MS4 permittees to provide reasonable assurances that progress is being made toward achieving all WLAs in TMDLs approved by EPA prior to the effective date of the permit. In doing so, they must determine if they are currently meeting their WLA(s). If the WLA is not being achieved at the time of application, a compliance schedule is required that includes interim milestones, expressed as BMPs, that will be implemented over the current five-year permit term to reduce loading of the pollutant of concern in the TMDL. Additionally, a long-term implementation strategy and target date for fully meeting the WLA must be included.

6.3 LOCAL MANAGEMENT

6.3.1 Local Comprehensive Water Management Plans

The City of Eagan has managed lakes and watersheds for nearly 25 years since 1990 in a comprehensive approach to improve water quality by reducing in-lake total phosphorus (TP) concentrations. In 1990, the city council adopted the first comprehensive stormwater and water quality plans by a Minnesota city to address concerns about impacts of rapid urbanization on Eagan's many waterbodies. This initiative also established a stormwater drainage utility to fund and implement programs. Eagan's Water Resources program received the 1991 Twin Cities Metropolitan Council Policy Implementation Award, and in 1996, the US EPA presented Eagan a National First Place Award for an outstanding municipal stormwater control program.

The city initially focused on its two highest priority lakes, Fish and Schwanz. In the mid to late 1990s, diagnostic/feasibility studies that evaluated problems in water quality and identified potential solutions via Public Works projects and public programs were completed with support from MPCA Clean Water Partnership (CWP) grants.

In 2007, Eagan adopted an updated WQWMP with emphases on: 1) managing surface water resources using scientifically-based common sense approaches, 2) controlling watershed loadings to help meet or exceed surface water quality requirements, 3) protecting surface water resources from impacts of land development and re-development activities, 4) managing wetlands in compliance with all regulations and according to the community's values and priorities, and 5) fostering citywide support for surface water management goals through an active education program.

With support from a CWP grant, Eagan completed a required TMDL study of Fish Lake that was approved by US EPA in 2010—10 years ahead of the schedule in the 2006 303(d) list. Eagan's approved $1.1 million TMDL Implementation Plan for Fish Lake (for 2011-2015) triggered the city to establish an alum-injection system and to apply a whole-lake alum treatment. After only three years in 2014, MPCA removed Fish Lake from the 303(d) list after the city showed water quality had dramatically improved for three straight years in 2011-2013 as a result of the city's aggressive execution of the TMDL plan. During the same time, Eagan's implementation of the nutrient management plan for Schwanz Lake has reduced an estimated 70% of the phosphorus entering the lake from a 28-acre residential neighborhood that contributes about 23% of the watershed's external load.

With support from two CWP grants in 2012, Eagan completed management plans for Blackhawk and Thomas lakes, the next priority lakes which are not impaired, and also began this three-year project to evaluate water quality and develop plans for 12 lakes.

The city's year-round water resources program is meant to protect and improve the natural, aesthetic, and recreational qualities of lakes, with special emphasis on "Neighborhood Fishing" lakes. Eagan integrates into its Public Works Capital Improvement Program projects specifically identified through the CWP studies, in addition to projects meant to fulfil requirements of Minnesota's MS4 General Permit. Twice monthly from May through September, the city monitors lake water quality. Water samples are analyzed for phosphorus, nitrogen, and chlorophyll a. Special instruments collect data on water pH, dissolved oxygen, conductivity, temperature, and transparency. Observations also are made of aquatic plants and wildlife, weather conditions, and lake levels. Monitored lakes may change year to year due to specific conditions and priorities. Long-term data help determine water quality trends. The city regularly sweeps neighbourhood streets, harvests aquatic plants from several lakes, and aerates "Neighborhood Fishing" lakes in the winter. It also provides numerous public education and involvement opportunities.

The City of Inver Grove Heights also has a small drainage area included in this study. All of the required reductions from the City of Inver Grove Heights were so small that the City of Eagan took responsibility for them. However, it is important to note that the City of Eagan and Inver Grove Heights have a good relationship and continually work together to improve water resources in their respective city.

6.3.2 Watershed Districts

Until recently, the City of Eagan was within the Gun Club Lake Watershed, the management plan for which was approved by the Gun Club Lake Watershed Management Organization (GCLWMO). In late 2013, the Organization was dissolved because one of the member cities consolidated its watershed with another organization. In place of the GCLWMO, the cities of Eagan and Inver Grove Heights formed the Eagan-Inver Grove Heights Watershed Management Organization. The board of the new WMO will be developing a new plan in 2014-2015. Statutory goals of the WMO include: to improve and enhance water quality, to control water flow, protect groundwater quality, to protect and restore critical areas, to promote wise public, private and natural use of water while maintaining, promoting wise land use management, enhancing and preserving public and private drainage for present and future residents while engaging residents in water resource management.

6.4 MONITORING

Two types of monitoring are necessary to determine progress toward achieving the load reductions required in TMDLs and the attainment of water quality standards. First, implementation of BMPs needs to be tracked. The city will monitor these projects as part of its SWPPP. Second, the city will extensively monitor its water resources to evaluate conditions over time.

This type of effectiveness monitoring is critical in the adaptive management approach. Results of the monitoring identify progress toward benchmarks as well as shape the next course of action for implementation. Adaptive management combined with obtainable benchmark goals and monitoring is the best approach for implementing TMDLs.

7.0 Public Participation

7.1 PUBLIC PARTICIPATION PROCESS

Public participation opportunities were provided during the project in the form of 3 pairs of public meetings. About two weeks before each meeting, the city listed the meetings on its online events calendar and mailed approximately 1,000 invitation letters to residents owning lakeshore properties adjacent to the Neighborhood Lakes. All meetings were recorded by local cable TV and available for viewing via links from the city's web site (www.cityofeagan.com). About 20-25 residents attended each of the 6 meetings.

In addition, an official TMDL public comment period was announced in the State Register and was held from April 20, 2015, to May 19, 2015.

7.2 PUBLIC MEETINGS

On March 27 and 28, 2013, the city combined its required SWPPP annual meeting with a public meeting to introduce residents to the then new "Neighborhood Lakes Project." Residents were encouraged to attend one of the two public forums from 6:00 p.m. to 8:30 p.m. The March 27 meeting focused on Bald, Bur Oaks, LeMay, North, and O'Leary lakes; the March 28 meeting on Carlson, Cliff, Fitz, Hay, Holz, LP-30, and Quigley lakes. At both meetings, after learning about the city's SWPPP, residents received a formal presentation about the lakes project that discussed: 1) project purpose, scope, and schedule; 2) summaries of lake watersheds and water quality; 3) information about lake ecology, restoration, and state water quality standards; and 4) concepts of future management and implementation efforts. There were opportunities for attendees to provide input on important issues the project should address.

The city held a second and similar pair of public forums on December 11 and 12, 2013. At these meetings, the project team presented results of technical modeling and phosphorus assessments, including estimated phosphorus and water contributions from various sources. Attendees learned about proposed phosphorus limits and proposed management strategies to improve the lakes' environments to support recreational activities. People were asked specifically to provide input, especially regarding proposed management strategies.

At the final set of public forums May 14 and 15, 2014, the project team presented draft lake management plans and implementation strategies and took comments before finalizing the plans.

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9.0 Glossary

Aeration Any active or passive process by which intimate contact between air and liquid is assured, generally by spraying liquid in the air, bubbling air through water, or mechanical agitation of the liquid to promote surface absorption of air.

Algae Microscopic organisms/aquatic plants that use sunlight as an energy source (e.g., diatoms, kelp, seaweed). One-celled (phytoplankton) or multicellular plants either suspended in water (plankton) or attached to rocks and other substrates (periphyton). Their abundance, as measured by the amount of chlorophyll-*a* (green pigment) in an open water sample, is commonly used to classify the trophic status of a lake.

Algal Bloom Population explosion of algae in surface waters due to an increase in plant nutrients such as nitrates and phosphates.

Alum Common name for commercial-grade Aluminum Sulfate. Its chemical formula is generally denoted by $Al_2(SO^4)_3$ X $12H_2O$. Most often used in lakes as a way to precipitate a floc that settles through the water column, removing fine particles to the sediment and building up a barrier layer to contain soluble phosphorus in the bottom sediments.

Anoxic Without oxygen.

Aquatic Organisms that live in or frequent water.

Aquifer A saturated permeable geologic unit that can transmit significant quantities of water.

Biomass The total quantity of plants and animals in a lake. Measured as organisms or dry matter per cubic meter, biomass indicates the degree of a lake system's eutrophication or productivity.

Chlorophyll-*a* Green pigment present in all plant life and necessary for photosynthesis. The amount present in lake water depends on the amount of algae and is therefore used as a common indicator of water quality.

Clarity The transparency of a water column. Measured with a Secchi disc.

Concentration Expresses the amount of a chemical dissolved in water. The most common units are milligrams per liter (mg/L) and micrograms per liter (µg/L). One milligram per liter is equal to one part per million (ppm). To convert micrograms per liter (µg/1) to milligrams per liter (mg/1), divide by 1000 (e.g. 30 µg/l = 0.03 mg/1). To convert milligrams per liter (mg/1) to micrograms per liter (µg/1), multiply by 1000 (e.g. 0.5 mg/l = 500 µg/1).

Daphnia Small crustacean (zooplankton) found in lakes. Prey for many fish species.

Dissolved Oxygen (DO) The amount of free oxygen absorbed by the water and available to aquatic organisms for respiration; amount of oxygen dissolved in a certain amount of water at a particular temperature and pressure, often expressed as a concentration in parts of oxygen per million parts of water.

Ecosystem A system formed by the interaction of a community of organisms with each other and with the chemical and physical factors making up their environment.

Erosion The wearing away and removal of materials of the earth's crust by natural means.

Eutrophic Pertaining to a lake or other body of water characterized by large nutrient concentrations such as nitrogen and phosphorous and resulting high productivity. Such waters are often shallow, with algal blooms and periods of oxygen deficiency. Lakes can be classified as *oligotrophic* (nutrient poor), *mesotrophic* (moderately productive), *eutrophic* (very productive and fertile), or *hypereutrophic* (extremely productive and fertile).

Eutrophication The process by which lakes and streams are enriched by nutrients, and the resulting increase in plant and algae growth. This process includes physical, chemical, and biological changes that take place after a lake receives inputs for plant nutrients – mostly nitrates and phosphates – from natural erosion and runoff from the surrounding land basin. *Cultural eutrophication* is the accelerated eutrophication that occurs as a result of human activities in the watershed that increase nutrient loads in runoff water that drains into lakes

Filamentous Algae Algae that forms filaments or mats attached to sediment, weeds, piers, etc.

Food Chain The transfer of food energy from plants through herbivores to carnivores. An example: insect-fish-bear or the sequence of algae being eaten by small aquatic animals (zooplankton) which in turn are eaten by small fish which are then eaten by larger fish and eventually by people or predators.

Groundwater Water contained in or flowing through the ground. Amounts and flows of groundwater depend on the permeability, size, and hydraulic gradient of the aquifer.

Habitat The place where an organism lives that provides an organism's needs for water, food, and shelter. It includes all living and non-living components with which the organism interacts.

Hydrologic Referring to or involving the distribution, uses, or conservation of water on the Earth’s surface and in the atmosphere. The hydrologic cycle is the process by which the Earth's water is recycled. Atmospheric water vapor condenses into the liquid or solid form and falls as precipitation to the ground surface. This water moves along or into the ground surface and finally returns to the atmosphere through transpiration and evaporation.

Hydrology The study of water, especially its natural occurrence, characteristics, control and conservation.

Impervious A term denoting the resistance to penetration by water or plant roots; incapable of being penetrated by water; non-porous.

Invertebrates Animals without an internal skeletal structure such as insects, mollusks, and crayfish.

Limiting Nutrient or Factor The nutrient or condition in shortest supply relative to plant growth requirements. Plants will grow until stopped by this limitation; for example, phosphorus in summer, temperature or light in fall or winter.

Littoral The near-shore shallow water zone of a lake, where aquatic plants grow.

Nitrate (NO3-) An inorganic form of nitrogen important for plant growth. Nitrogen is in this stable form when oxygen is present. Nitrate often contaminates groundwater when water originates from manure pits, fertilized fields, lawns or septic systems.

Non-native A species of plant or animal that has been introduced.

Nutrients Elements or substances such as nitrogen and phosphorus that are necessary for plant growth. Large amounts of these substances can become a nuisance by promoting excessive aquatic plant growth.

Organic Matter Elements or material containing carbon, a basic component of all living matter.

Permeability The ability of a substance, such as rock or soil, to allow a liquid to pass or soak through it.

Phosphorus Key nutrient influencing plant growth in freshwater lakes. Soluble reactive phosphorus is the amount of phosphorus in solution that is available to plants. Total phosphorus includes the amount of phosphorus in solution (reactive) and in particulate form.

Photosynthesis The process by which green plants convert carbon dioxide (CO2) dissolved in water to sugar and oxygen using sunlight for energy. Photosynthesis is essential in producing a lake's food base, and is an important source of oxygen for many lakes.

Phytoplankton Microscopic floating plants, mainly algae, that live suspended in bodies of water and that drift about because they cannot move by themselves or because they are too small or too weak to swim effectively against a current.

Plankton Small plant organisms (phytoplankton and nanoplankton) and animal organisms (zooplankton) that float or swim weakly though the water.

Precipitation Rain, snow, hail, or sleet falling to the ground.

Predator An animal that hunts and kills other animals for food.

Prey An animal that is hunted or killed by another for food.

Runoff Water that flows over the surface of the land because the ground surface is impermeable or unable to absorb the water.

Secchi Disc An 8-inch diameter plate with alternating quadrants painted black and white that is used to measure water clarity (light penetration). The disc is lowered into water until it disappears from view. It is then raised until just visible. An average of the two depths, taken from the shaded side of the boat, is recorded as the Secchi disc reading.

Sedimentation The removal, transport, and deposition of detached soil particles by flowing water or wind. Accumulated organic and inorganic matter on the lake bottom. Sediment includes decaying algae and weeds, marl, and soil and organic matter eroded from the lake's watershed. The sedimentation rate of lakes or impoundments can be estimated by measuring the amount of suspended solids (particulate matter) of inflowing streams.

Shorelines With banks, those areas along streams, lakes, ponds, rivers, wetlands, and estuaries where water meets land. The topography of shorelines and banks can range from very steep to very gradual.

Soluble Capable of being dissolved.

Species A group of animals or plants that share similar characteristics such as can reproduce.

Stormwater Runoff Water falling as rain during a storm and entering a surface water body like a stream by flowing over the land. Stormwater runoff picks up heat and pollutants from developed surfaces such as parking lots.

Submerged Aquatic Vegetation (SAV) Aquatic plants larger than algae with all photosynthetic parts below the surface of the water. Many are rooted, but some are free-floating.

Subwatershed A smaller geographic section of a larger watershed unit with a drainage area of between 2 and 15 square miles and whose boundaries include all the land area draining to a point where two second order streams combine to form a third order stream.

Water Table The top or “surface” of groundwater. The water table level changes in response to amounts of groundwater recharge flowing in, and amounts of water leaving the ground through seeps, springs, and wells.

Watershed The geographic region within which water drains into a particular river, stream, or body of water.

Wetland Transitional between terrestrial and aquatic ecosystems, wetlands are places where the water table is at or near the surface and where hydric soils and hydrophytic (water-loving) vegetation predominate.

Zooplankton Microscopic or barely visible animals that eat algae. These suspended plankton are an important component of the lake food chain and ecosystem. For many fish, they are the primary source of food.

Appendix A

Historic Lake Aerial Photos

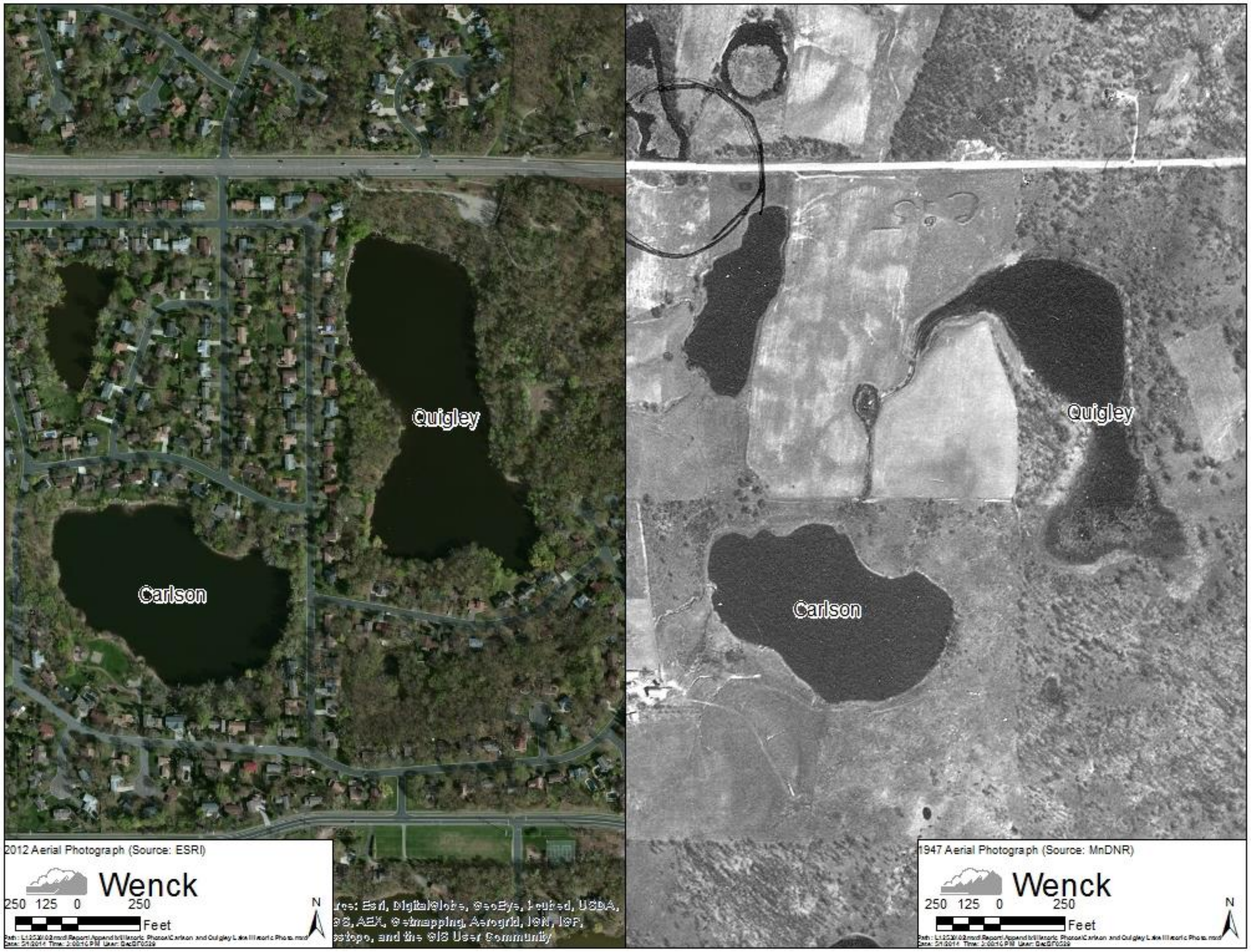
Bald Lake current and historic aerial photographs.

2012 Aerial Photograph (Source: ESRI)

rces: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, GS, AEX, Getmapping, Aerogrid, IGN, IGP, stopo, and the GIS User Community

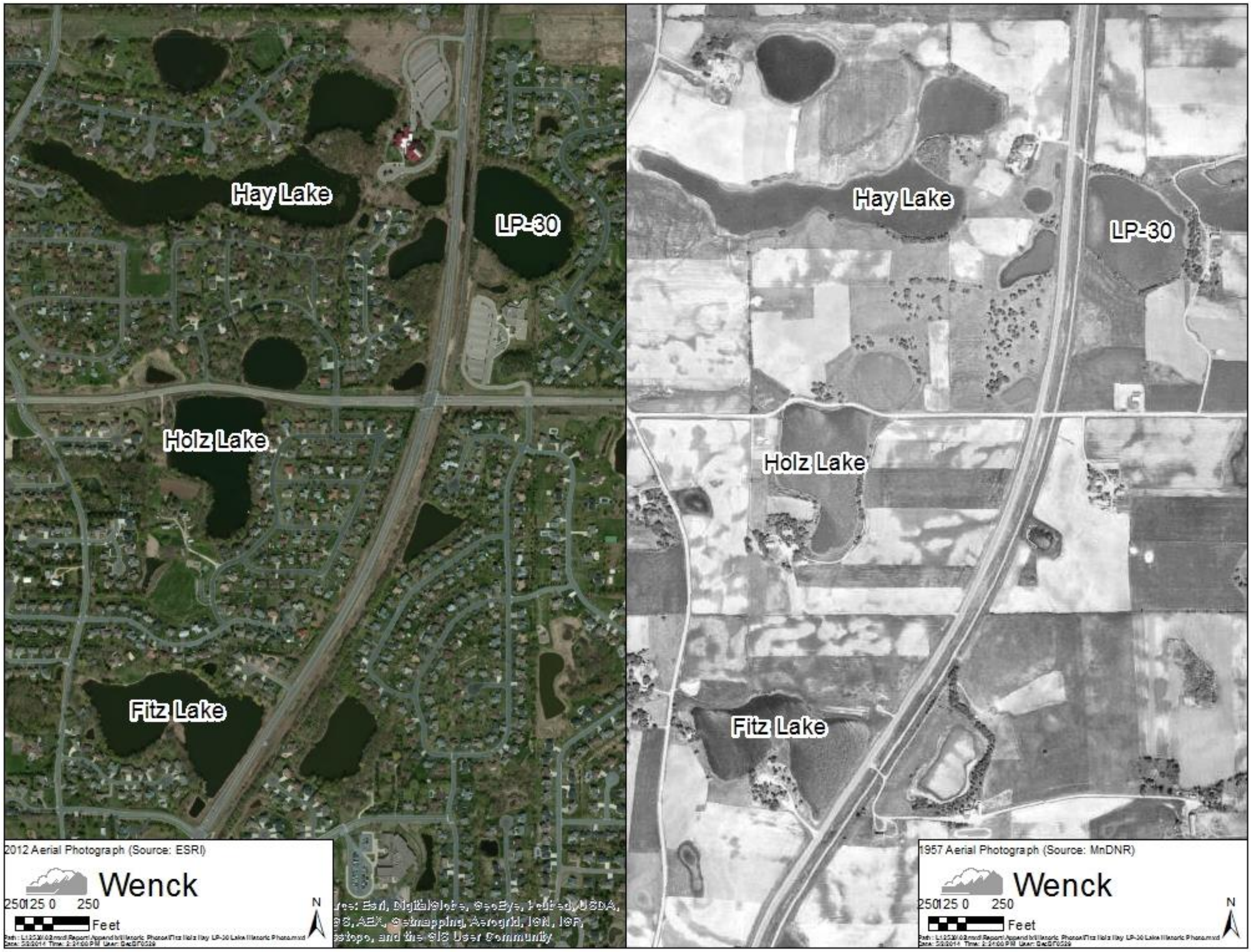
1947 Aerial Photograph (Source: MnDNR)

Bur Oaks Lake current and historic aerial photographs.



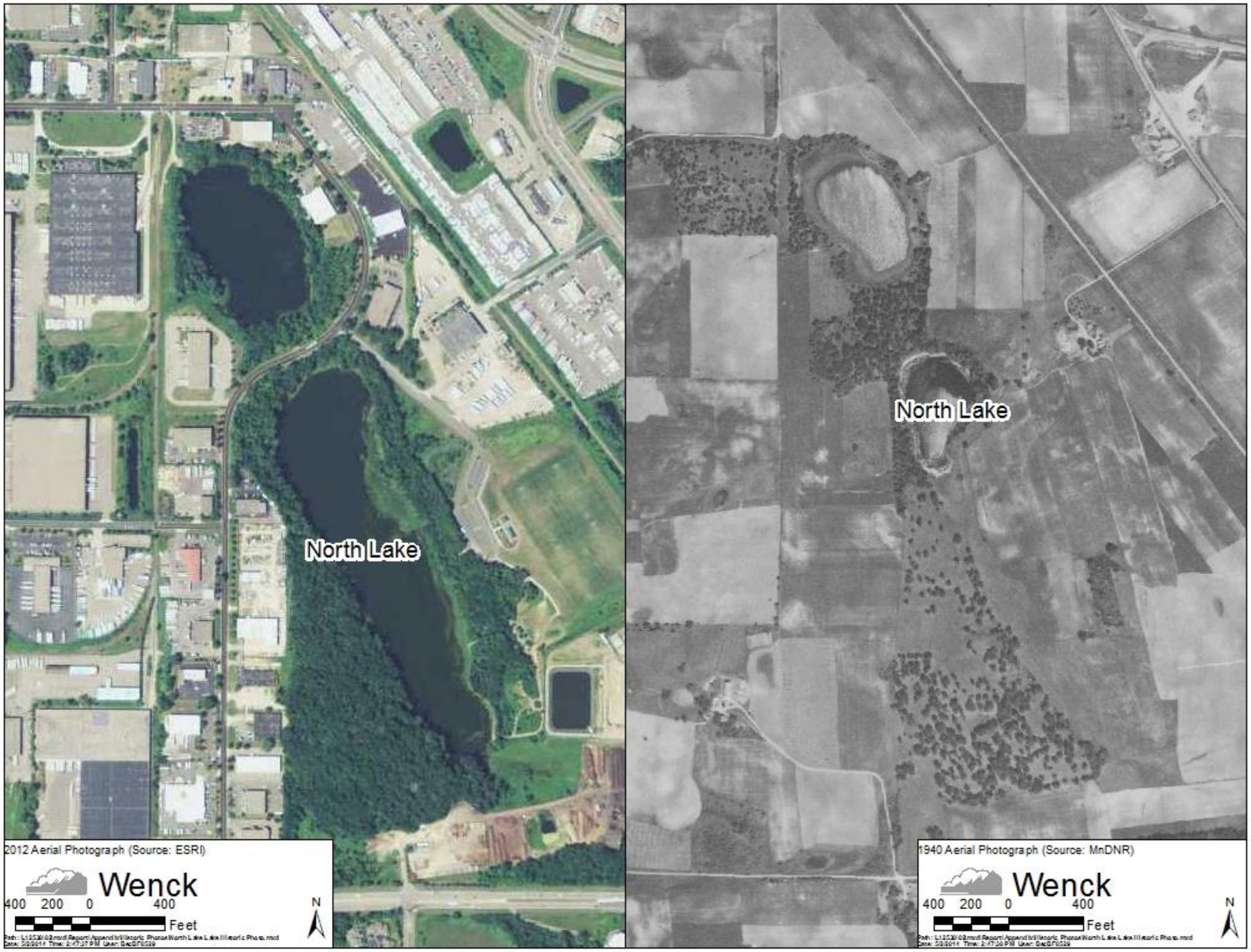
Carlson and Quigley Lake current and historic aerial photographs.

Cliff Lake current and historic aerial photographs.



Fitz, Hay Holz, and LP-30 current and historic aerial photographs.

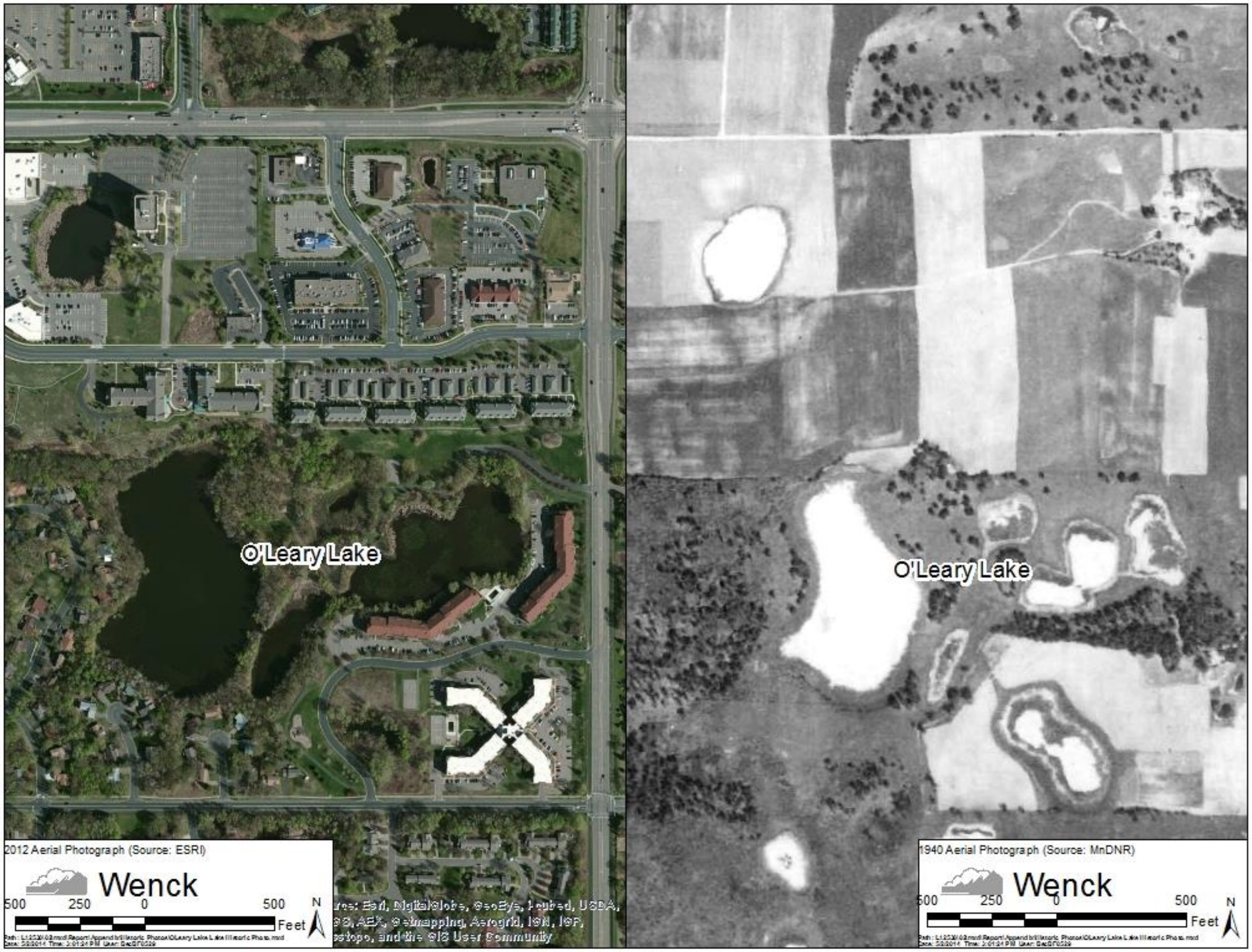
Lemay Lake current and historic aerial photographs.



2012 Aerial Photograph (Source: ESRI)

1940 Aerial Photograph (Source: MnDNR)

North Lake current and historic aerial photographs.



2012 Aerial Photograph (Source: ESRI)

rces: Esri, DigitalGlobe, GeoEye, i-cubed, USDA,
S, AEX, Getmapping, Aerogrid, IGN, IGP,
stopo, and the GIS User Community

1940 Aerial Photograph (Source: MnDNR)

O’Leary Lake current and historic aerial photographs.

Appendix B

Lake Bathymetry Images and Data

Lake depth and area derived from bathymetric maps.

Bald Lake	
Depth (ft)	Area (acres)
0	9.9
2	8.8
4	8.1
6	6.8
8	2.6

Bur Oaks Lake	
Depth (ft)	Area (acres)
0	10.8
1	9.4
2	7.7
3	6.4
4	5.4
5	4.3
6	2.6
7	1.1
10	0.3

Carlson Lake	
Depth (ft)	Area (acres)
0	8.5
5	7.3
10	5.4
15	2.2
21	0.0

Cliff Lake	
Depth (ft)	Area (acres)
0.0	11.8
1.0	10.3
2.0	9.0
3.0	6.9
6.6	1.4

Fitz Lake	
Depth (ft)	Area (acres)
0	12.3
2	9.9
5	5.8
10	2.7
11	1.4

Hay Lake	
Depth (ft)	Area (acres)
0	22.0
1	21.1
2	19.0
3	15.4
4	9.0
5	4.9
6	2.5
7	0.0
8	0.0

Holz Lake	
Depth (ft)	Area (acres)
0	10.0
1	9.6
2	9.1
3	8.5
4	7.9
5	7.1
6	6.0
7	4.3
8	2.3
9	0.0

Lemay Lake	
Depth (ft)	Area (acres)
0	31.7
5	17.7
10	1.5
16	0.4

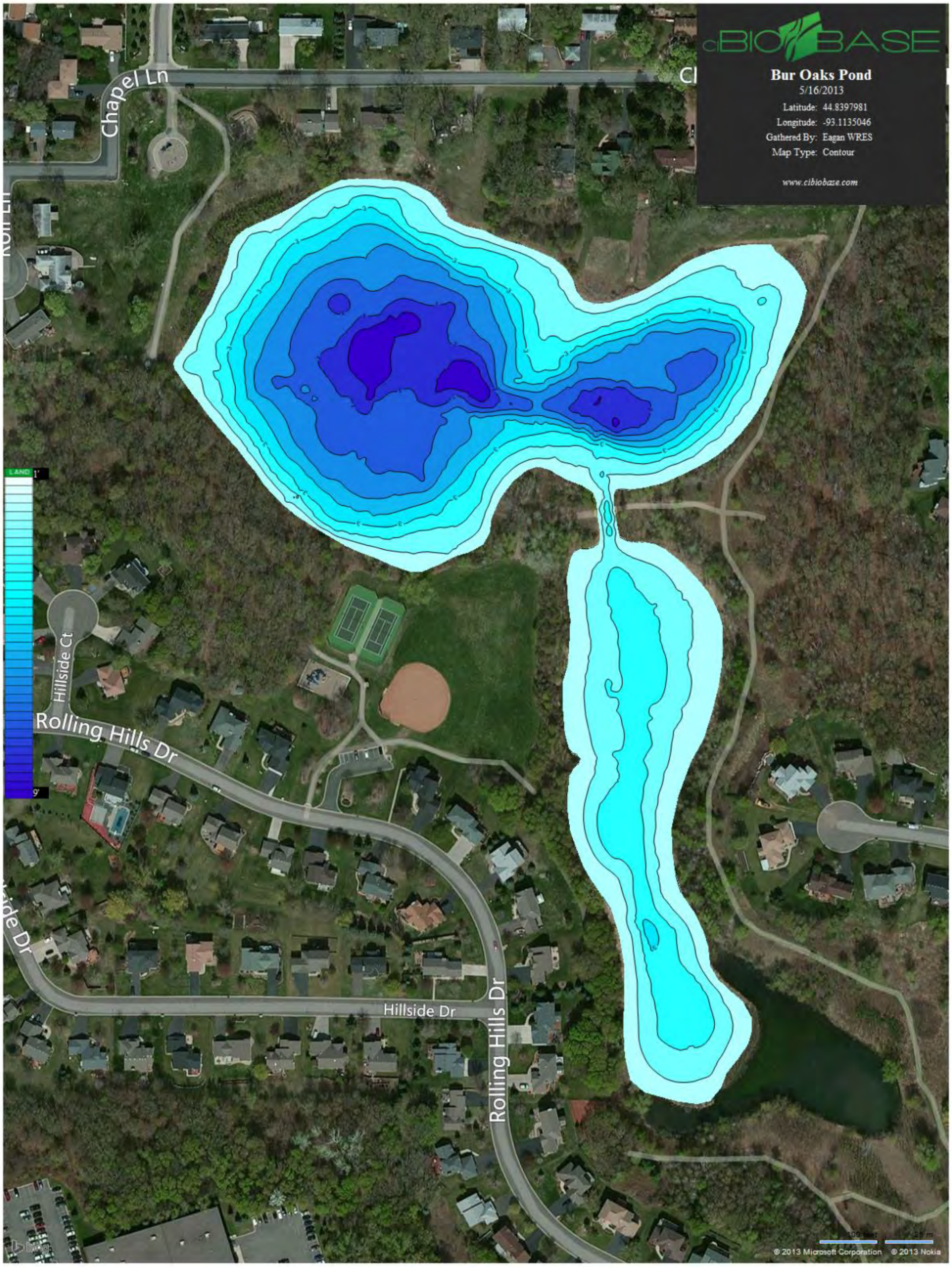
LP-30	
Depth (ft)	Area (acres)
0.0	9.1
1.0	9
2.0	8.67
3.0	8.32
4.0	7.97
5.0	7.6
6.0	7.1
7.0	6.5
8	4.9
9	2.5
10	1.4
11	0.6

North Lake	
Depth (ft)	Area (acres)
0	16
2	10.6
5	6.6
10	3.7

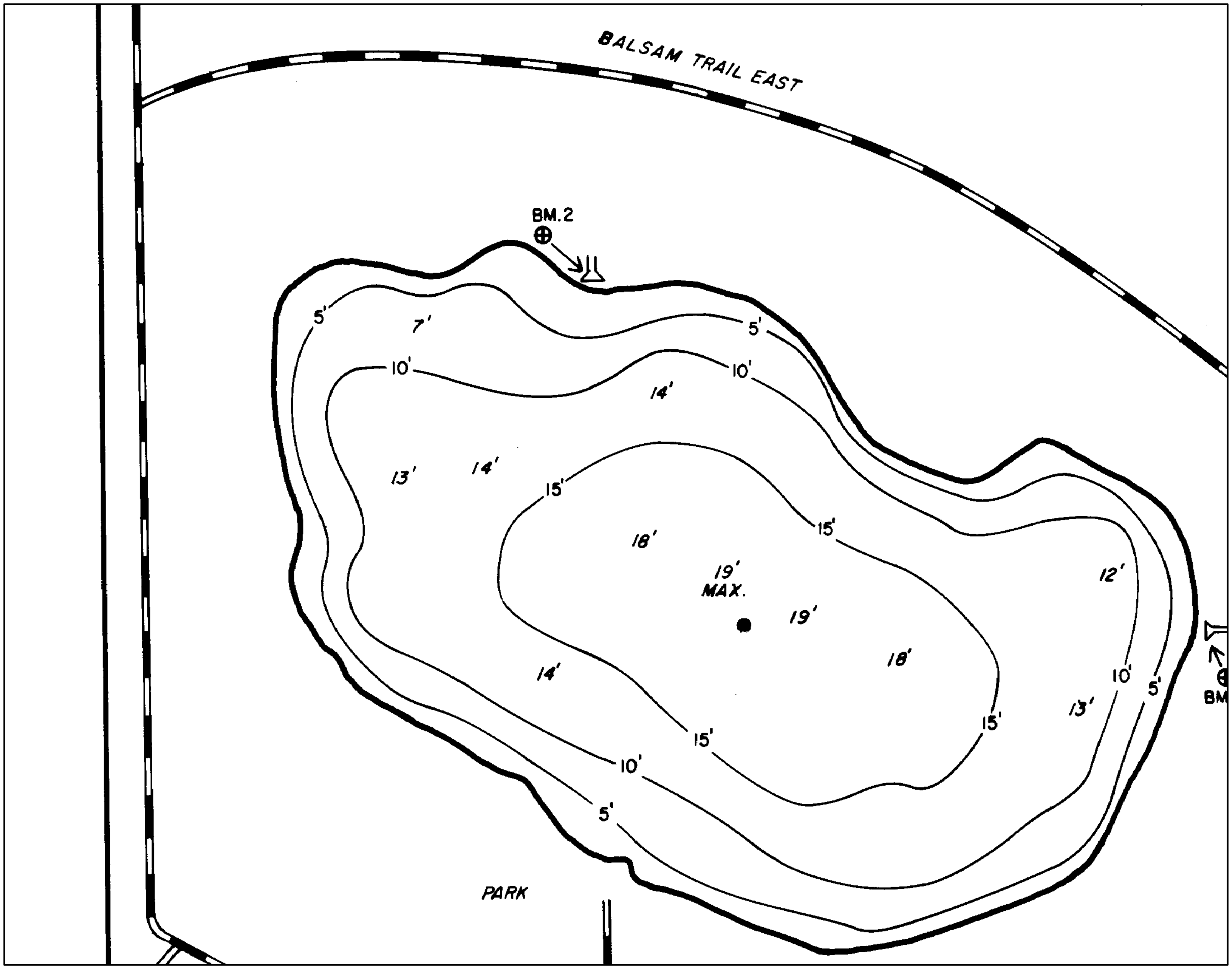
O'Leary Lake	
Depth (ft)	Area (acres)
0	9.3
2	6.9
4	3.8

Quigley Lake	
Depth (ft)	Area (acres)
0	11.2
3	8.2
5	4.9

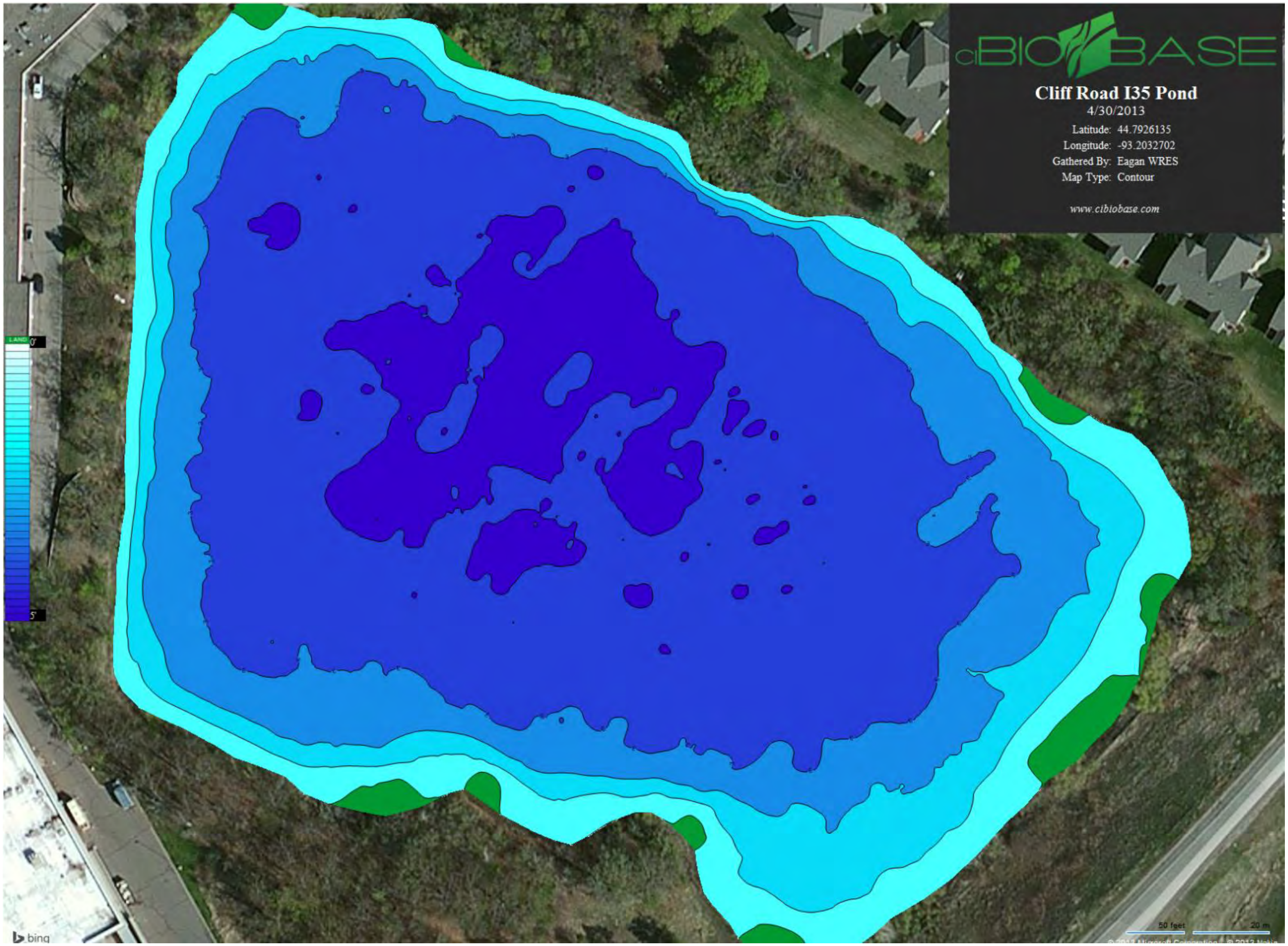
Bald Lake Bathymetry (Source: City of Eagan).



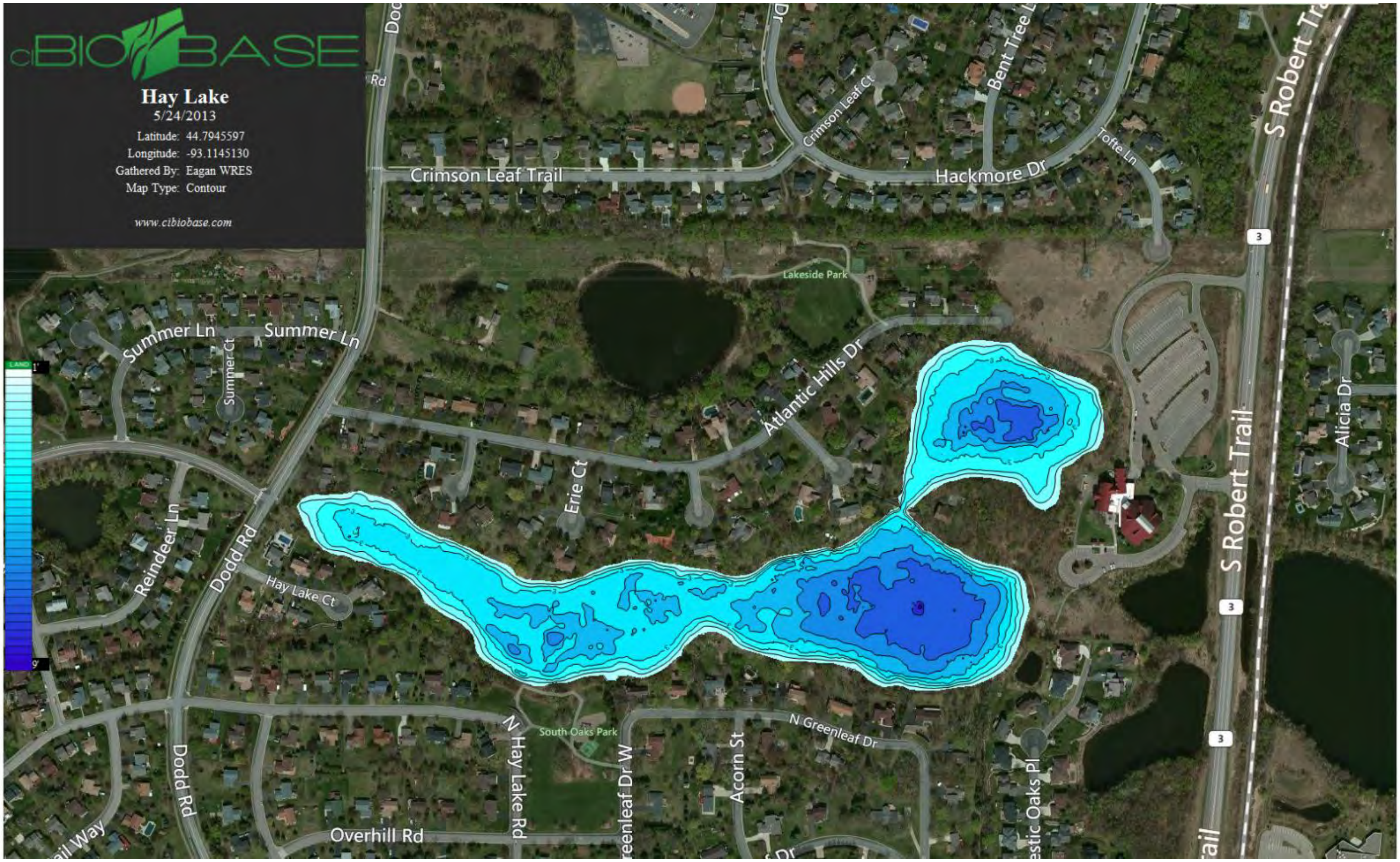
Bur Oaks Lake Bathymetry (Source: City of Eagan and BioBase).



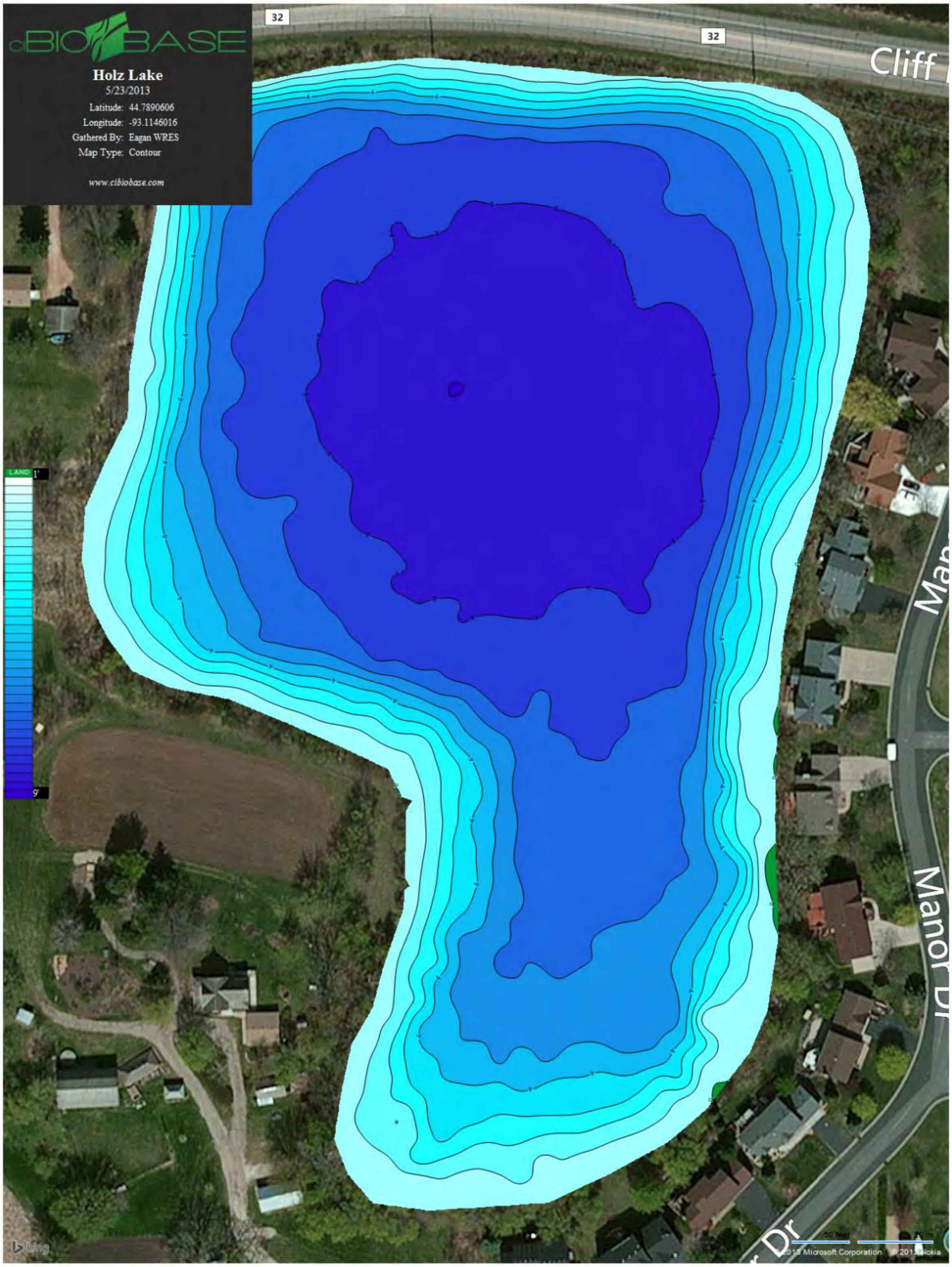
Carlson Lake Bathymetry (Source: Minnesota DNR)



Cliff Lake Bathymetry (Source: City of Eagan and BioBase)

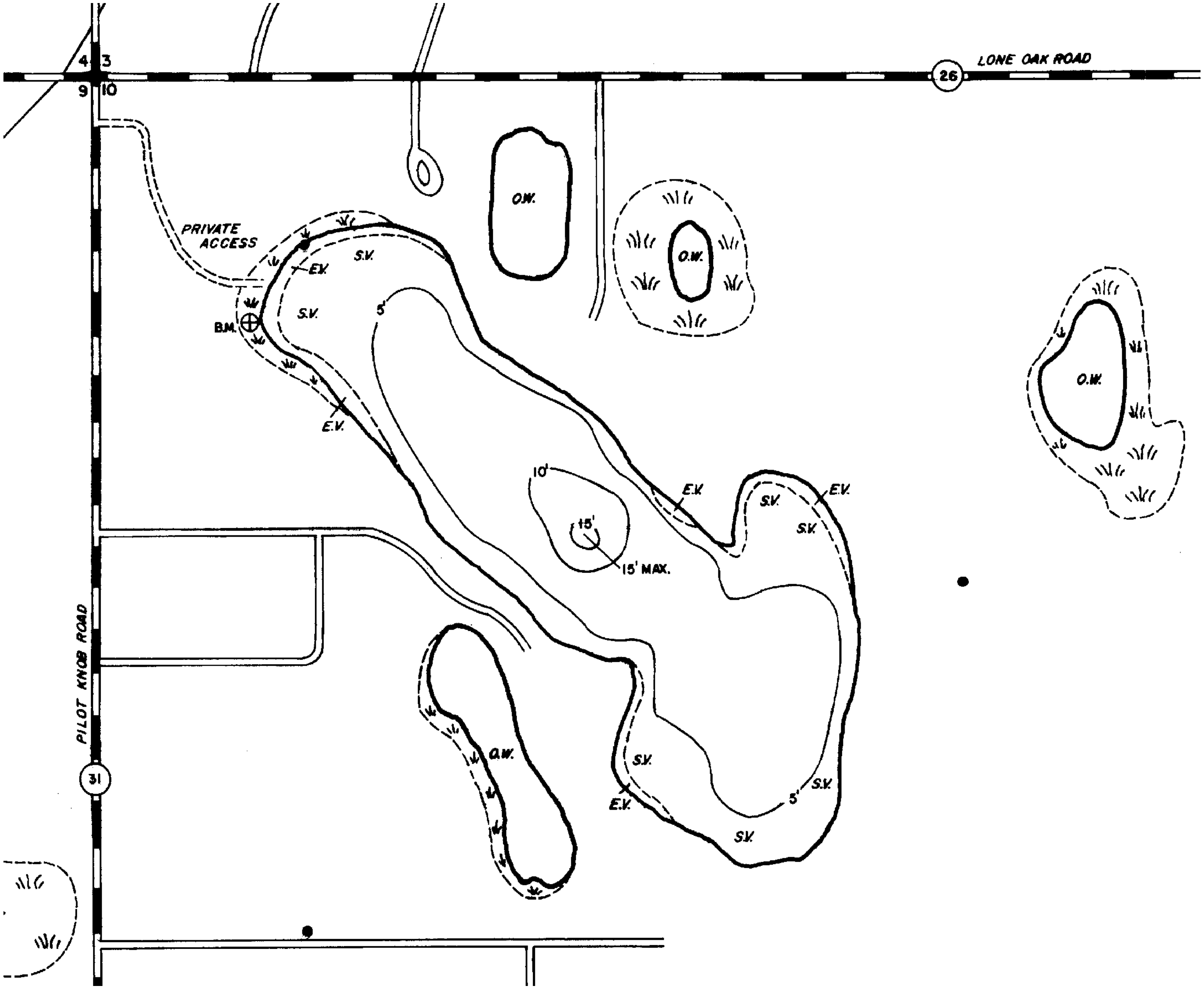


Hay Lake Bathymetry (Source: City of Eagan and BioBase)

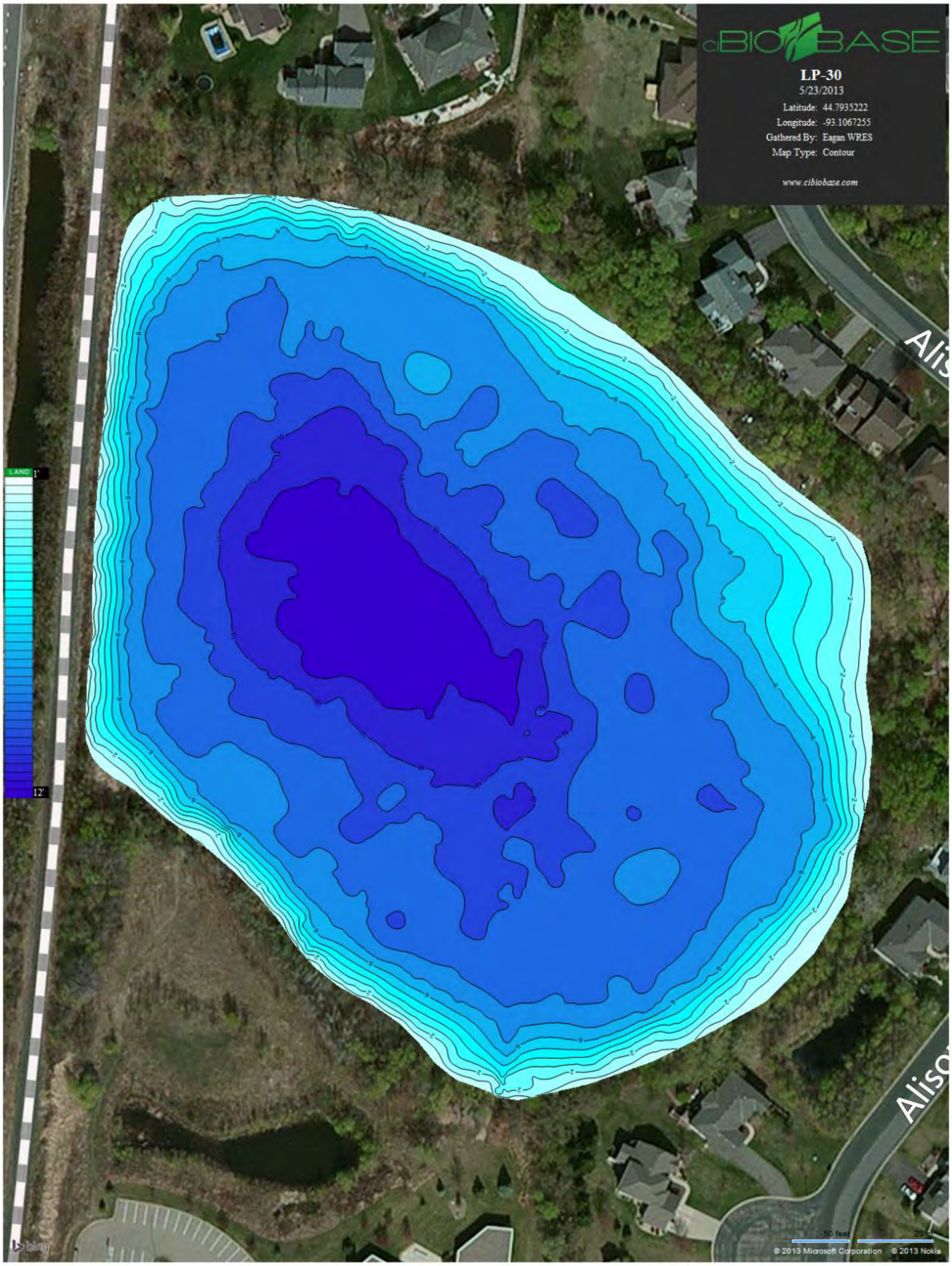


Holz Lake Bathymetry (Source: City of Eagan and BioBase)

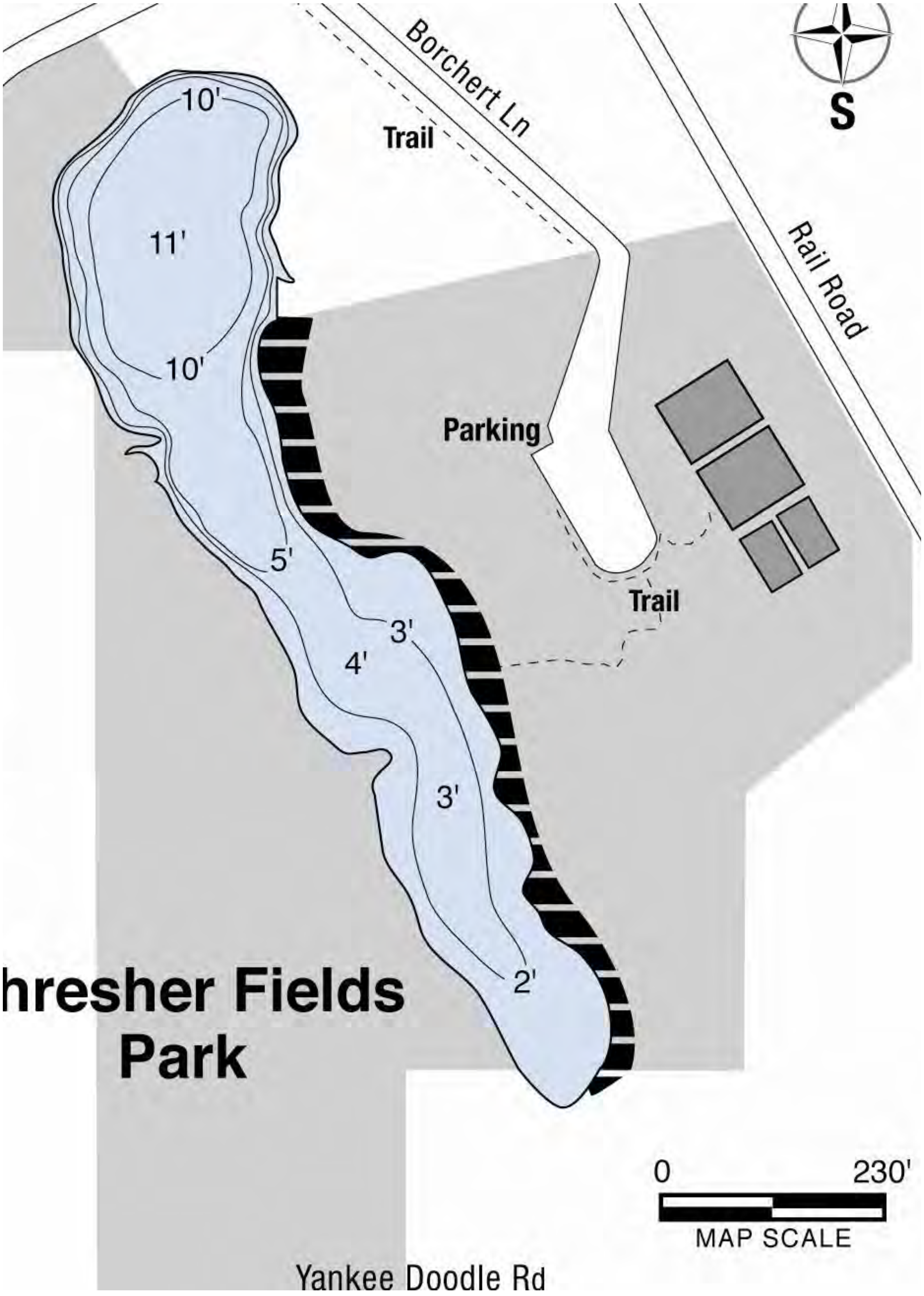
Fitz Lake Bathymetry



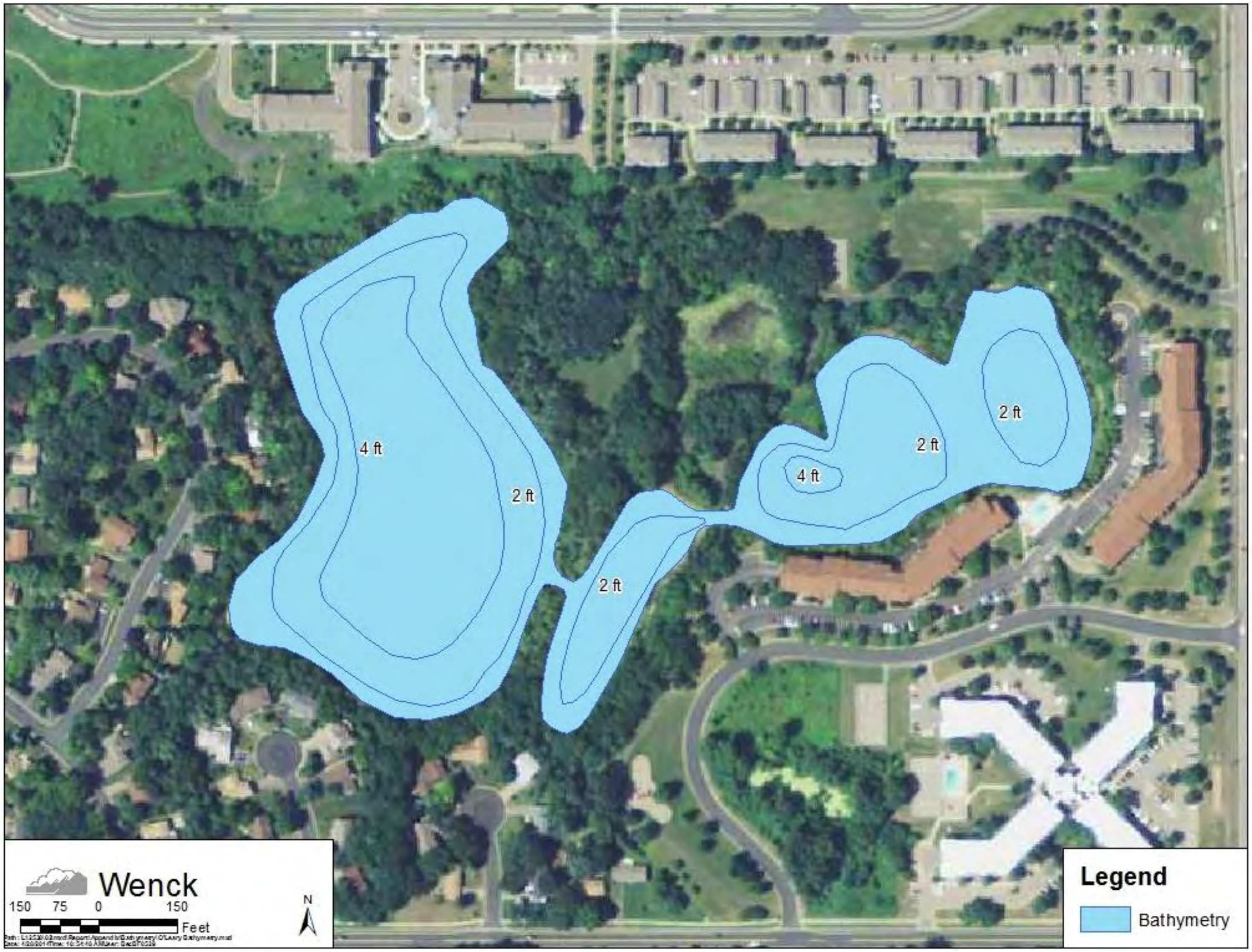
Lemay Lake Bathymetry (Source: Minnesota DNR)



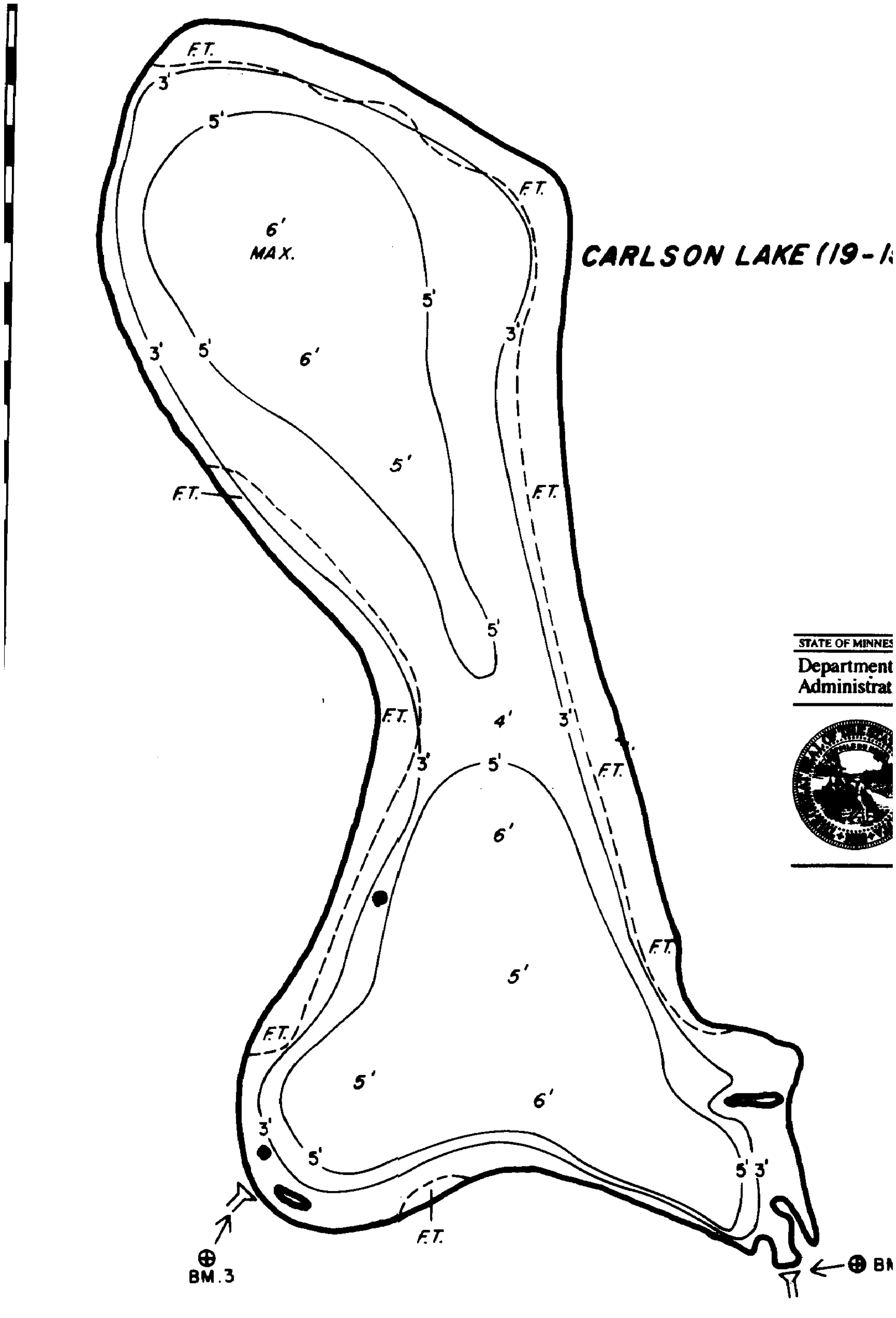
LP-30 Lake Bathymetry (Source: City of Eagan and BioBase)



North Lake Bathymetry (Source: City of Eagan).



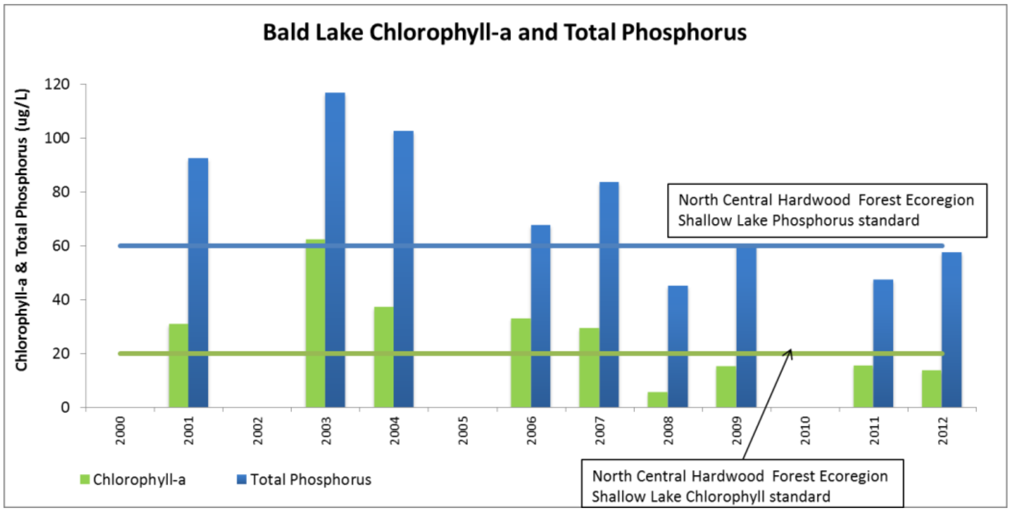
Fitz Lake Bathymetry

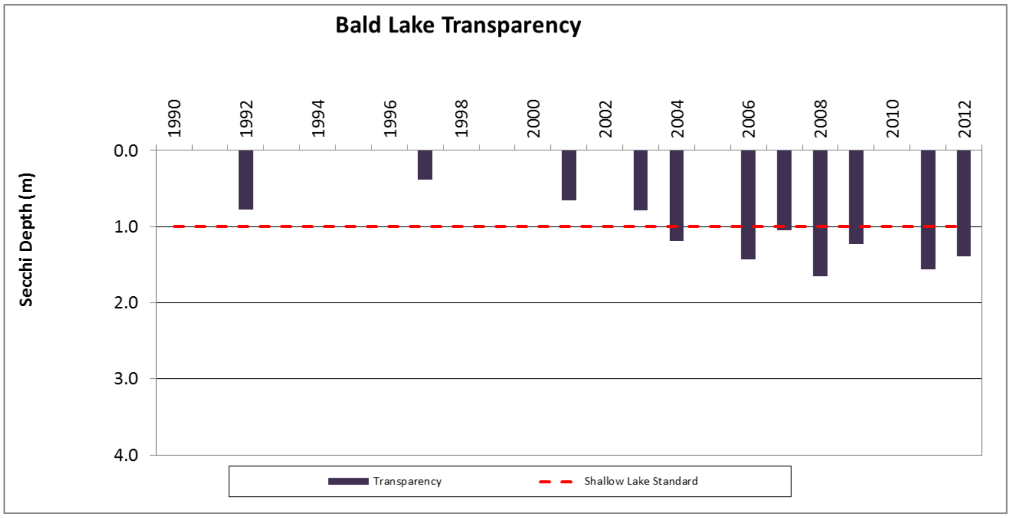


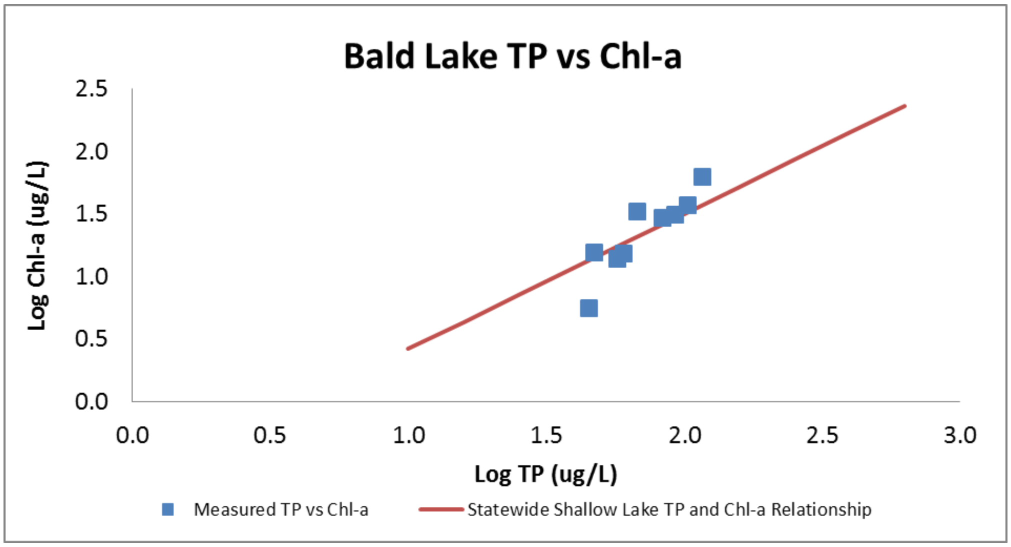
Quigley Lake Bathymetry (Source: Minnesota DNR).

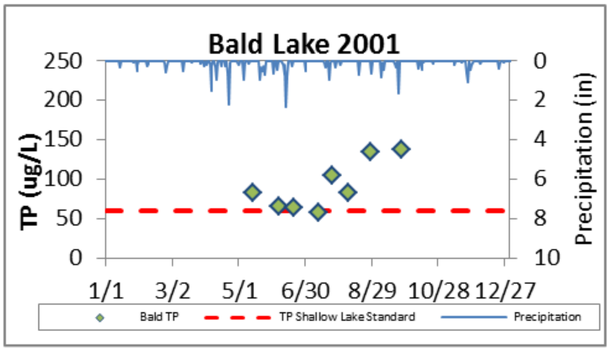
Appendix C

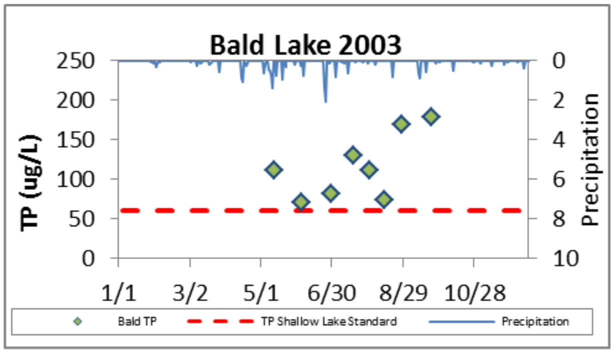
Neighborhood Lake Water Quality Figures

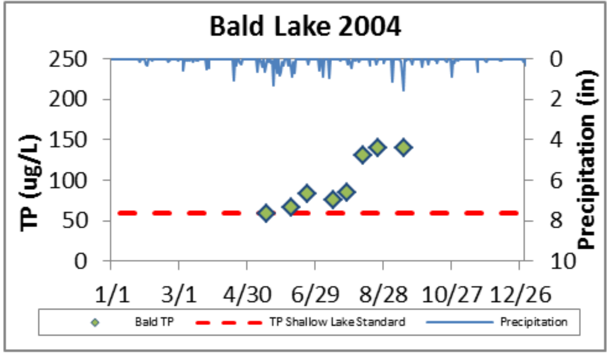

Bald Lake Chlorophyll-a and Total Phosphorus
Chlorophyll-a & Total Phosphorus (ug/L)
0
20
40
60
80
100
120
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
North Central Hardwood Forest Ecoregion Shallow Lake Phosphorus standard
North Central Hardwood Forest Ecoregion Shallow Lake Chlorophyll standard
Chlorophyll-a
Total Phosphorus

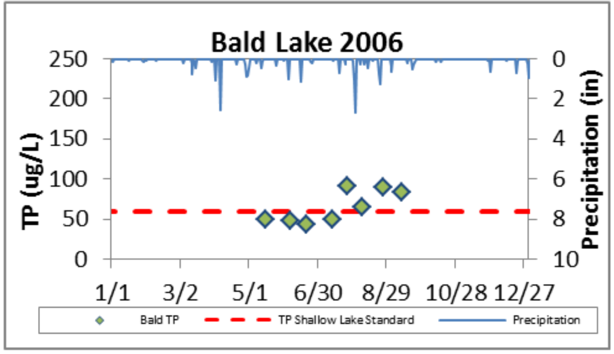

Bald Lake Transparency
Secchi Depth (m)
0.0
1.0
2.0
3.0
4.0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Transparency
Shallow Lake Standard

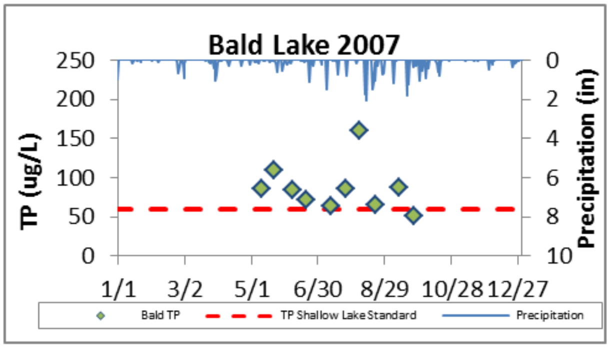

Bald Lake TP vs Chl-a
Log Chl-a (ug/L)
0.0
0.5
1.0
1.5
2.0
2.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Log TP (ug/L)
Measured TP vs Chl-a
Statewide Shallow Lake TP and Chl-a Relationship

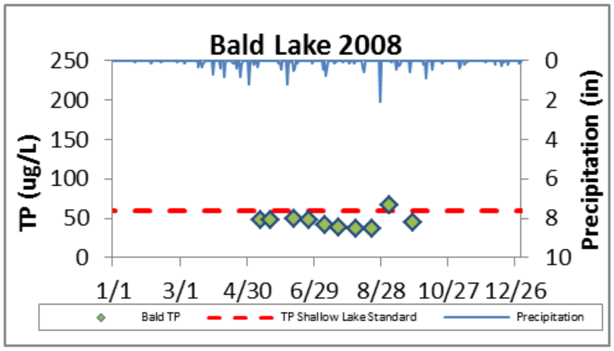

Bald Lake 2001

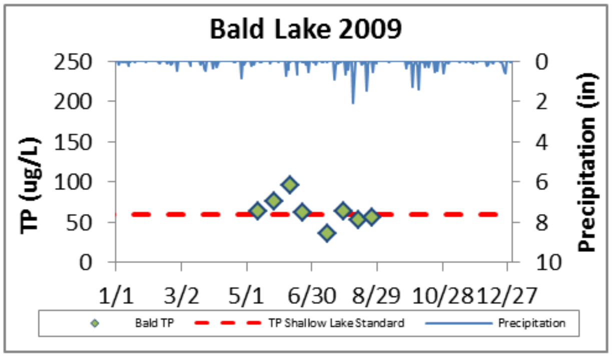

Bald Lake 2003

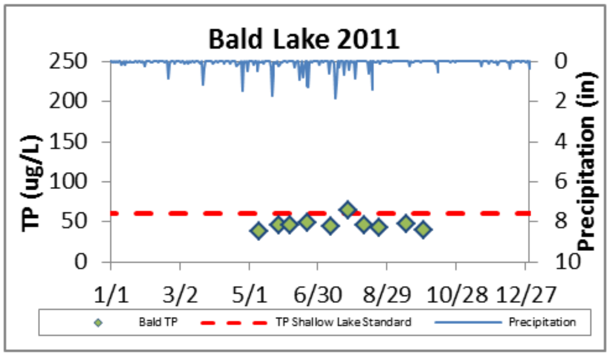

Bald Lake 2004

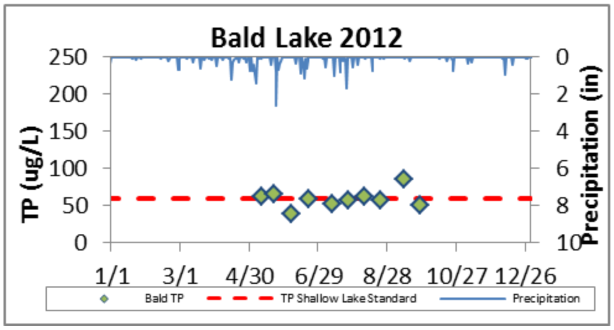

Bald Lake 2006

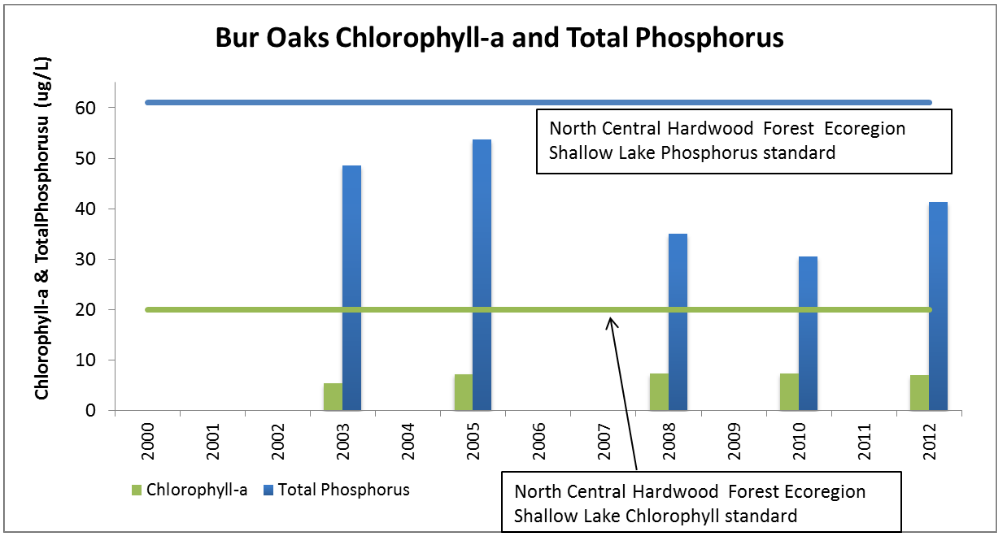

Bald Lake 2007

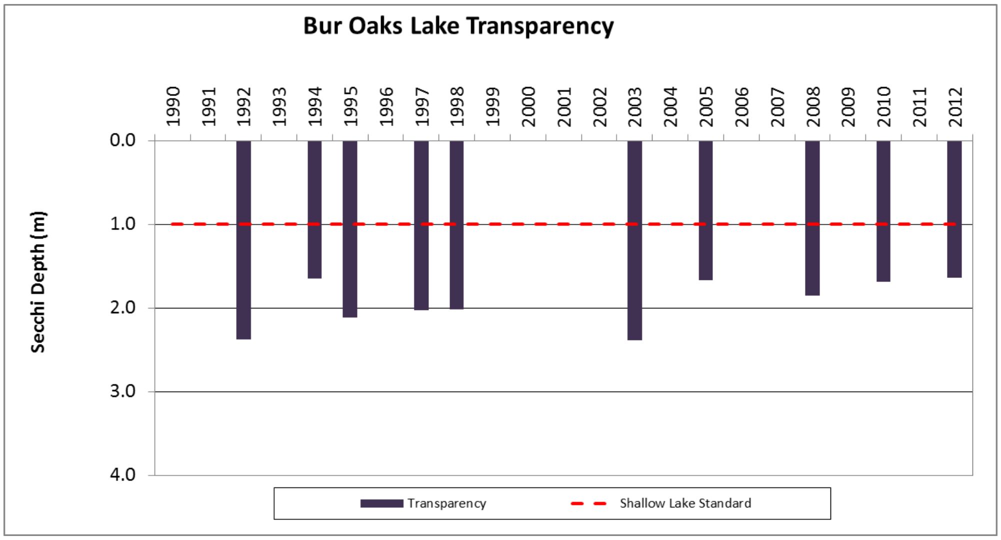

Bald Lake 2008

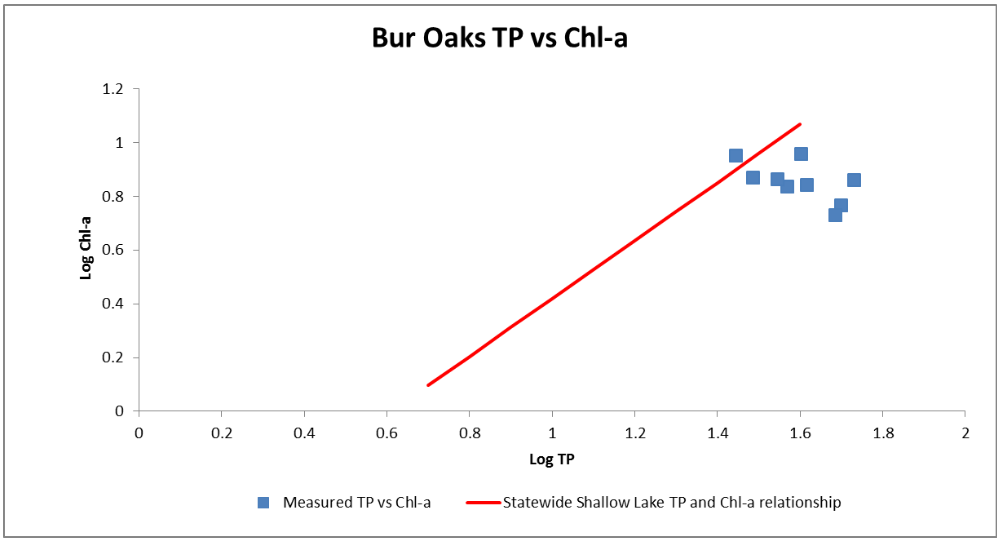

Bald Lake 2009

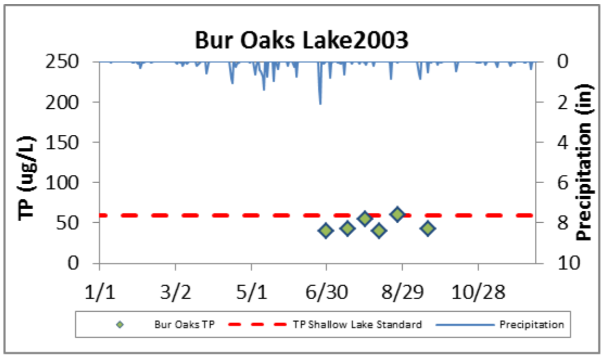

Bald Lake 2011

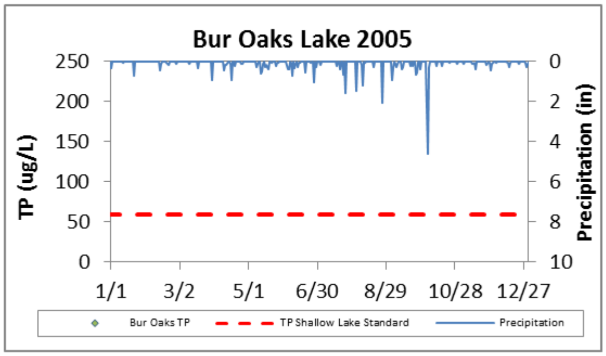

Bald Lake 2012

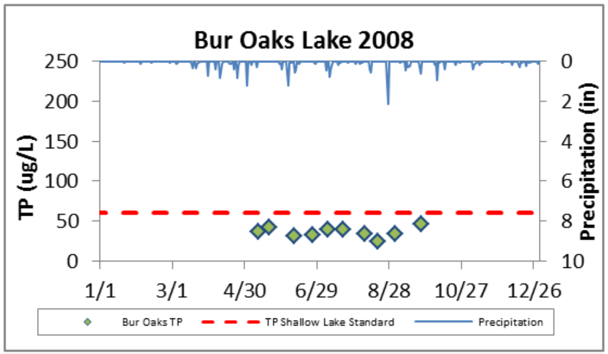

Bur Oaks Chlorophyll-a and Total Phosphorus
Chlorophyll-a & TotalPhosphorusu (ug/L)
0
10
20
30
40
50
60
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
North Central Hardwood Forest Ecoregion Shallow Lake Phosphorus standard
North Central Hardwood Forest Ecoregion Shallow Lake Chlorophyll standard
Chlorophyll-a
Total Phosphorus

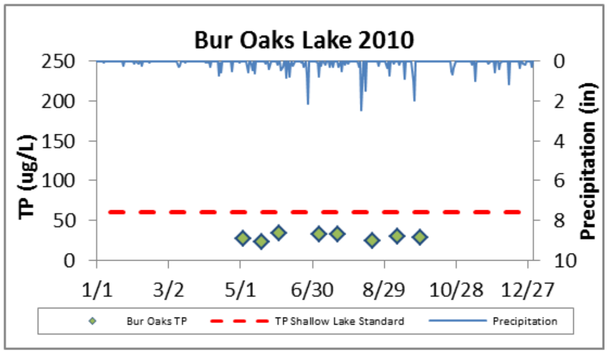

Bur Oaks Lake Transparency
Secchi Depth (m)
0.0
1.0
2.0
3.0
4.0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Transparency
Shallow Lake Standard

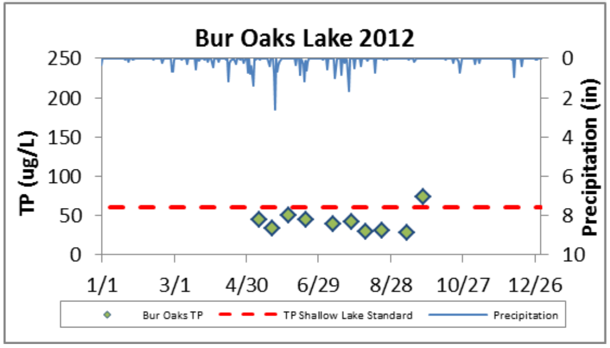

Bur Oaks TP vs Chl-a
Log Chl-a
0
0.2
0.4
0.6
0.8
1
1.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Log TP
Measured TP vs Chl-a
Statewide Shallow Lake TP and Chl-a relationship

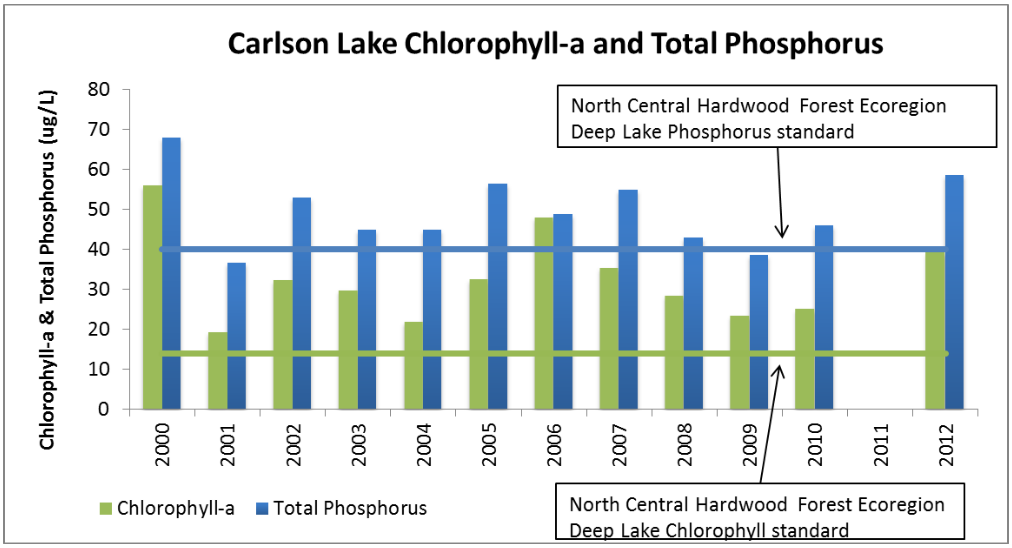

Bur Oaks Lake2003
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
Bur Oaks TP
TP Shallow Lake Standard
Precipitation

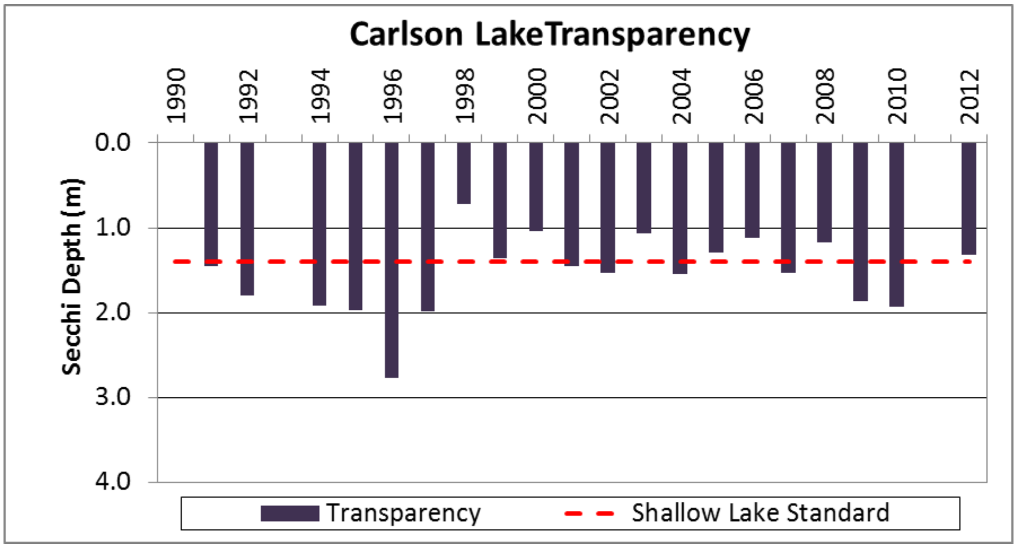

Bur Oaks Lake 2005
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Bur Oaks TP
TP Shallow Lake Standard
Precipitation

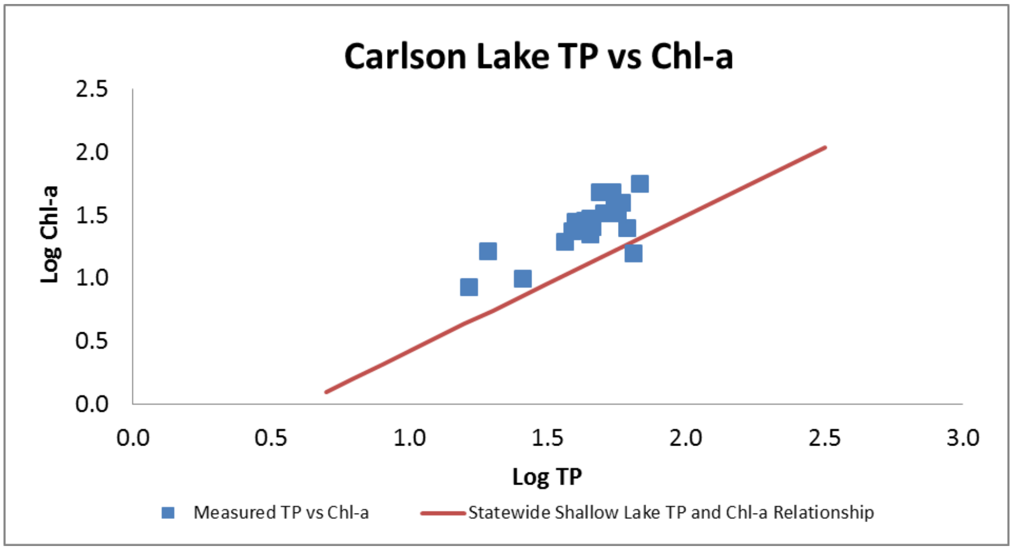

Bur Oaks Lake 2008
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
Bur Oaks TP
TP Shallow Lake Standard
Precipitation

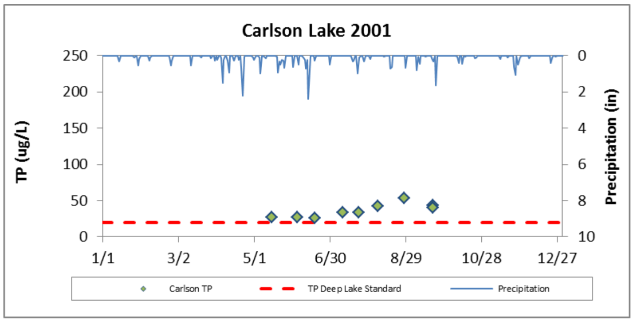

Bur Oaks Lake 2010
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Bur Oaks TP
TP Shallow Lake Standard
Precipitation

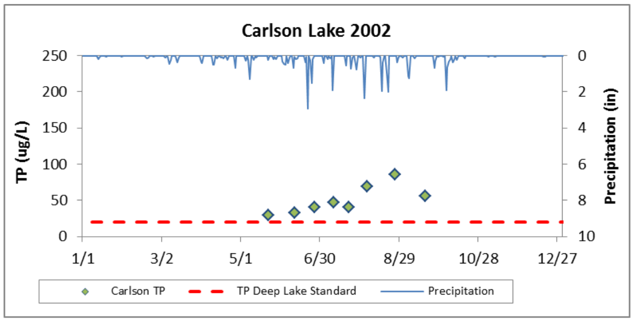

Bur Oaks Lake 2012
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
Bur Oaks TP
TP Shallow Lake Standard
Precipitation

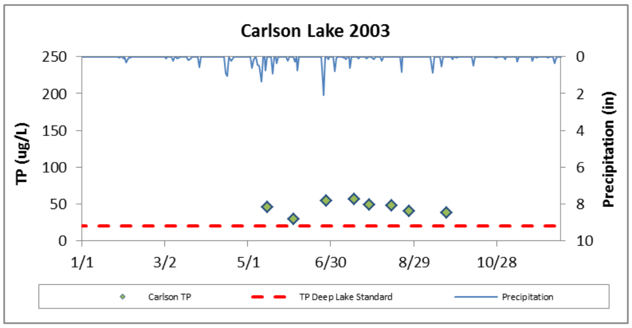

Carlson Lake Chlorophyll-a and Total Phosphorus
Chlorophyll-a & Total Phosphorus (ug/L)
0
10
20
30
40
50
60
70
80
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
North Central Hardwood Forest Ecoregion Deep Lake Phosphorus standard
North Central Hardwood Forest Ecoregion Deep Lake Chlorophyll standard
Chlorophyll-a
Total Phosphorus

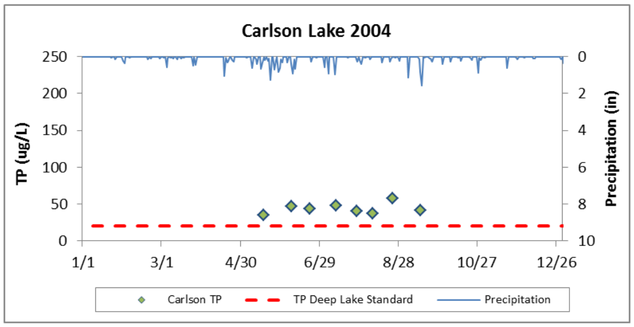

Carlson LakeTransparency
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Secchi Depth (m)
0.0
1.0
2.0
3.0
4.0
Transparency
Shallow Lake Standard

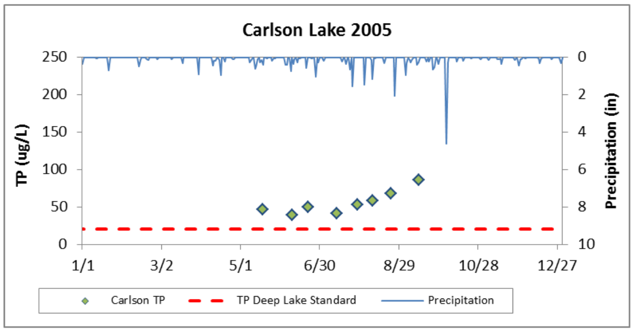

Carlson Lake TP vs Chl-a
Log Chl-a
0.0
0.5
1.0
1.5
2.0
2.5
Log TP
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Measured TP vs Chl-a
Statewide Shallow Lake TP and Chl-a Relationship

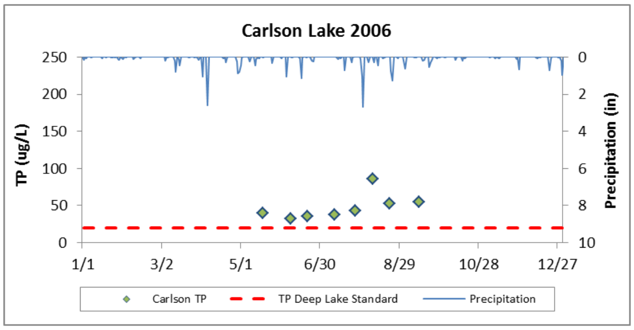

Carlson Lake 2001
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Carlson TP
TP Deep Lake Standard
Precipitation

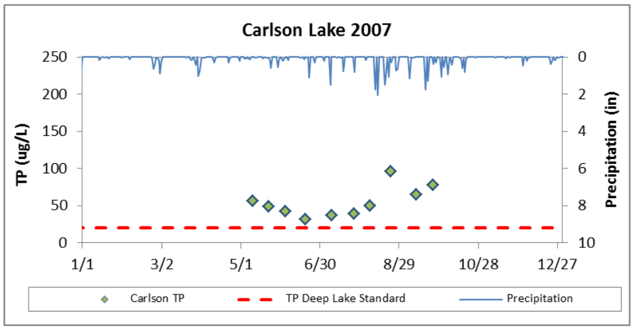

Carlson Lake 2002
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Carlson TP
TP Deep Lake Standard
Precipitation

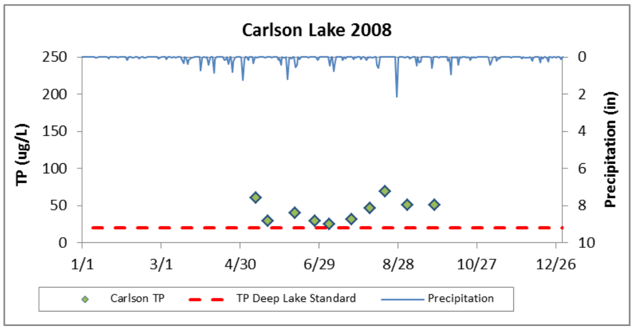

Carlson Lake 2003
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
Carlson TP
TP Deep Lake Standard
Precipitation

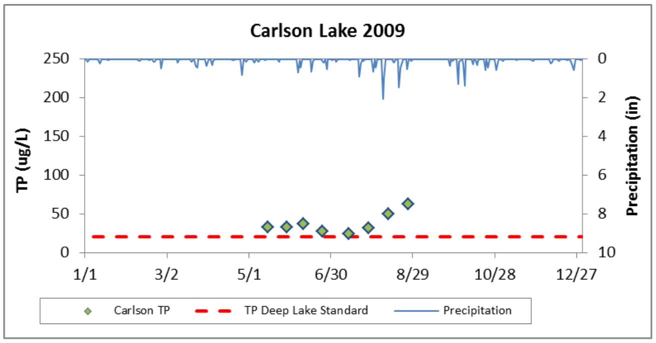

Carlson Lake 2004
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
Carlson TP
TP Deep Lake Standard
Precipitation

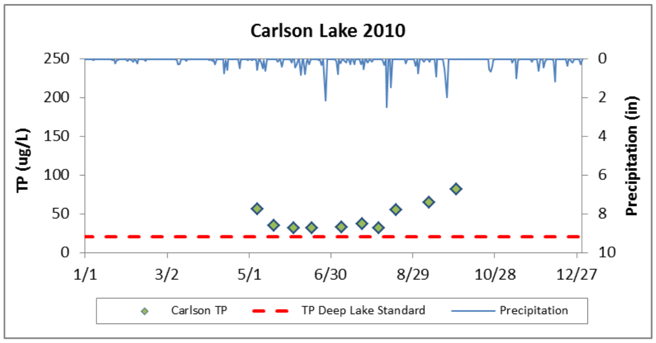

Carlson Lake 2005
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Carlson TP
TP Deep Lake Standard
Precipitation

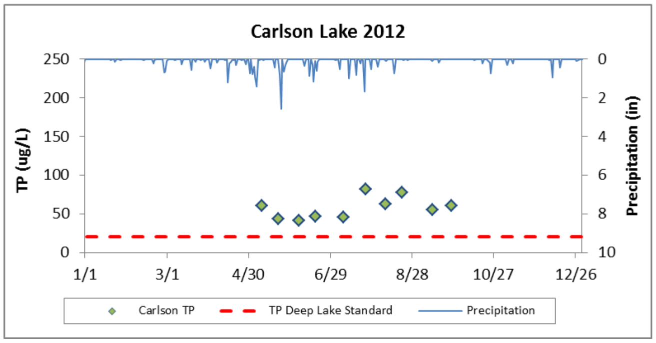

Carlson Lake 2006
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Carlson TP
TP Deep Lake Standard
Precipitation

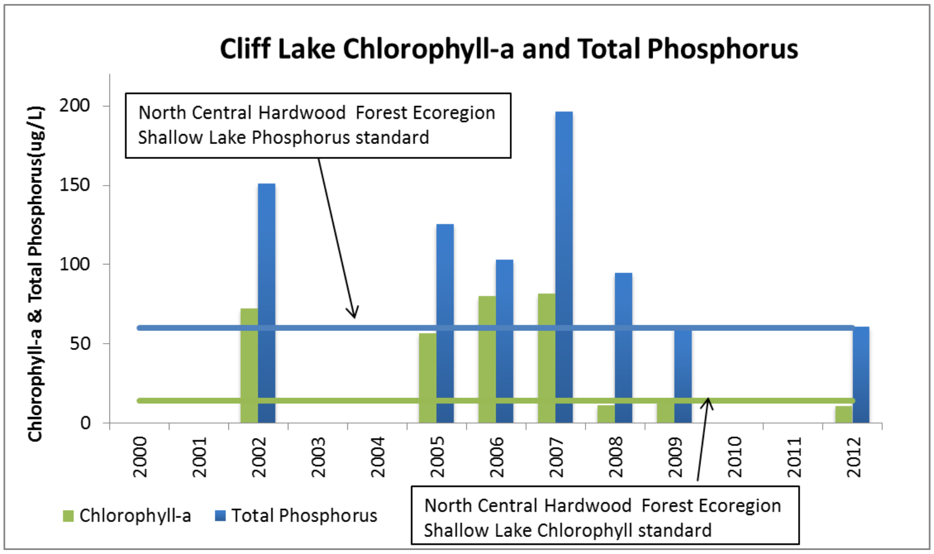

Carlson Lake 2007
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Carlson TP
TP Deep Lake Standard
Precipitation

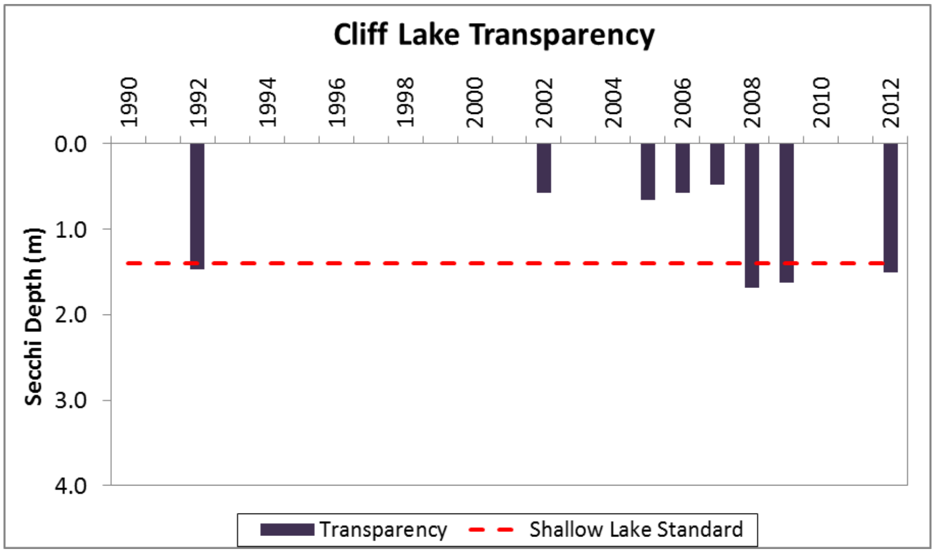

Carlson Lake 2008
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
Carlson TP
TP Deep Lake Standard
Precipitation

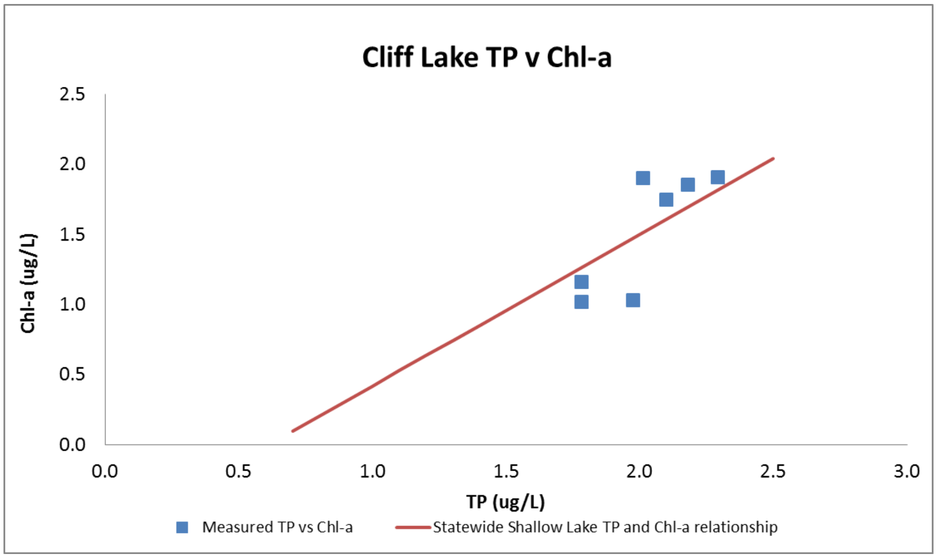

Carlson Lake 2009
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Carlson TP
TP Deep Lake Standard
Precipitation

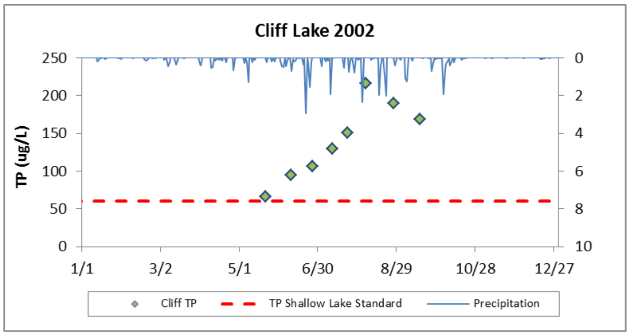

Carlson Lake 2010
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Carlson TP
TP Deep Lake Standard
Precipitation

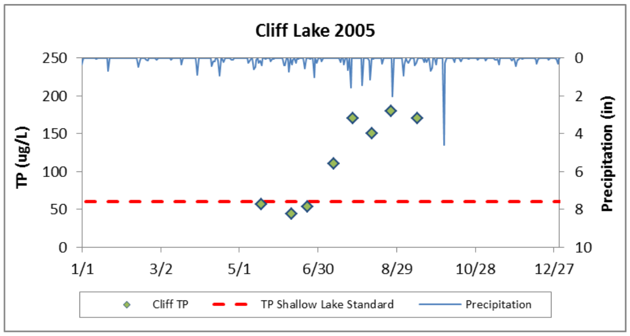

Carlson Lake 2012
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
Carlson TP
TP Deep Lake Standard
Precipitation

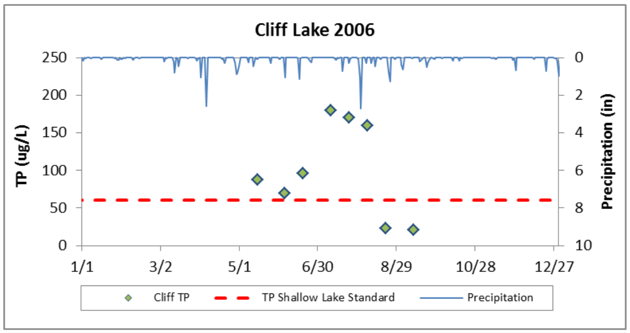

Cliff Lake Chlorophyll-a and Total Phosphorus
Chlorophyll-a & Total Phosphorus(ug/L)
200
150
100
50
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
North Central Hardwood Forest Ecoregion Shallow Lake Phosphorus standard
North Central Hardwood Forest Ecoregion Shallow Lake Chlorophyll standard
Chlorophyll-a
Total Phosphorus

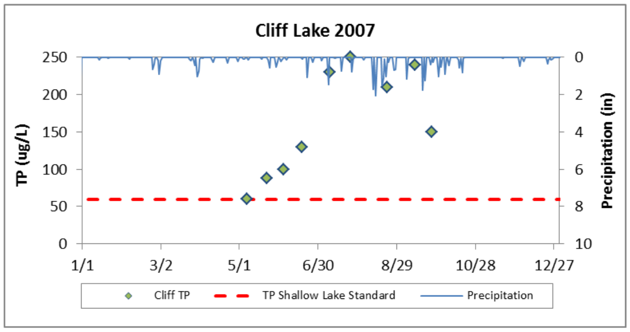

Cliff Lake Transparency
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
0.0
1.0
2.0
3.0
4.0
Secchi Depth (m)
Transparency
Shallow Lake Standard

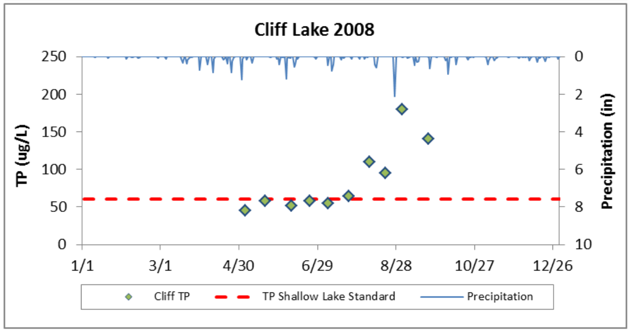

Cliff Lake TP v Chl-a
2.5
2.0
1.5
1.0
0.5
0.0
Chl-a (ug/L)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
TP (ug/L)
Measured TP vs Chl-a
Statewide Shallow Lake TP and Chl-a relationship

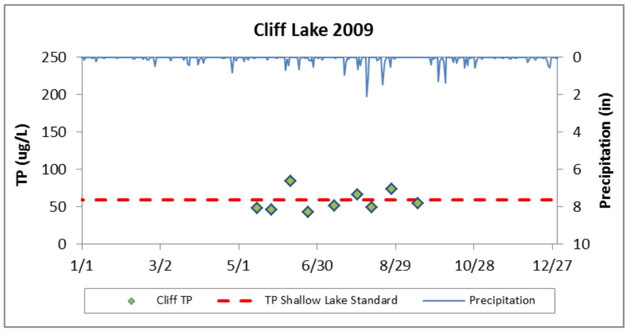

Cliff Lake 2002

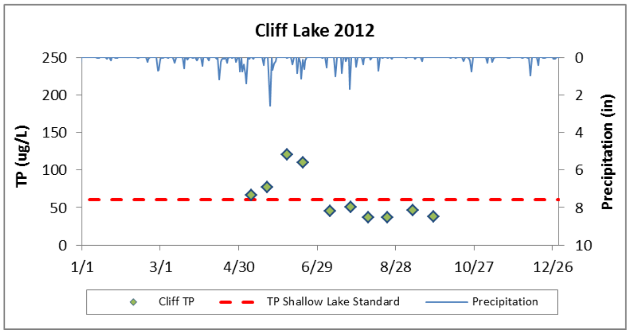

Cliff Lake 2005

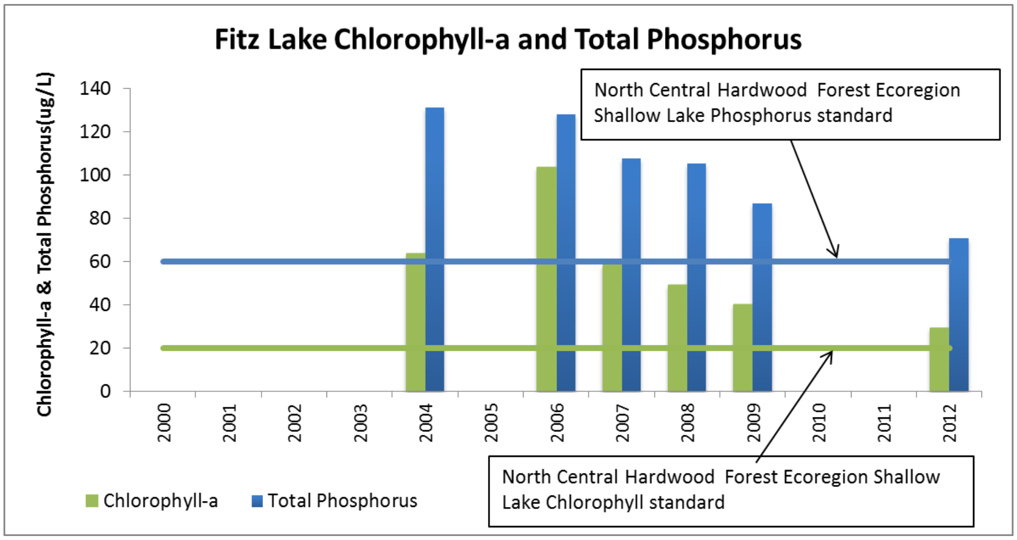

Cliff Lake 2006

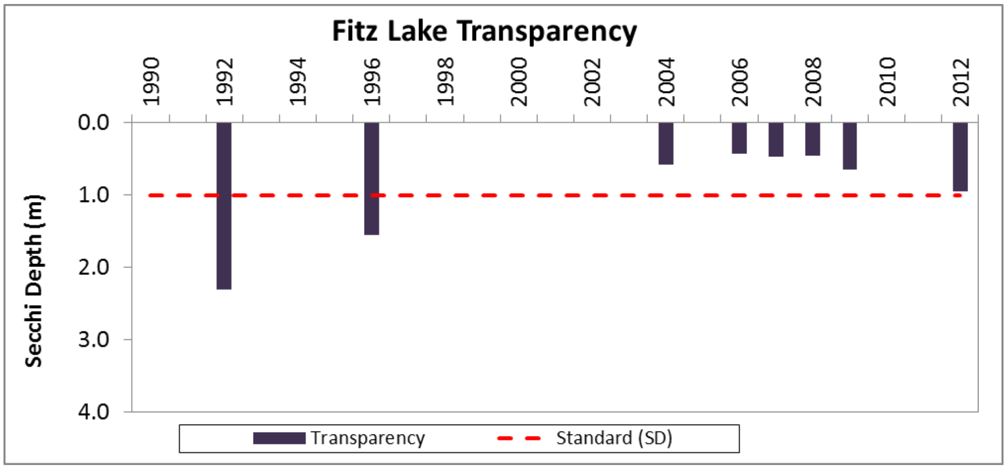

Cliff Lake 2007

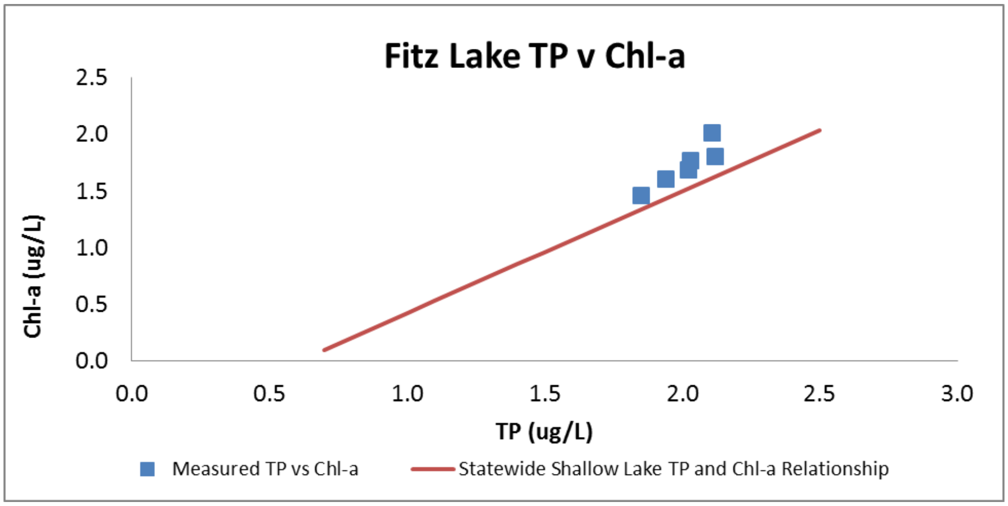

Cliff Lake 2008

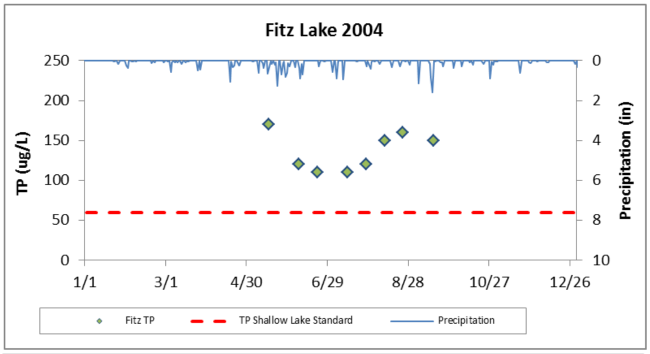

Cliff Lake 2009

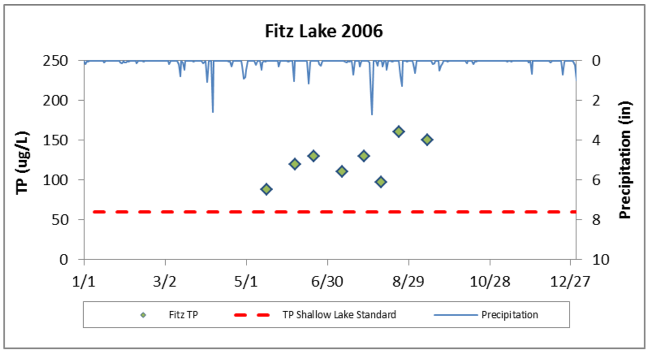

Cliff Lake 2012

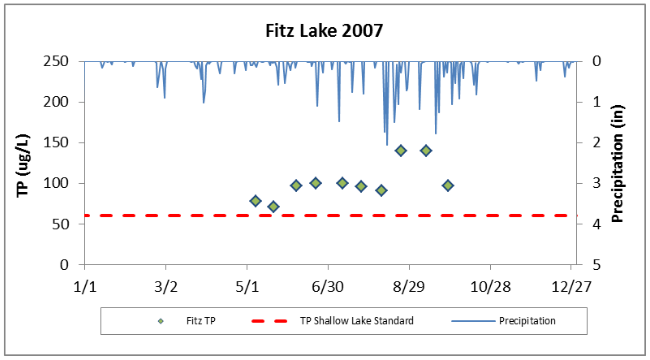

Fitz Lake Chlorophyll-a and Total Phosphorus
Chlorophyll-a & Total Phosphorus(ug/L)
140
120
100
80
60
40
20
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
North Central Hardwood Forest Ecoregion Shallow Lake Phosphorus standard
North Central Hardwood Forest Ecoregion Shallow Lake Chlorophyll standard
🟩 Chlorophyll-a
🟦 Total Phosphorus

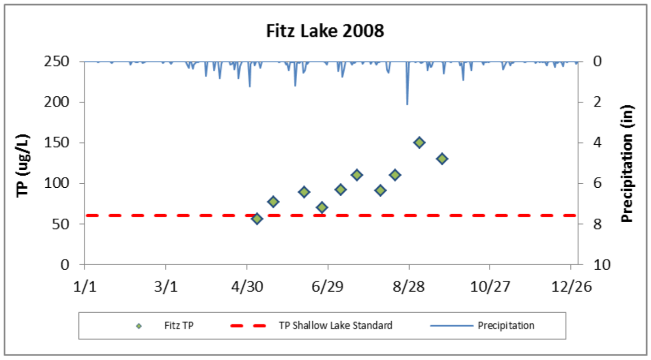

Fitz Lake Transparency
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Secchi Depth (m)
0.0
1.0
2.0
3.0
4.0
Transparency
Standard (SD)

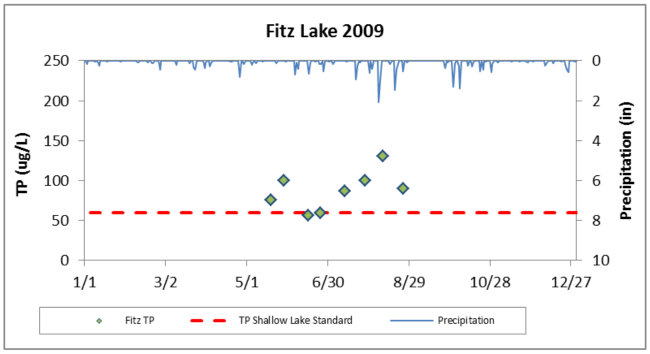

Fitz Lake TP v Chl-a
Chl-a (ug/L)
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
TP (ug/L)
Measured TP vs Chl-a
Statewide Shallow Lake TP and Chl-a Relationship

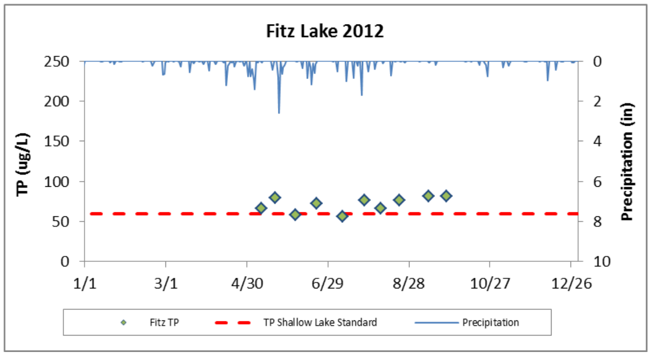

Fitz Lake 2004
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
Fitz TP
TP Shallow Lake Standard
Precipitation

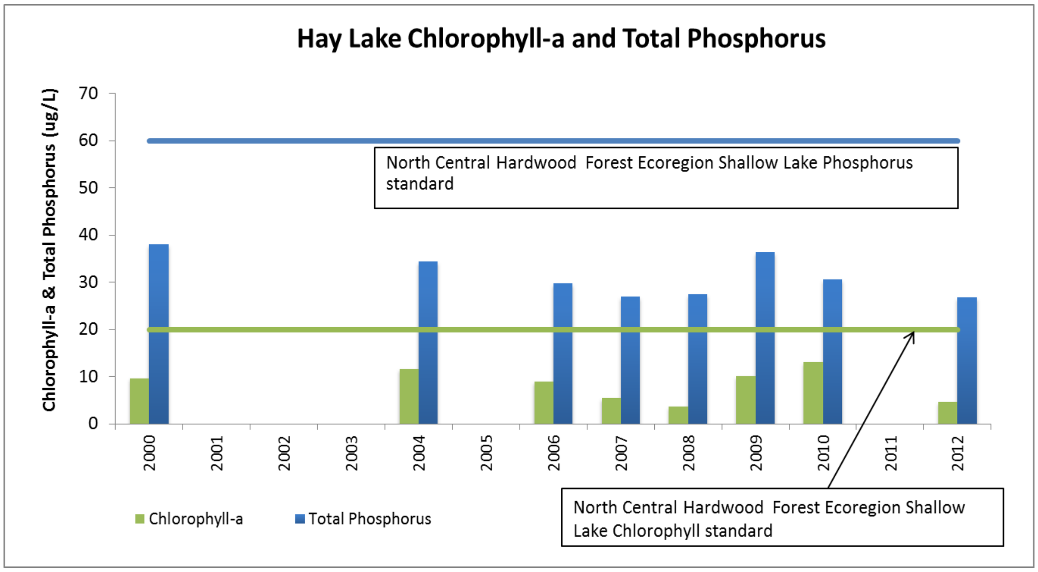

Fitz Lake 2006
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Fitz TP
TP Shallow Lake Standard
Precipitation

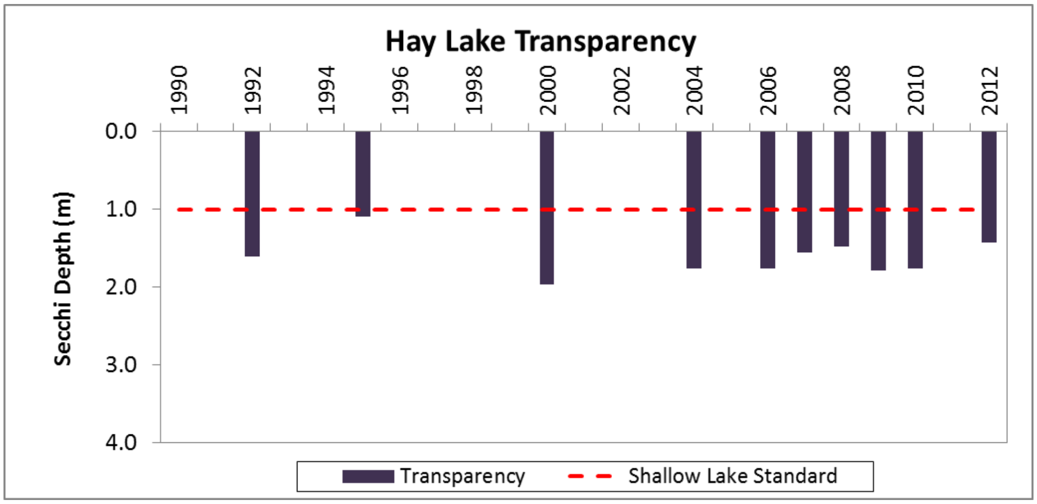

Fitz Lake 2007
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
1
2
3
4
5
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Fitz TP
TP Shallow Lake Standard
Precipitation

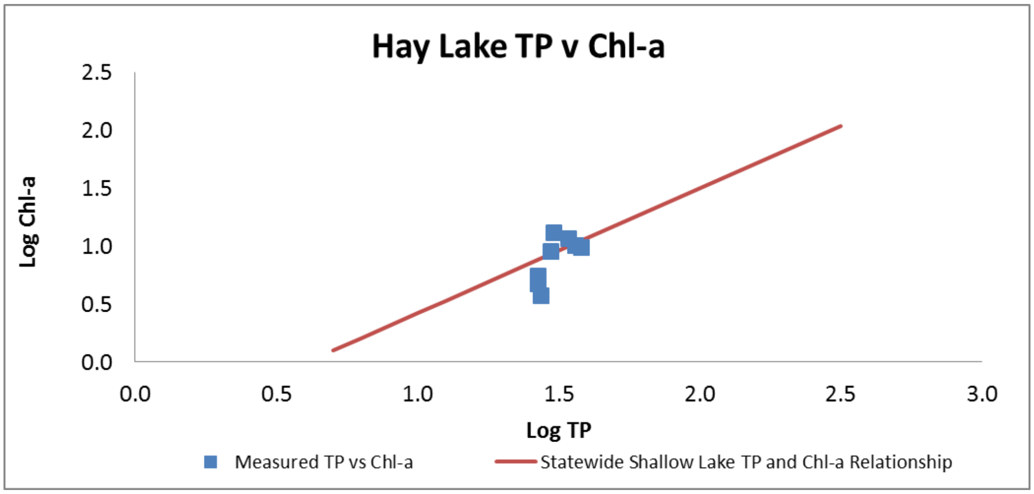

Fitz Lake 2008
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
Fitz TP
TP Shallow Lake Standard
Precipitation

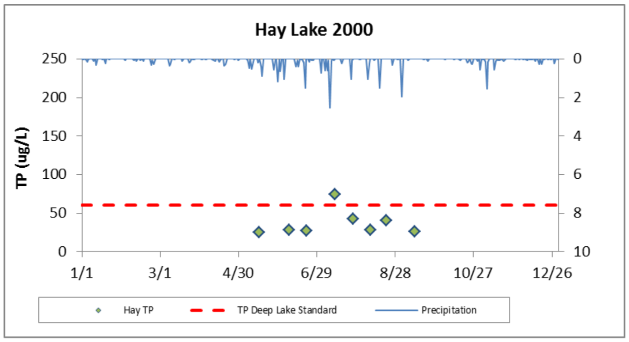

Fitz Lake 2009
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Fitz TP
TP Shallow Lake Standard
Precipitation

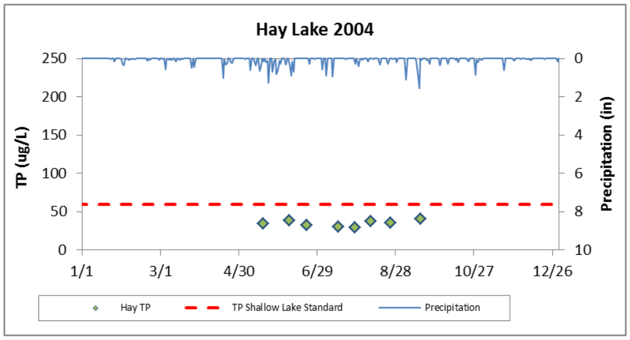

Fitz Lake 2012
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
Fitz TP
TP Shallow Lake Standard
Precipitation

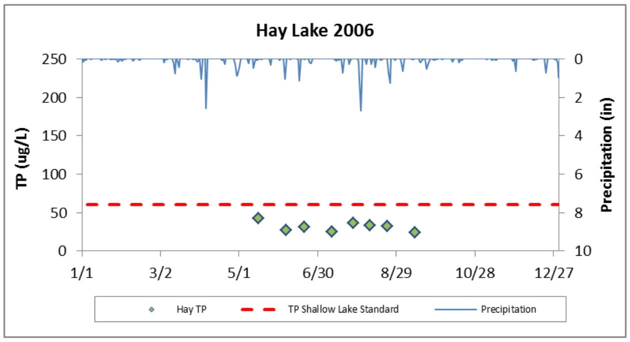

Hay Lake Chlorophyll-a and Total Phosphorus
Chlorophyll-a & Total Phosphorus (ug/L)
70
60
50
40
30
20
10
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
North Central Hardwood Forest Ecoregion Shallow Lake Phosphorus standard
North Central Hardwood Forest Ecoregion Shallow Lake Chlorophyll standard
Chlorophyll-a
Total Phosphorus

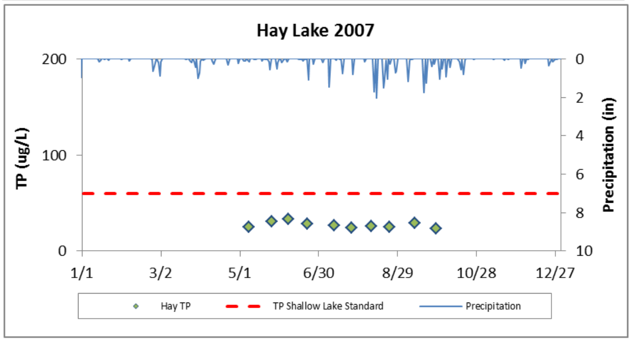

Hay Lake Transparency
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Secchi Depth (m)
0.0
1.0
2.0
3.0
4.0
Transparency
Shallow Lake Standard

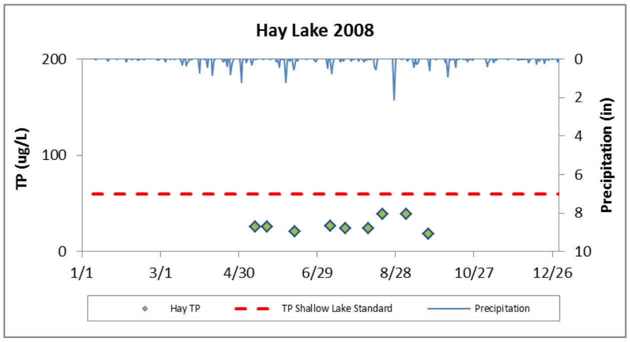

Hay Lake TP v Chl-a
Log Chl-a
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Log TP
Measured TP vs Chl-a
Statewide Shallow Lake TP and Chl-a Relationship

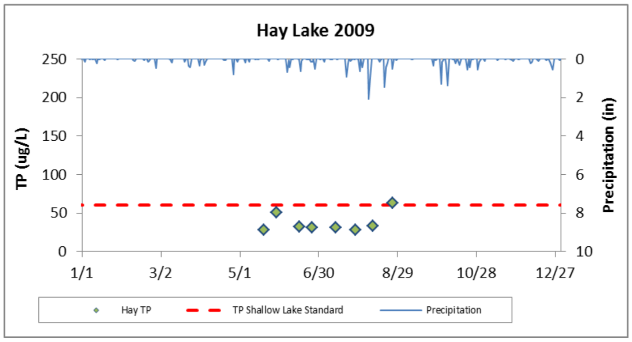

Hay Lake 2000

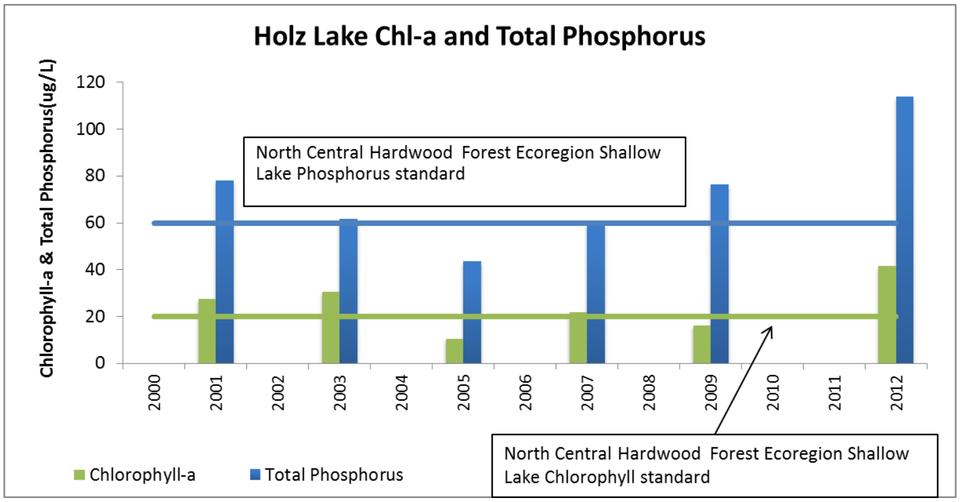

Hay Lake 2004

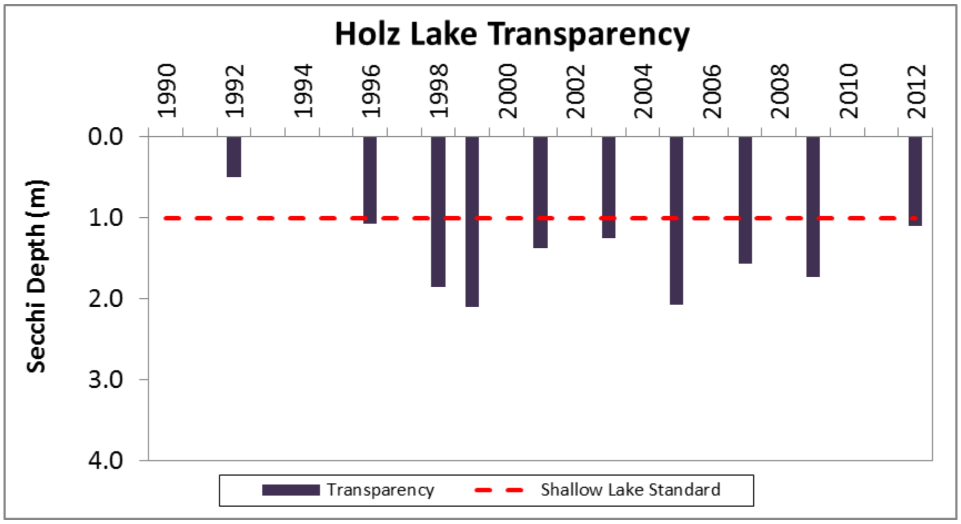

Hay Lake 2006

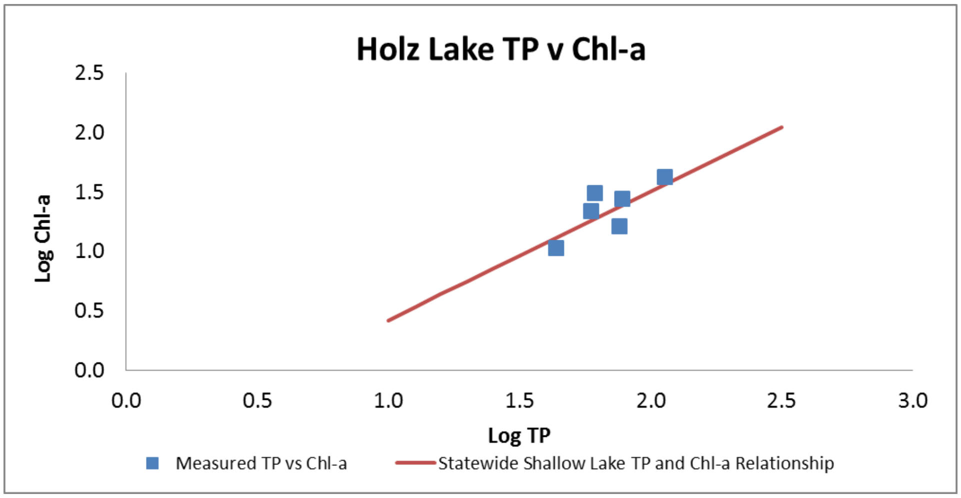

Hay Lake 2007

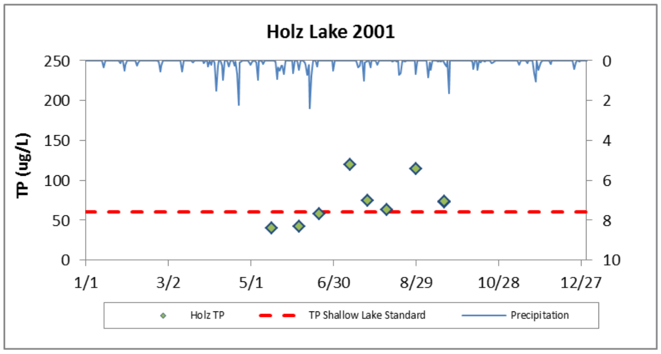

Hay Lake 2008

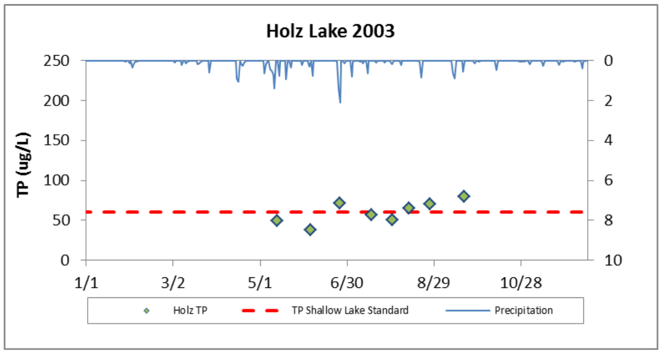

Hay Lake 2009

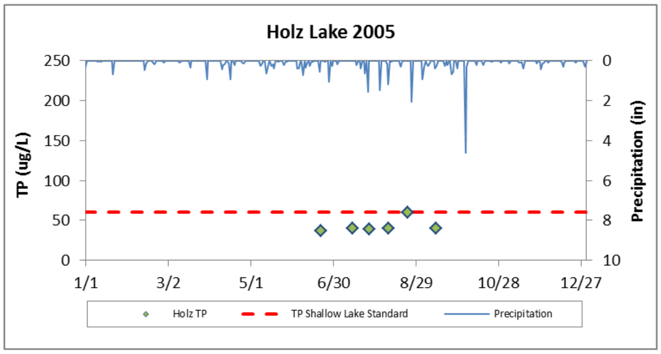

Holz Lake Chl-a and Total Phosphorus
Chlorophyll-a & Total Phosphorus(ug/L)
120
100
80
60
40
20
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
North Central Hardwood Forest Ecoregion Shallow Lake Phosphorus standard
North Central Hardwood Forest Ecoregion Shallow Lake Chlorophyll standard
Chlorophyll-a
Total Phosphorus

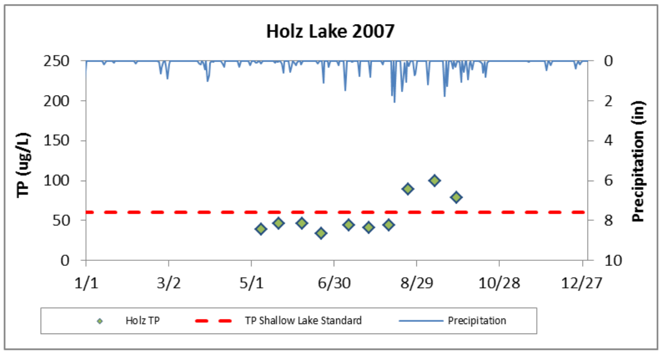

Holz Lake Transparency
Secchi Depth (m)
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
0.0
1.0
2.0
3.0
4.0
Transparency
Shallow Lake Standard

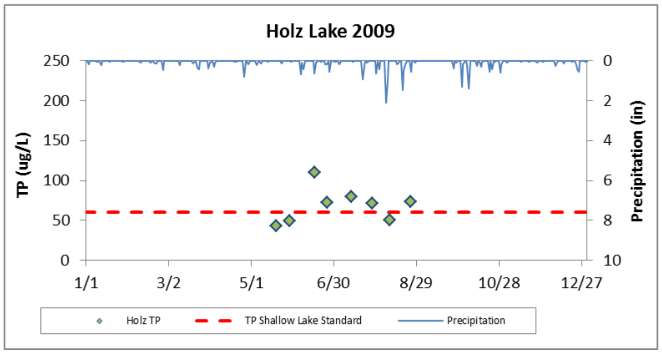

Holz Lake TP v Chl-a
Log Chl-a
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Log TP
Measured TP vs Chl-a
Statewide Shallow Lake TP and Chl-a Relationship

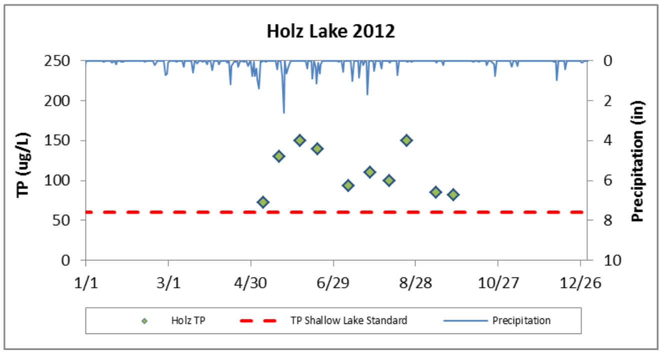

Holz Lake 2001
TP (ug/L)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Holz TP
TP Shallow Lake Standard
Precipitation

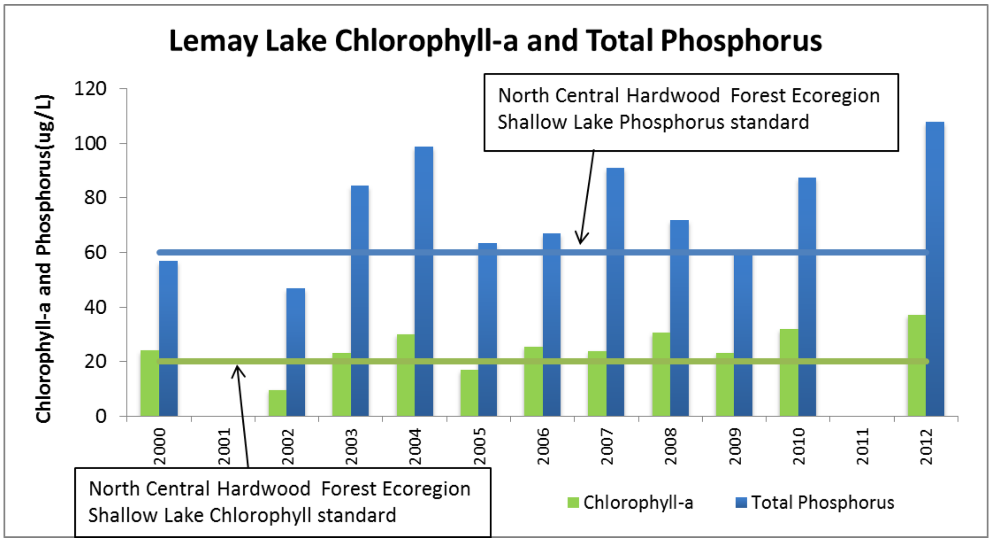

Holz Lake 2003
TP (ug/L)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
Holz TP
TP Shallow Lake Standard
Precipitation


Holz Lake 2005
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Holz TP
TP Shallow Lake Standard
Precipitation


Holz Lake 2007
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Holz TP
TP Shallow Lake Standard
Precipitation

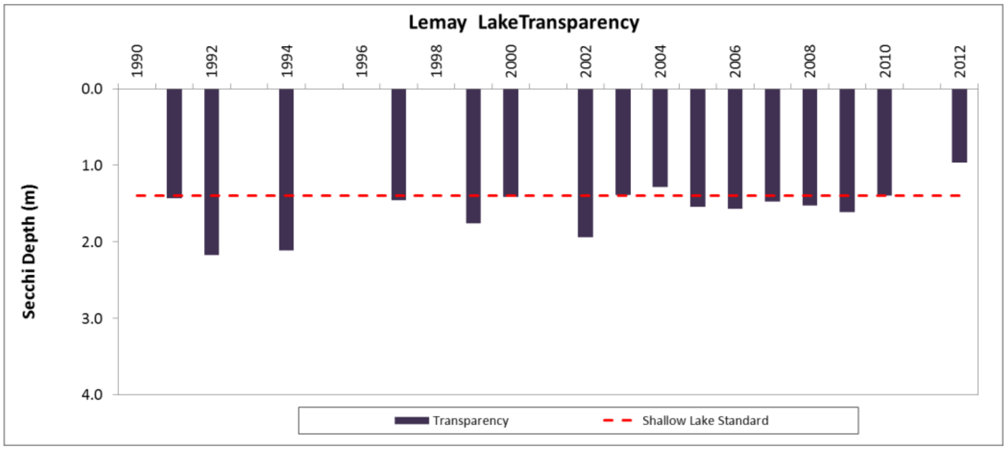

Holz Lake 2009
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Holz TP
TP Shallow Lake Standard
Precipitation

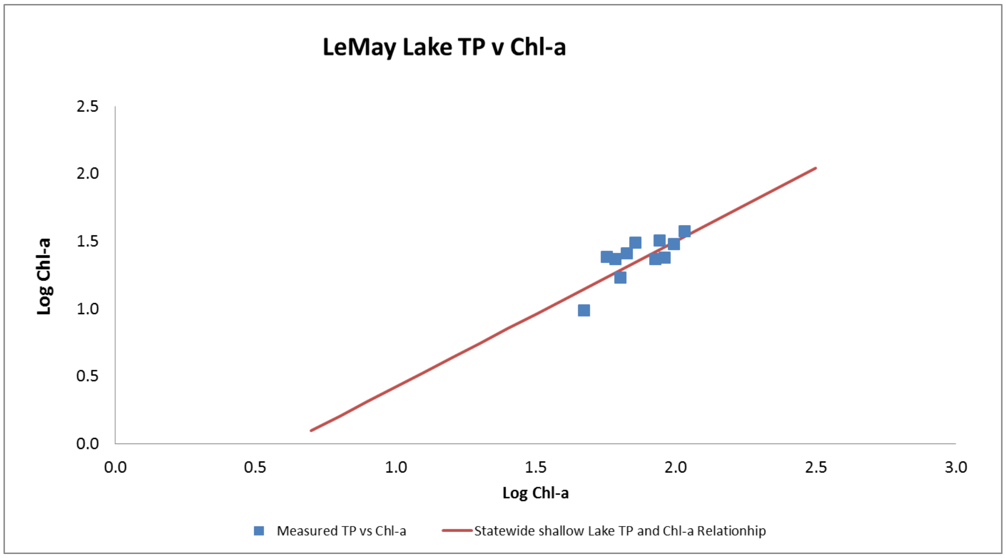

Holz Lake 2012
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
Holz TP
TP Shallow Lake Standard
Precipitation

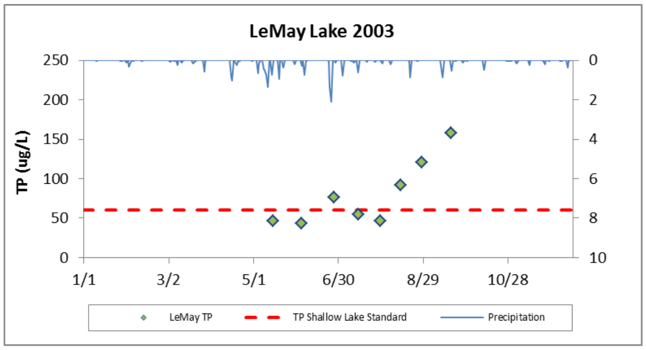

Lemay Lake Chlorophyll-a and Total Phosphorus

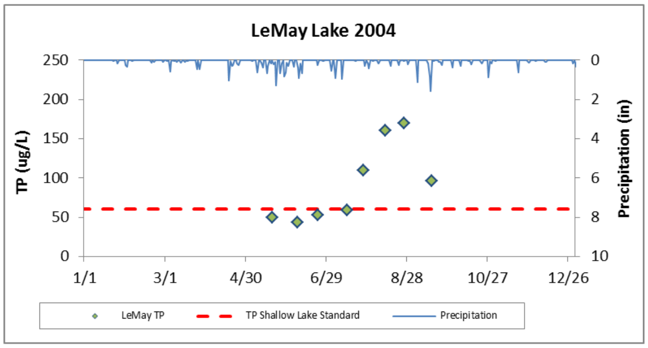
North Central Hardwood Forest Ecoregion Shallow Lake Phosphorus standard

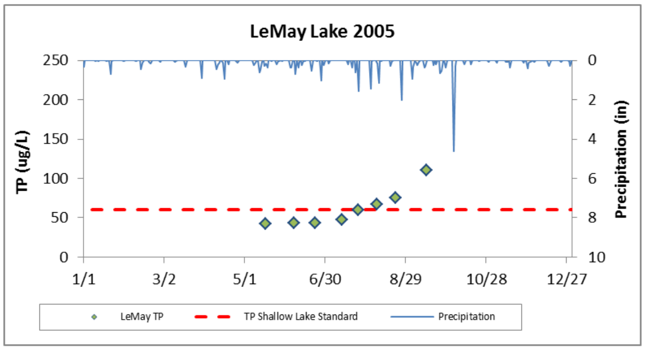
North Central Hardwood Forest Ecoregion Shallow Lake Chlorophyll standard

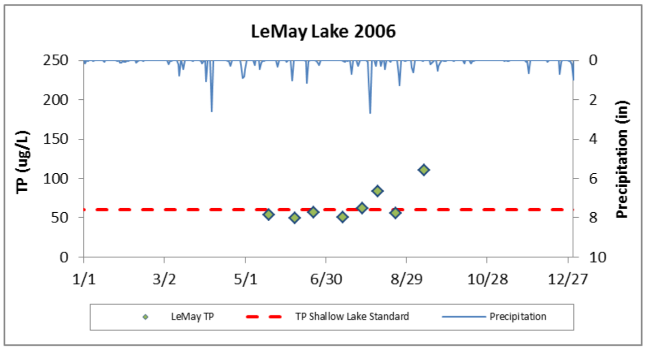

Lemay LakeTransparency

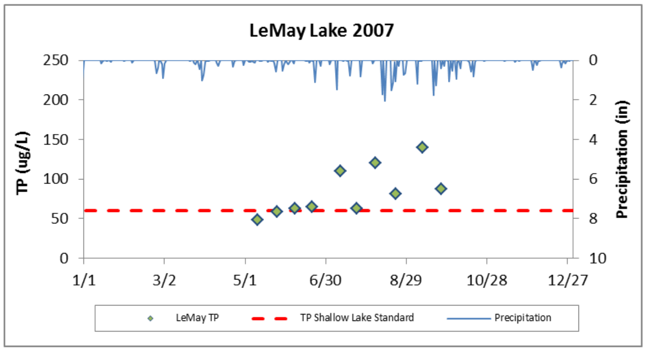

LeMay Lake TP v Chl-a

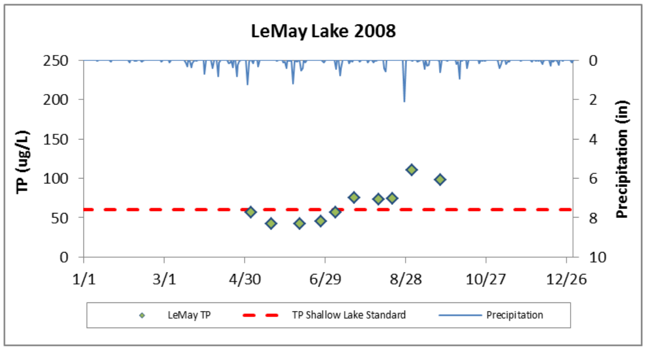

LeMay Lake 2003
TP (ug/L)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
LeMay TP
TP Shallow Lake Standard
Precipitation

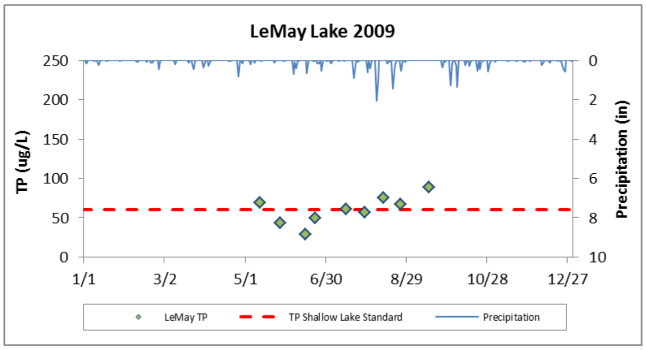

LeMay Lake 2004
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
LeMay TP
TP Shallow Lake Standard
Precipitation

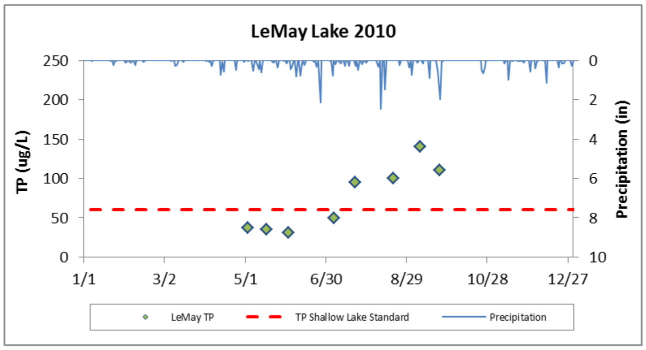

LeMay Lake 2005
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
LeMay TP
TP Shallow Lake Standard
Precipitation

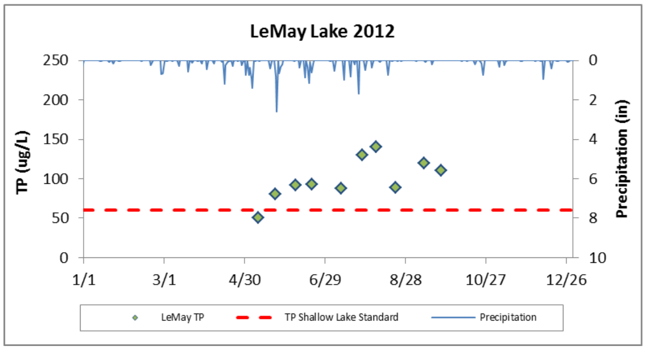

LeMay Lake 2006
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
LeMay TP
TP Shallow Lake Standard
Precipitation

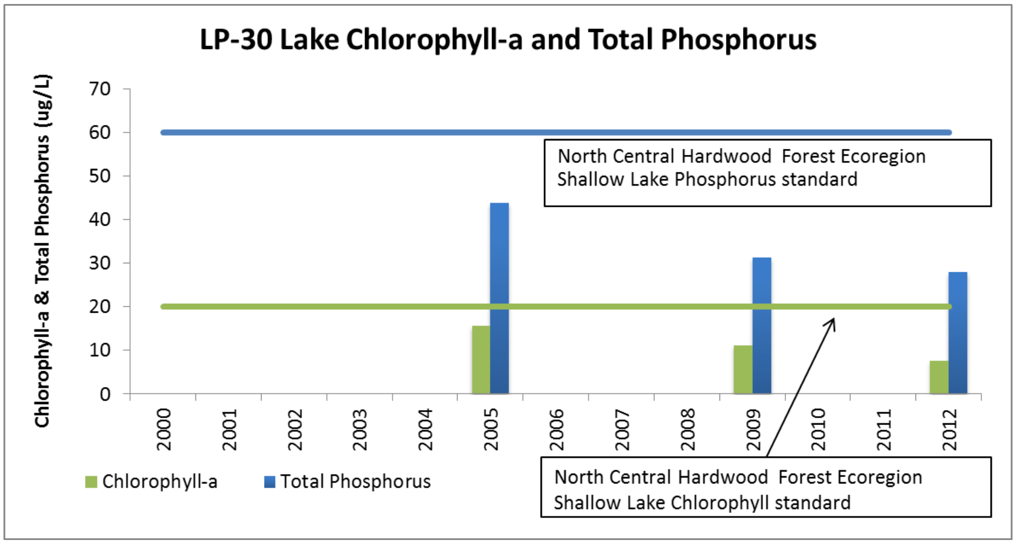

LeMay Lake 2007
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
LeMay TP
TP Shallow Lake Standard
Precipitation

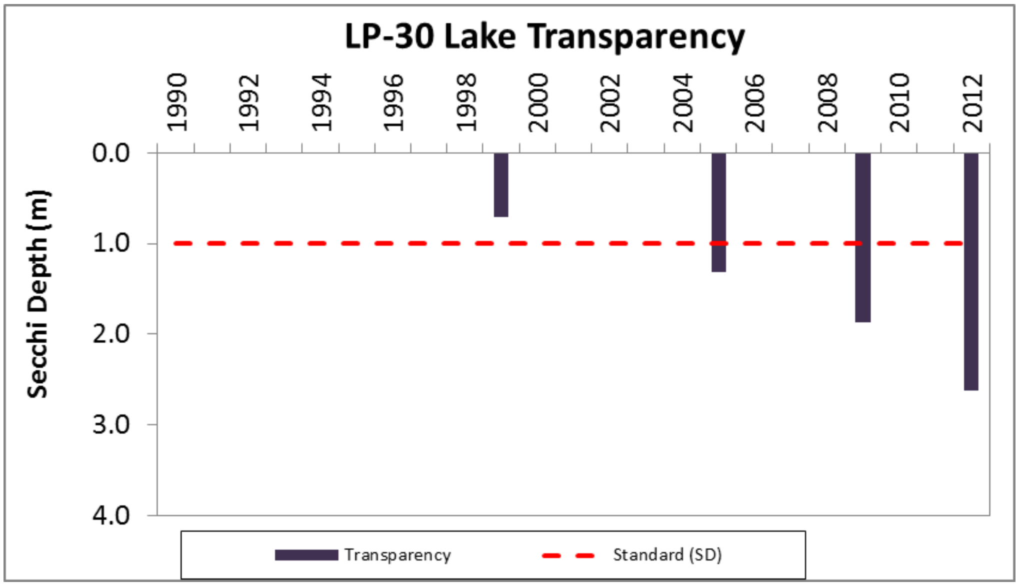

LeMay Lake 2008
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
LeMay TP
TP Shallow Lake Standard
Precipitation

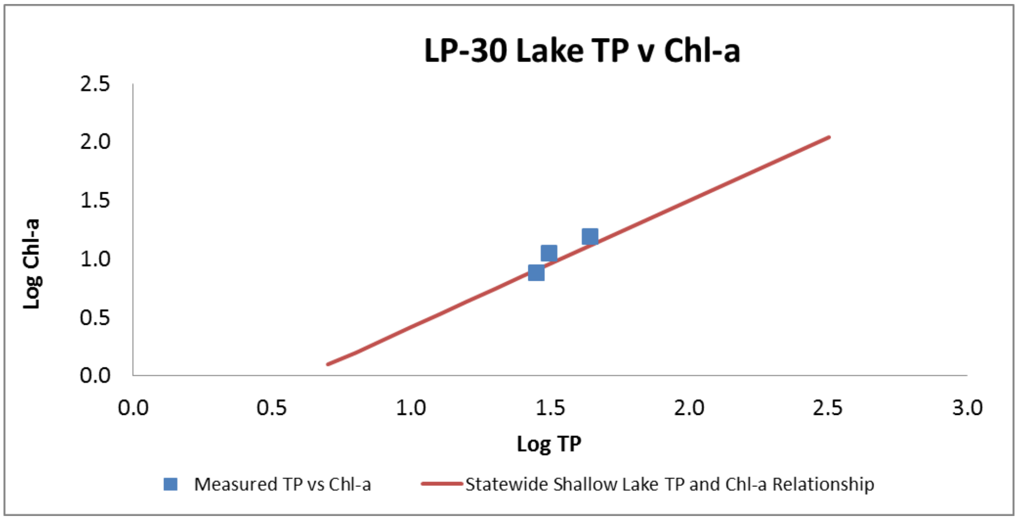

LeMay Lake 2009
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
LeMay TP
TP Shallow Lake Standard
Precipitation

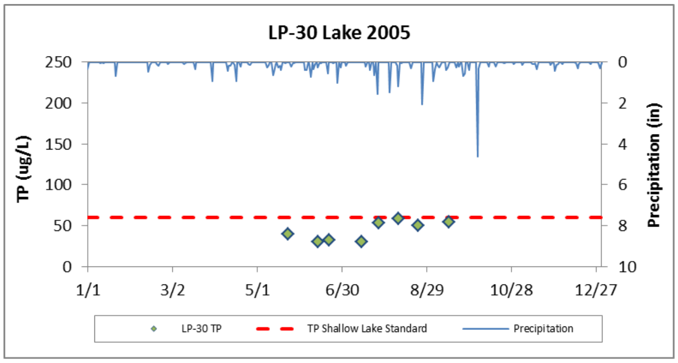

LeMay Lake 2010
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
LeMay TP
TP Shallow Lake Standard
Precipitation

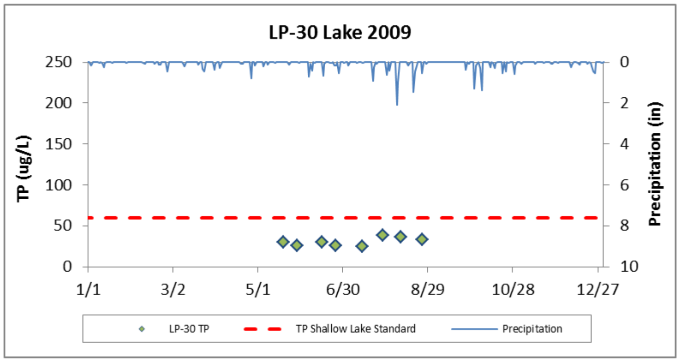

LeMay Lake 2012
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
LeMay TP
TP Shallow Lake Standard
Precipitation

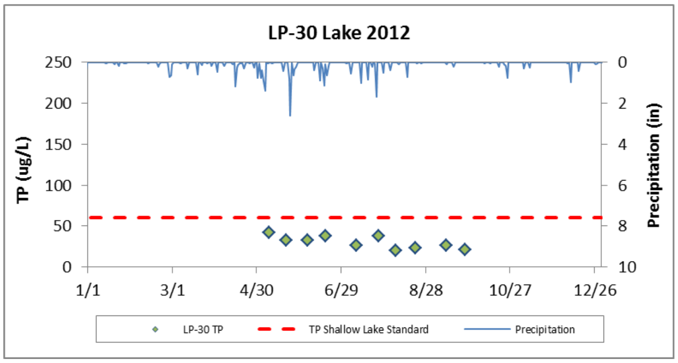

LP-30 Lake Chlorophyll-a and Total Phosphorus
Chlorophyll-a & Total Phosphorus (ug/L)
0
10
20
30
40
50
60
70
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
North Central Hardwood Forest Ecoregion Shallow Lake Phosphorus standard
North Central Hardwood Forest Ecoregion Shallow Lake Chlorophyll standard
Chlorophyll-a
Total Phosphorus

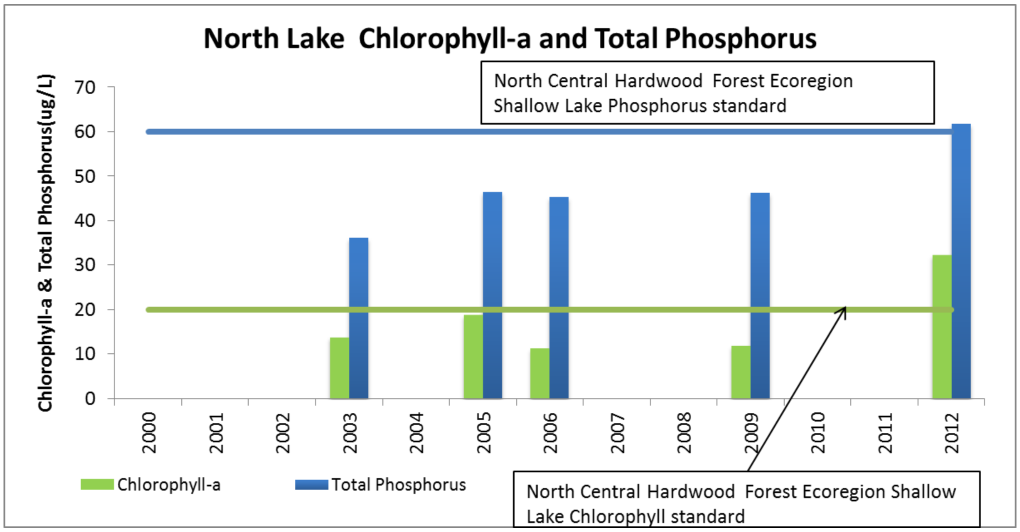

LP-30 Lake Transparency
Secchi Depth (m)
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
0.0
1.0
2.0
3.0
4.0
Transparency
Standard (SD)

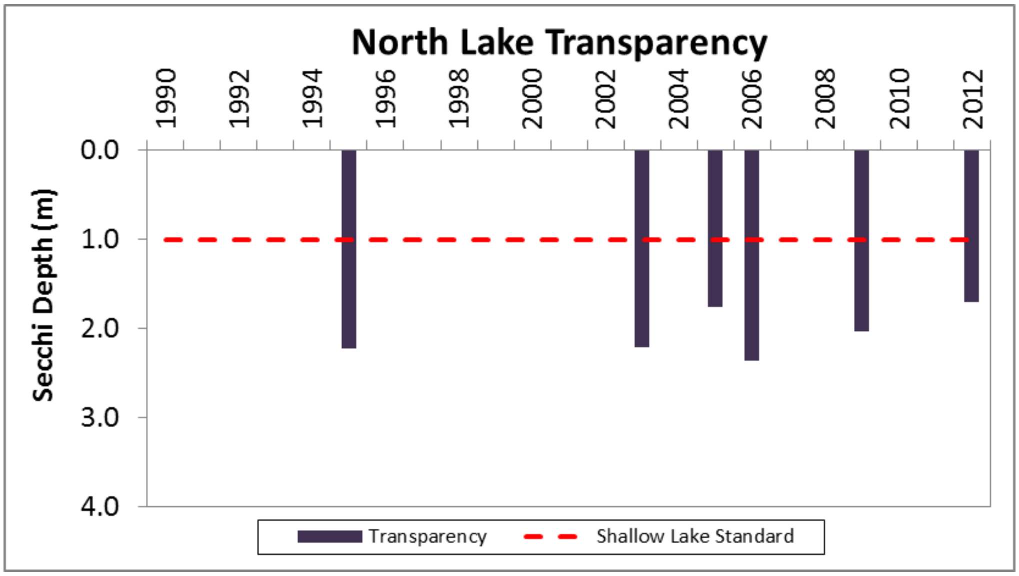

LP-30 Lake TP v Chl-a
Log Chl-a
0.0
0.5
1.0
1.5
2.0
2.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Log TP
Measured TP vs Chl-a
Statewide Shallow Lake TP and Chl-a Relationship

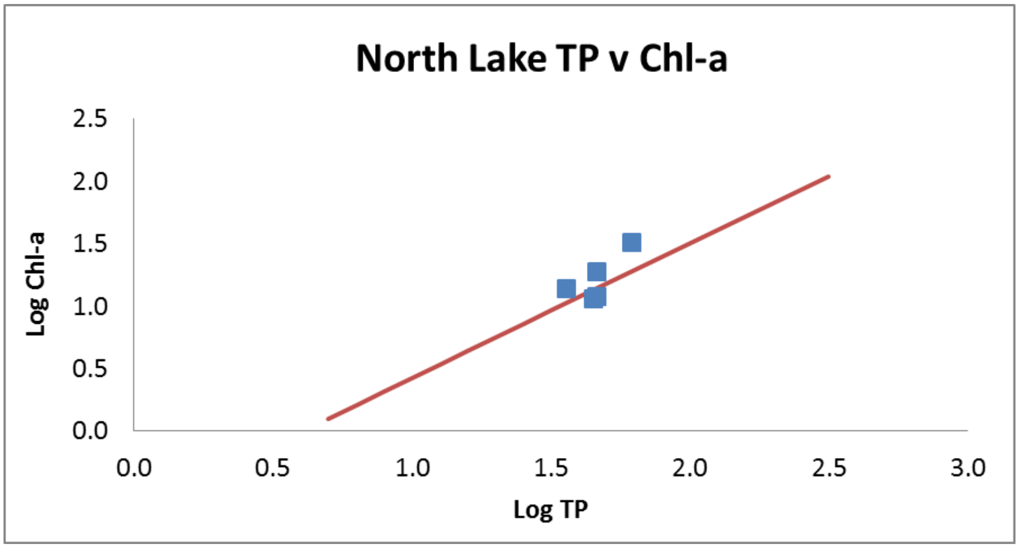

LP-30 Lake 2005
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
LP-30 TP
TP Shallow Lake Standard
Precipitation

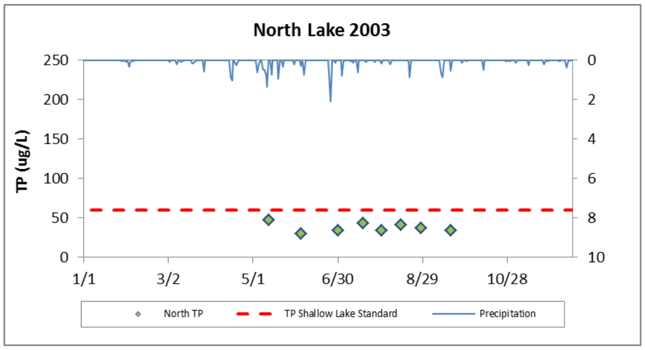

LP-30 Lake 2009
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
LP-30 TP
TP Shallow Lake Standard
Precipitation

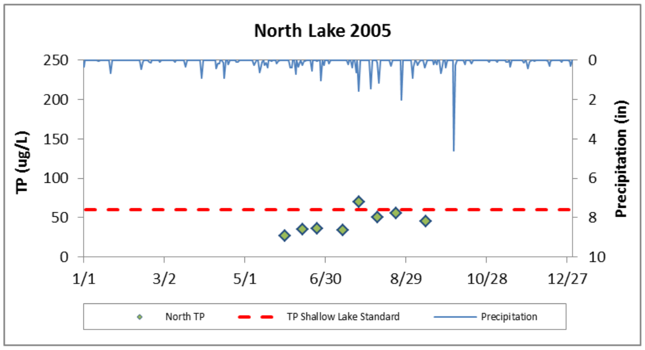

LP-30 Lake 2012
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
LP-30 TP
TP Shallow Lake Standard
Precipitation

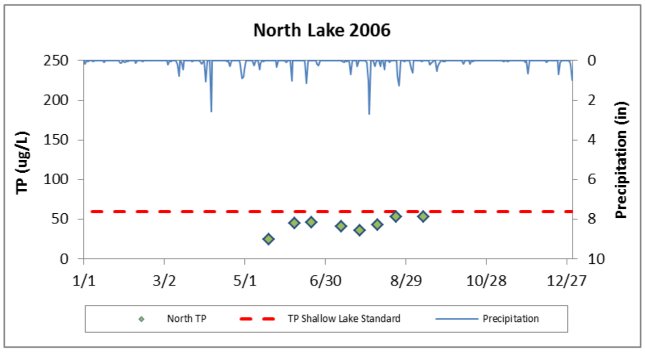

North Lake Chlorophyll-a and Total Phosphorus
North Central Hardwood Forest Ecoregion
Shallow Lake Phosphorus standard
Chlorophyll-a & Total Phosphorus(ug/L)
70
60
50
40
30
20
10
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Chlorophyll-a
Total Phosphorus
North Central Hardwood Forest Ecoregion Shallow
Lake Chlorophyll standard

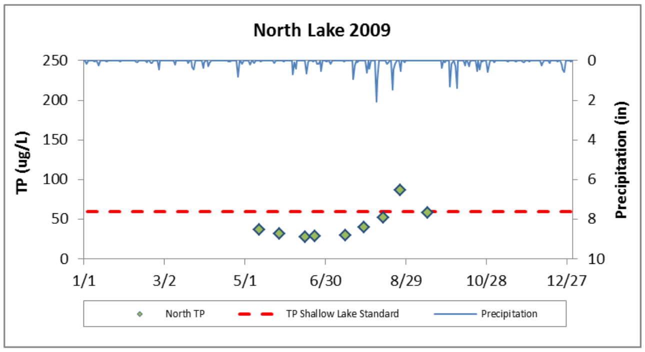

North Lake Transparency
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
0.0
1.0
2.0
3.0
4.0
Secchi Depth (m)
Transparency
Shallow Lake Standard

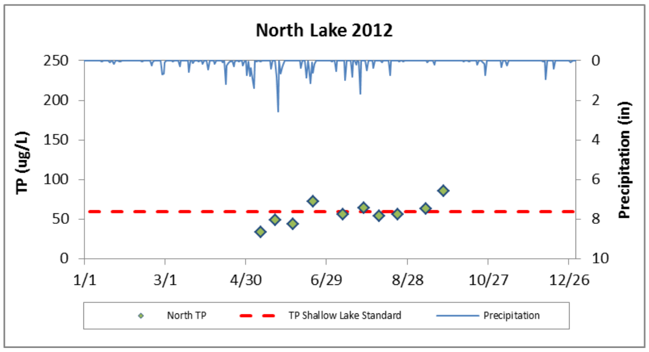

North Lake TP v Chl-a
2.5
2.0
1.5
1.0
0.5
0.0
Log Chl-a
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Log TP

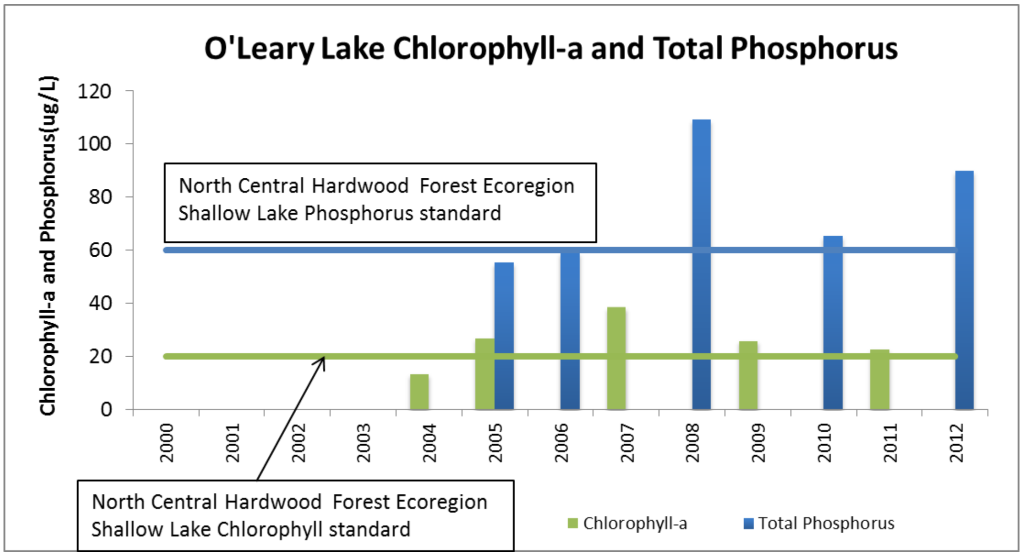

North Lake 2003
TP (ug/L)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
North TP
TP Shallow Lake Standard
Precipitation

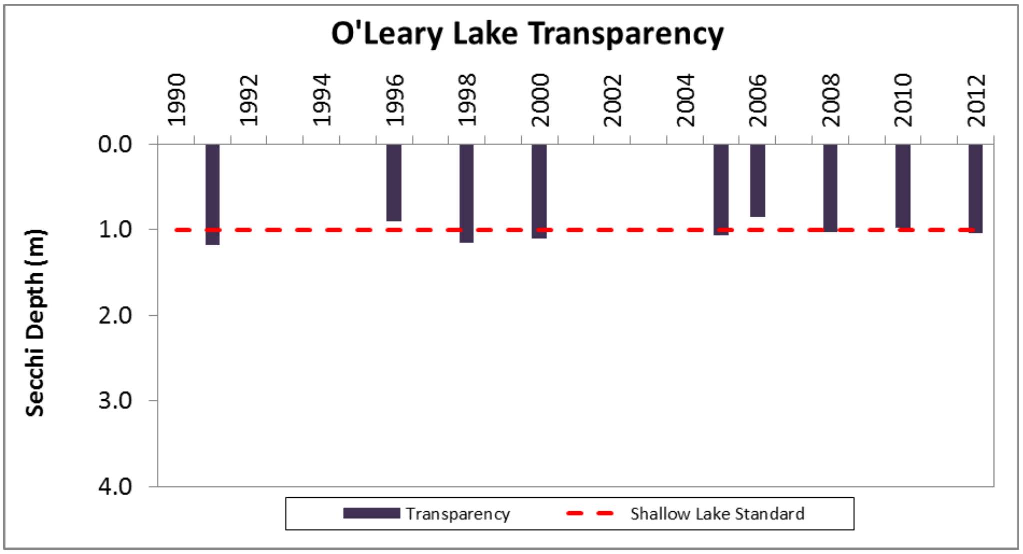

North Lake 2005
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
North TP
TP Shallow Lake Standard
Precipitation

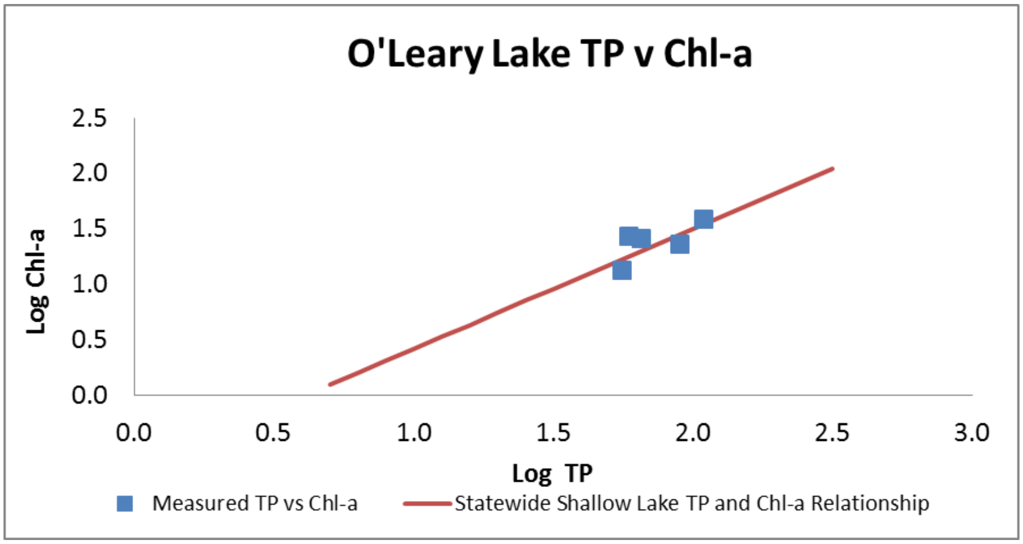

North Lake 2006
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
North TP
TP Shallow Lake Standard
Precipitation

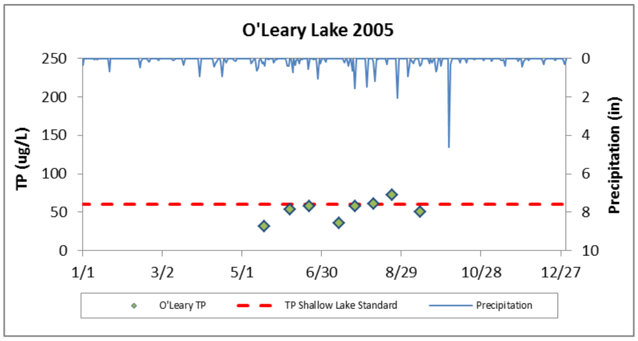

North Lake 2009
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
North TP
TP Shallow Lake Standard
Precipitation

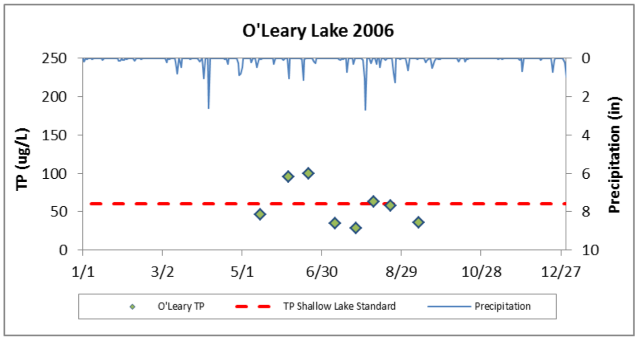

North Lake 2012
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
North TP
TP Shallow Lake Standard
Precipitation

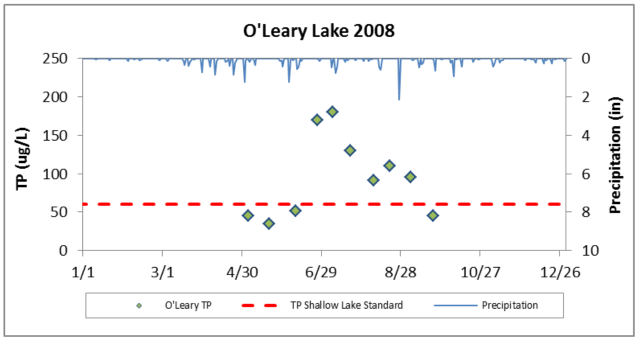

O'Leary Lake Chlorophyll-a and Total Phosphorus

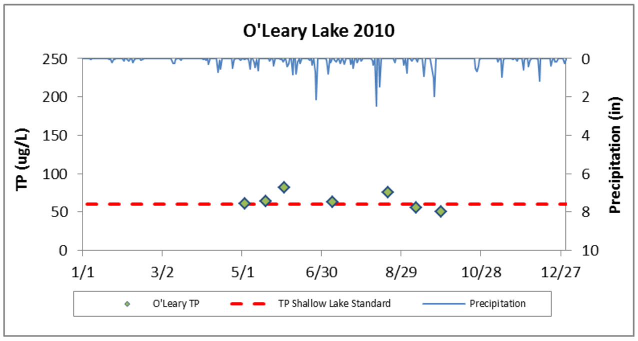

O'Leary Lake Transparency

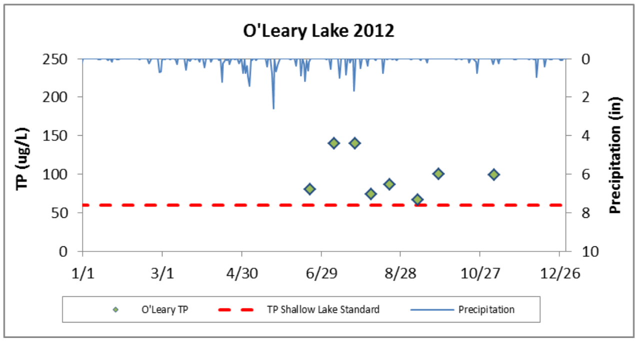

O'Leary Lake TP v Chl-a

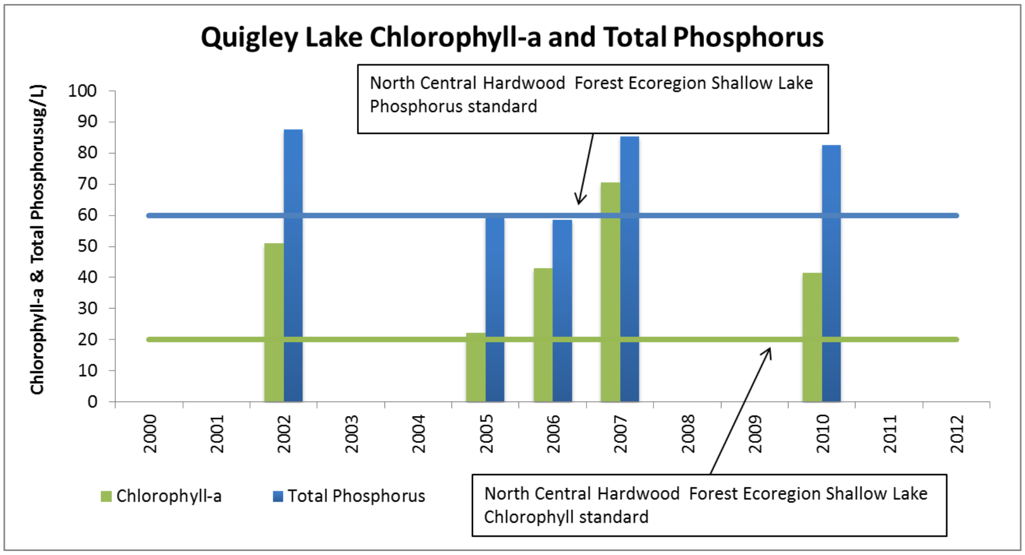

O'Leary Lake 2005
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
O'Leary TP
TP Shallow Lake Standard
Precipitation

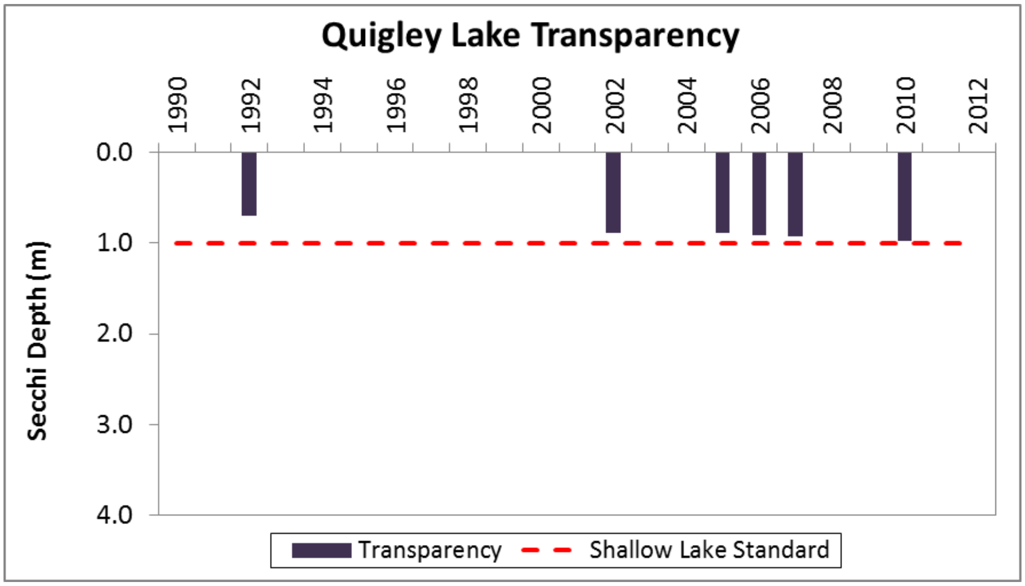

O'Leary Lake 2006
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
O'Leary TP
TP Shallow Lake Standard
Precipitation

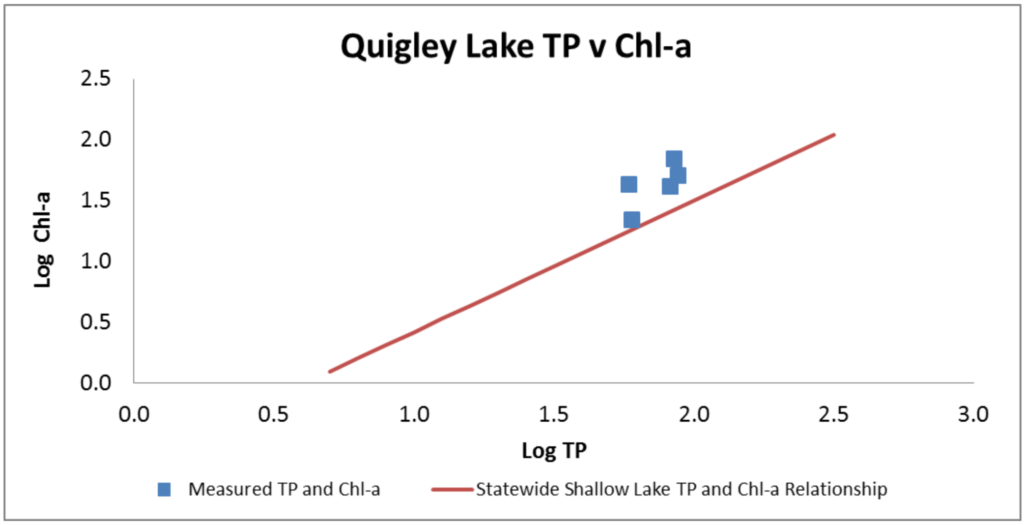

O'Leary Lake 2008
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
O'Leary TP
TP Shallow Lake Standard
Precipitation

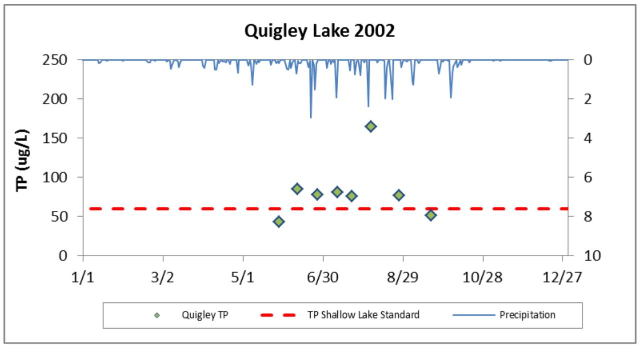

O'Leary Lake 2010
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
O'Leary TP
TP Shallow Lake Standard
Precipitation

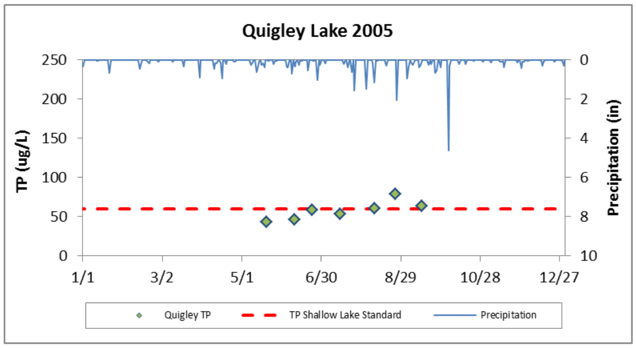

O'Leary Lake 2012
TP (ug/L)
250
200
150
100
50
0
Precipitation (in)
0
2
4
6
8
10
1/1
3/1
4/30
6/29
8/28
10/27
12/26
O'Leary TP
TP Shallow Lake Standard
Precipitation

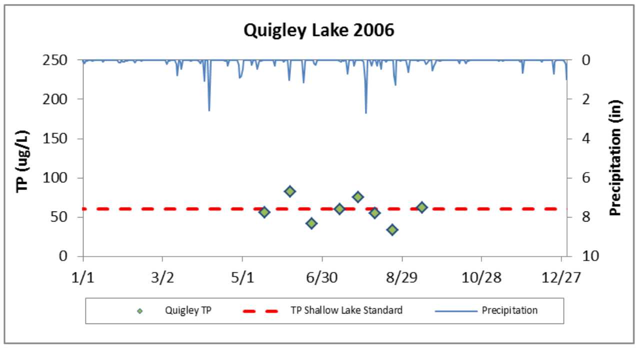

Quigley Lake Chlorophyll-a and Total Phosphorus
North Central Hardwood Forest Ecoregion Shallow Lake Phosphorus standard
Chlorophyll-a & Total Phosphorusug/L)
100
90
80
70
60
50
40
30
20
10
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Chlorophyll-a
Total Phosphorus
North Central Hardwood Forest Ecoregion Shallow Lake Chlorophyll standard

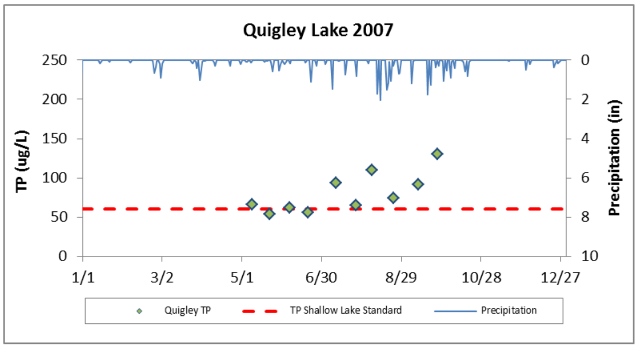

Quigley Lake Transparency
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Secchi Depth (m)
0.0
1.0
2.0
3.0
4.0
Transparency
Shallow Lake Standard

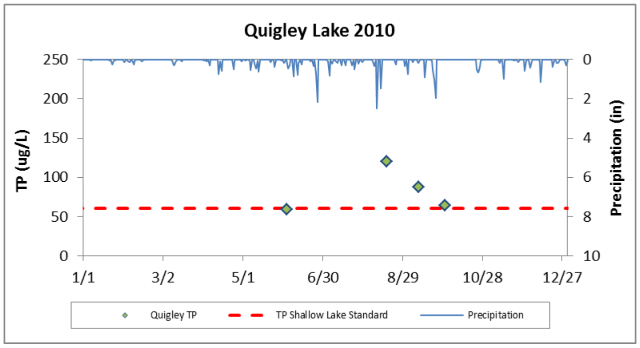

Quigley Lake TP v Chl-a
Log Chl-a
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Log TP
Measured TP and Chl-a
Statewide Shallow Lake TP and Chl-a Relationship


Quigley Lake 2002
TP (ug/L)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Quigley TP
TP Shallow Lake Standard
Precipitation


Quigley Lake 2005
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Quigley TP
TP Shallow Lake Standard
Precipitation

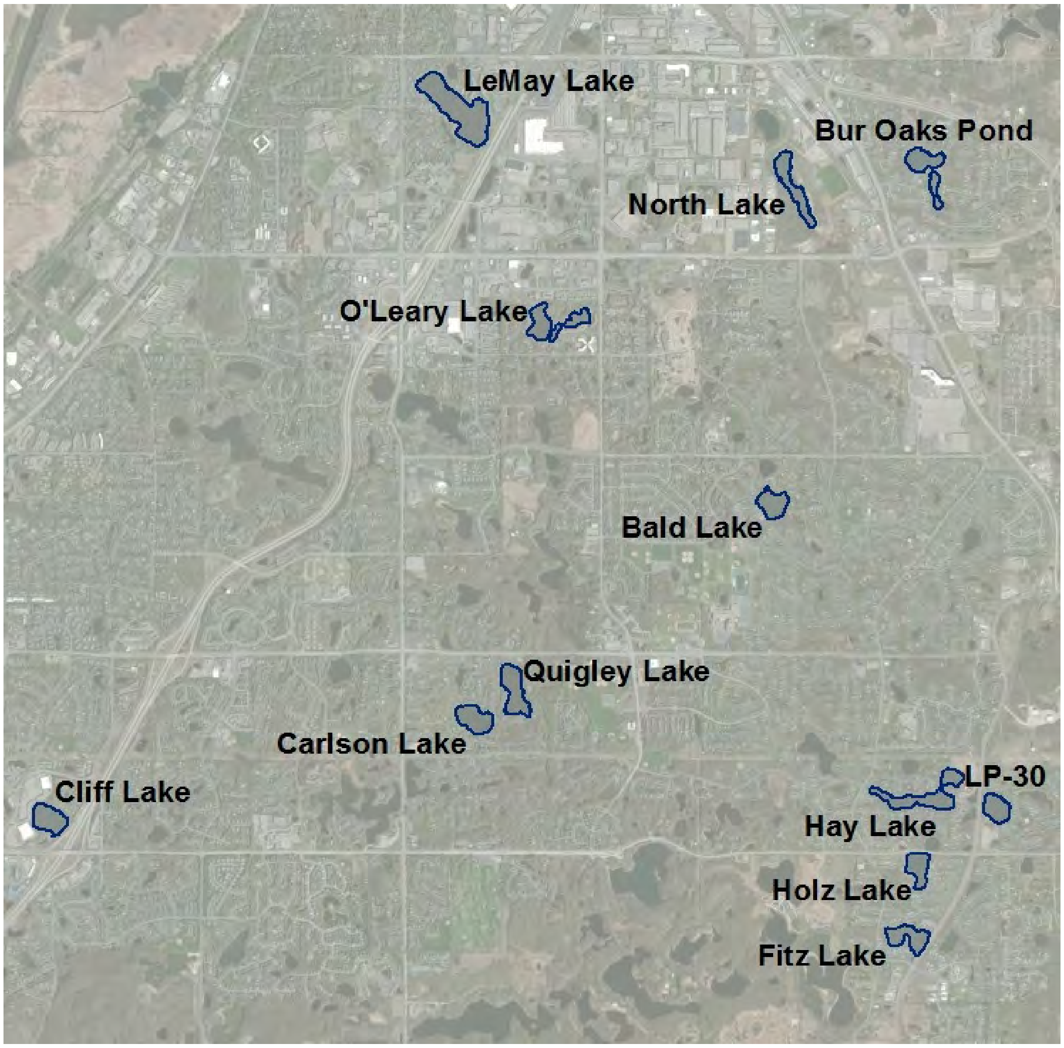

Quigley Lake 2006
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Quigley TP
TP Shallow Lake Standard
Precipitation


Quigley Lake 2007
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Quigley TP
TP Shallow Lake Standard
Precipitation


Quigley Lake 2010
TP (ug/L)
Precipitation (in)
250
200
150
100
50
0
0
2
4
6
8
10
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Quigley TP
TP Shallow Lake Standard
Precipitation

Appendix D

Aquatic Vegetation Data



City of Eagan Study Lakes (Google Earth Map)

Aquatic Plant Surveys for Twelve Lakes in Eagan, Minnesota in 2013

Lakes: Bald, Bur Oaks Pond, Carlson, Cliff, Fitz, Hay, Holz, LeMay, LP-30 (Southern Lake), North, O'Leary, Quigley

DRAFT

Prepared for:
City of Eagan, Minnesota

Prepared by:
Steve McComas and
Jo Stuckert
Blue Water Science
St. Paul, MN 55116

March 27, 2014

Aquatic Plant Surveys for Twelve Lakes in Eagan, Minnesota in 2013

Summary

Over the growing season of 2013, early summer and late summer aquatic plant point-intercept surveys were conducted for twelve Eagan lakes. Early summer results are shown in Table S1 and late summer results are show in Table S2.

Early Summer Aquatic Plant Surveys: Early summer aquatic plant surveys were conducted in June for all twelve lakes. The dominant plant was coontail in all twelve lakes in June. Coontail, a native plant, was somewhat sparse in Holz and North Lakes while it was abundant in the remaining ten lakes. Curlyleaf pondweed was the only non-native plant observed and it was found in 9 out of 12 lakes. It's distribution and abundance in the lakes is shown in Figure S1. Curlyleaf growth was mostly light in the lakes where it was found.

Table S1. The percent occurrence of early summer aquatic plants for select Eagan Lakes in 2013. Percent occurrence is calculated based on the number of times a plant species occurs at a sampling station div ided into the total number of stations for the survey.

	Bald **Jun 14** **(16 sites)**	**Bur Oaks** **Jun 14** **(23 sites)**	**Carlson** **Jun 19** **(19 sites)**	**Cliff** **Jun 19** **(18 sites)**	**Fitz** **Jun 6** **(19 sites)**	**Hay** **Jun 7** **(31 sites)**	**Holz** **Jun 7** **(15 sites)**	**LeMay** **Jun 20** **(61sites)**	**LP-30** **Jun 6** **(15 sites)**	**North** **Jun 14** **(24 sites)**	**O'Leary** **Jun 19** **(25 sites)**	**Quigley** **Jun 7** **(25 sites)**
Cattails (*Typha sp*)												
Duckweed (*Lemna sp*)											24	
Spatterdock (*Nuphar variegatum*)											40	
White waterlilies (*Nymphaea sp*)						42					36	76
Watermeal (*Wolffia columbiana*)												
Coontail (*Ceratophyllum demersum*)	100	91	42	94	84	97	20	75	100	17	80	76
Chara (*Chara sp*)										4		
Moss (*Drepanocladus sp*)						3						
Elodea (*Elodea canadensis*)	63		42		47						20	
Star duckweed (*L. trisulca*)												20
Northern watermilfoil (*Myriophyllum sibiricum*)										4		
Naiads (*Najas flexilis*)												
Curlyleaf pondweed (*Potamogeton crispus*)	56	22	16	78	32	16	53	59		4		
Floatingleaf pondweed (*P. natans*)		30										
Stringy pondweed (*P. sp*)	25	30	11	6	21	13		5		21	48	16
Flatstem pondweed (*P. zosteriformis*)		4			47			11	7	4	36	4
Buttercup (*Ranunculus sp*)		26										
Sago pondweed (*Stuckenia pectinata*)		22						3				
Bladderwort (*Ultricularia sp*)											12	4
Water stargrass (*Zosterella dubia*)												
Filamentous algae	31			17		61		8	7			
Aquatic Plant Coverage (ac)	10.3	13.2	8.2	11.8	10.9	19.8	5.6	32.3	9.2	5.9	16.0	15.2
Total submerged species	4	7	4	3	5	4	2	5	2	6	5	5

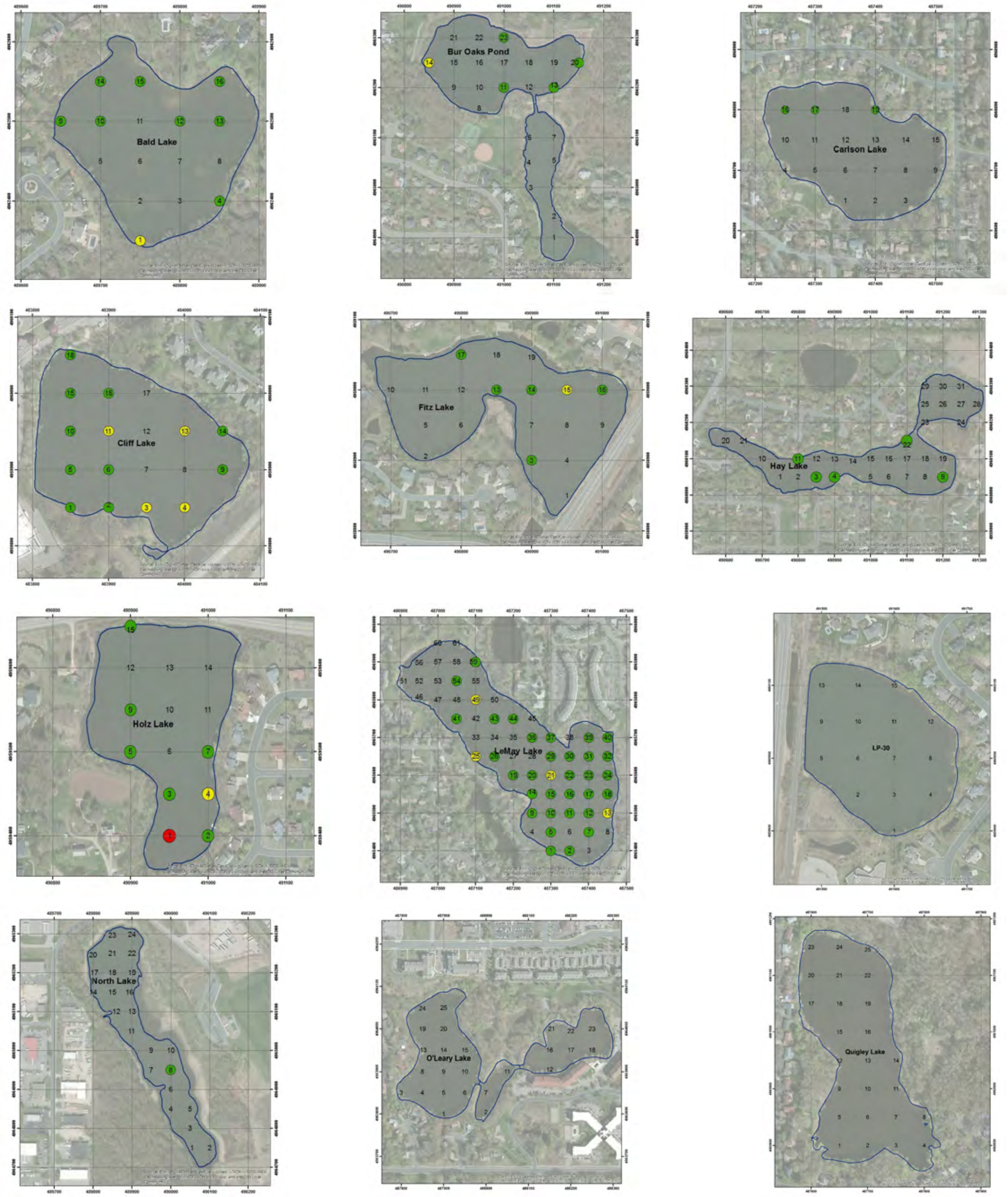


Figure S1. Curlyleaf pondweed distribution in the early summer plant surveys for the selected twelve Eagan lakes. Key: green shading = light growth, yellow shading = moderate growth, and red shading = heavy growth.

Late Summer Aquatic Plant Surveys: Late summer aquatic plant surveys for all twelve lakes were conducted in August, 2013. Coontail maintained its presence as the dominant plant species in the twelve lakes (Table S2). The non-native plant, curlyleaf pondweed, had resprouted in only one lake, Cliff, in August. Several lakes had heavy aquatic plant growth in August including Hay and Quigley (Figure S2).

Table S2. The percent occurrence of late summer aquatic plants for select Eagan Lakes in 2013. Percent occurrence is calculated based on the number of times a plant species occurs at a sampling station divided into the total number of stations for the survey.

	Bald Aug 8 (16 sites)	**Bur Oaks Aug 23 (23 sites)**	**Carlson Aug 8 (19 sites)**	**Cliff Aug 8 (18 sites)**	**Fitz Aug 6 (19 sites)**	**Hay Aug 6 (31 sites)**	**Holz Aug 6 (15 sites)**	**LeMay Aug 19 (61 sites)**	**LP-30 Aug 6 (15 sites)**	**North Aug 15 (24 sites)**	**O'Learly Aug 15 (25 sites)**	**Quigley Aug 8 (25 sites)**
Burreed (*Sparganium sp*)											4	
Cattails (*Typha sp*)								3				
Duckweed (*Lemna sp*)											52	
Spatterdock (*Nuphar variegatum*)											36	
White waterlilies (*Nymphaea sp*)						65					40	88
Watermeal (*Wolffia columbiana*)		74				55		3			20	
Coontail (*Ceratophyllum demersum*)	88	100	37	94	74	97	33	66	93	58	60	88
Chara (*Chara sp*)	6	13								4		
Moss (*Drepanocladus sp*)												
Elodea (*Elodea canadensis*)	69	9	26		21						16	
Star duckweed (*L. trisulca*)											60	4
Northern watermilfoil (*Myriophyllum sibiricum*)										8		
Naiads (*Najas flexilis*)			5		5		7					
Curlyleaf pondweed (*Potamogeton crispus*)				11								
Floatingleaf pondweed (*P. natans*)		57										
Stringy pondweed (*P. sp*)		13	5	11	16		13	5	7	8	24	8
Flatstem pondweed (*P. zosteriformis*)		22			63			16	7	4	28	12
Sago pondweed (*Stuckenia pectinata*)		13						2				
Bladderwort (*Ultricularia sp*)											8	4
Water stargrass (*Zosterella dubia*)		9								4		
Filamentous algae	6	48		6				11	27			
Aquatic Plant Coverage (ac)	9.3	13.8	5.0	11.2	9.0	19.2	3.7	25.2	8.6	8.3	16.0	15.2
Total submerged species	3	7	4	3	5	1	3	4	3	6	6	5

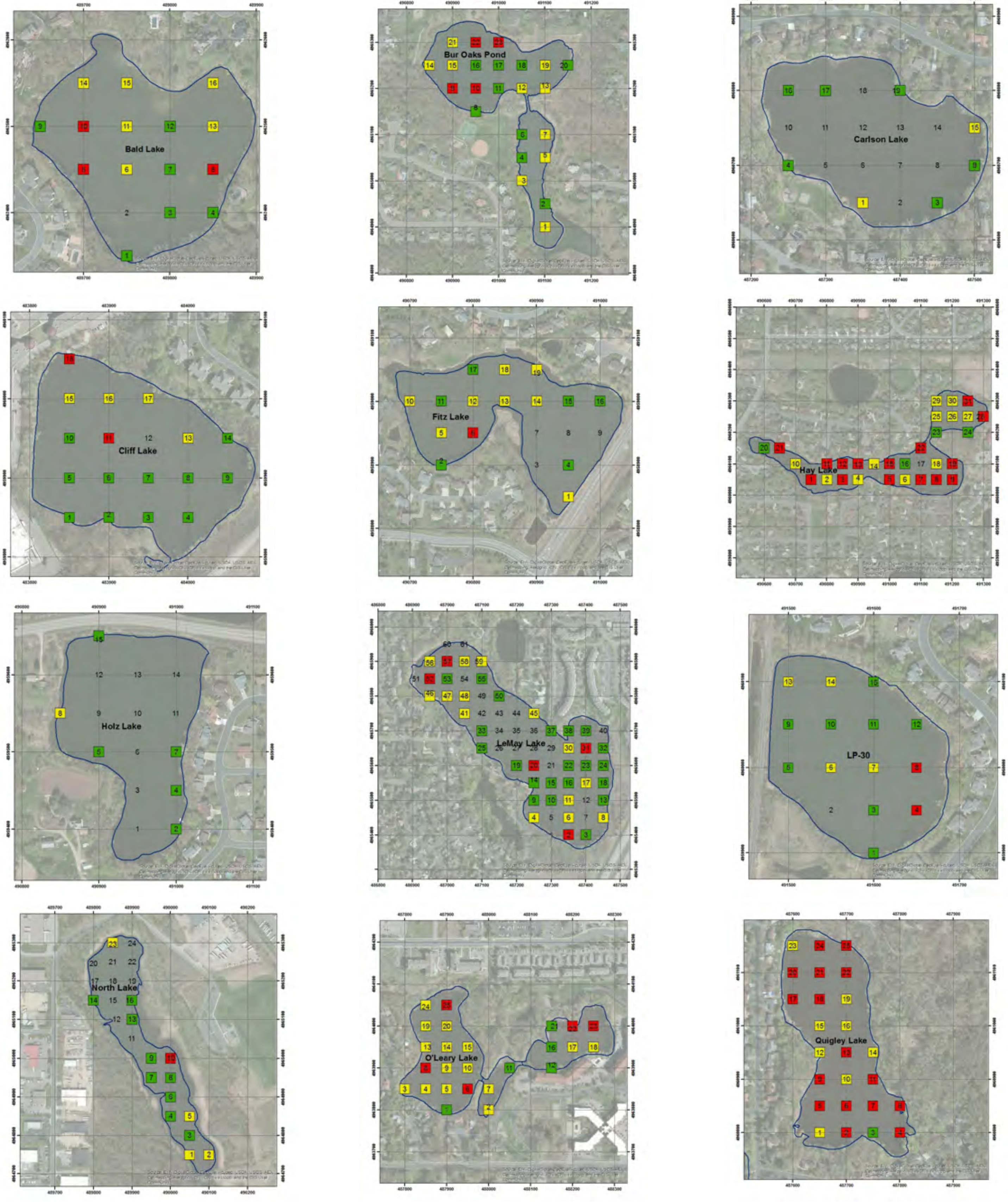


Figure S2. Native plant distribution in the late summer plant surveys for the selected twelve Eagan lakes. Key: green shading = light growth, yellow shading = moderate growth, and red shading = heavy growth.

Appendix E

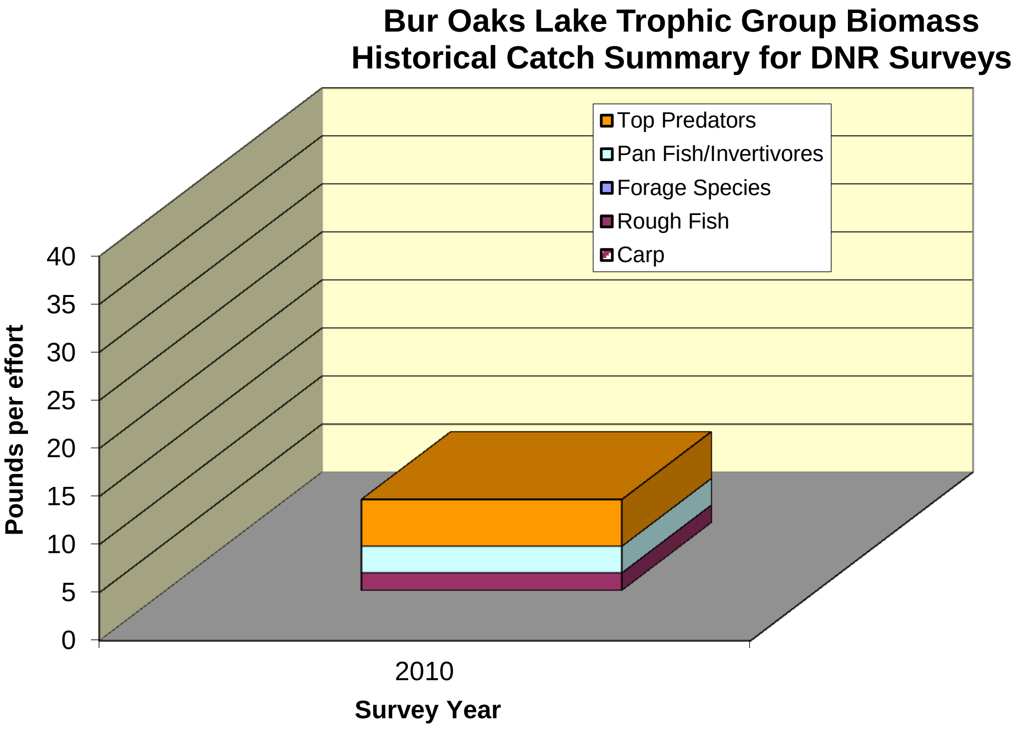
Fisheries Data

Fish Survey Data Availability

Lake Name	DNR Lake ID	Fish Data Availability (by year)
Bald	19-0061	none
Bur Oaks	19-0259	2009*,2010
Carlson (Quigley)	19-0155	1993, 2006, 2011, 2012
LeMay	19-0055	2004 and 2009
O'Leary	19-0056	None
Cliff	19-0068	2011*, 2013±
Quigley (Carlson)	19-0066	none
Fitz	19-0077	2013±
Hay	19-0062	2010
Holz	19-0064	2011*, 2013±
LP-30	19-0053	None
North	19-0136	2012±

*Electrofishing only

± Trapnet Data Only


Bur Oaks Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys

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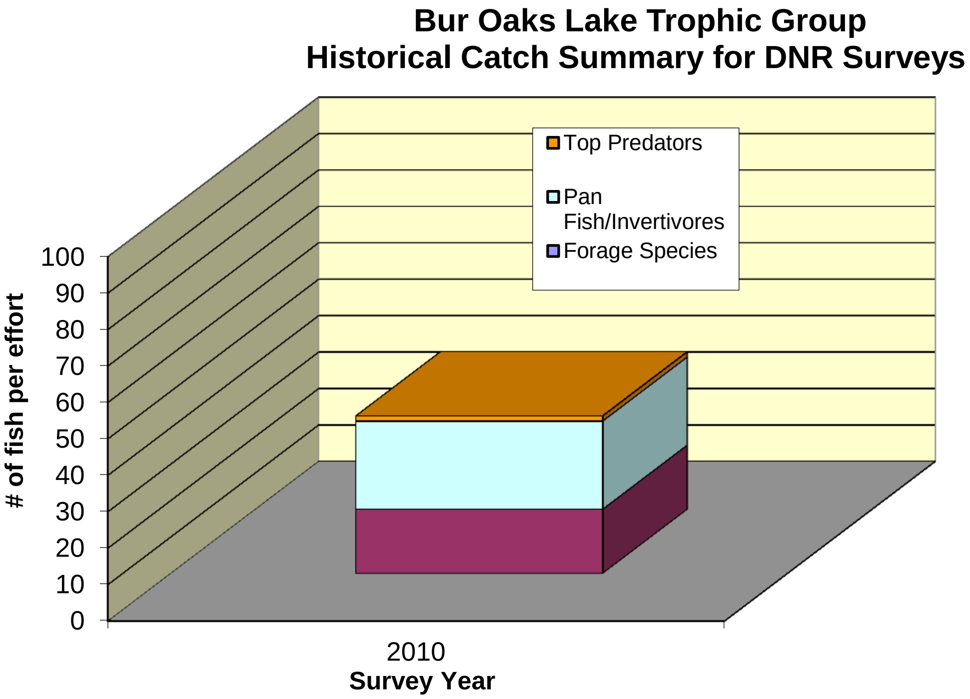
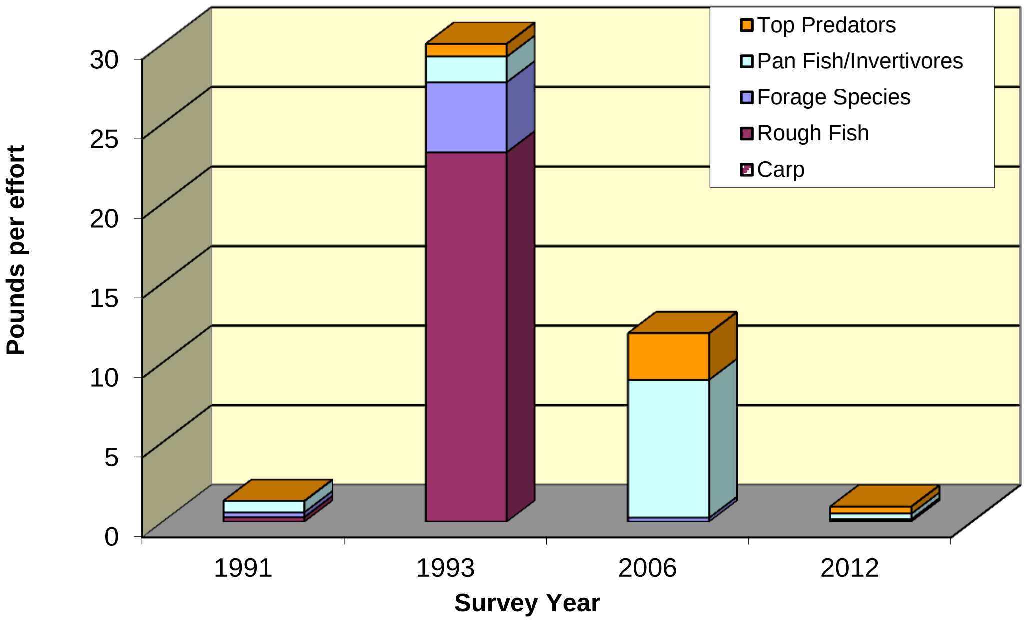
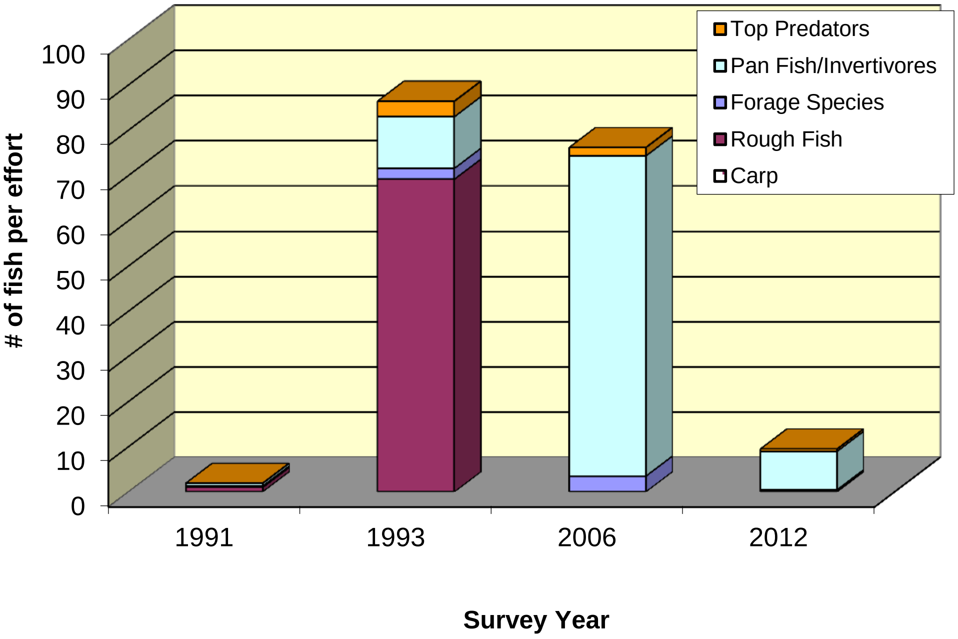

Bur Oaks Lake Trophic Group
Historical Catch Summary for DNR Surveys

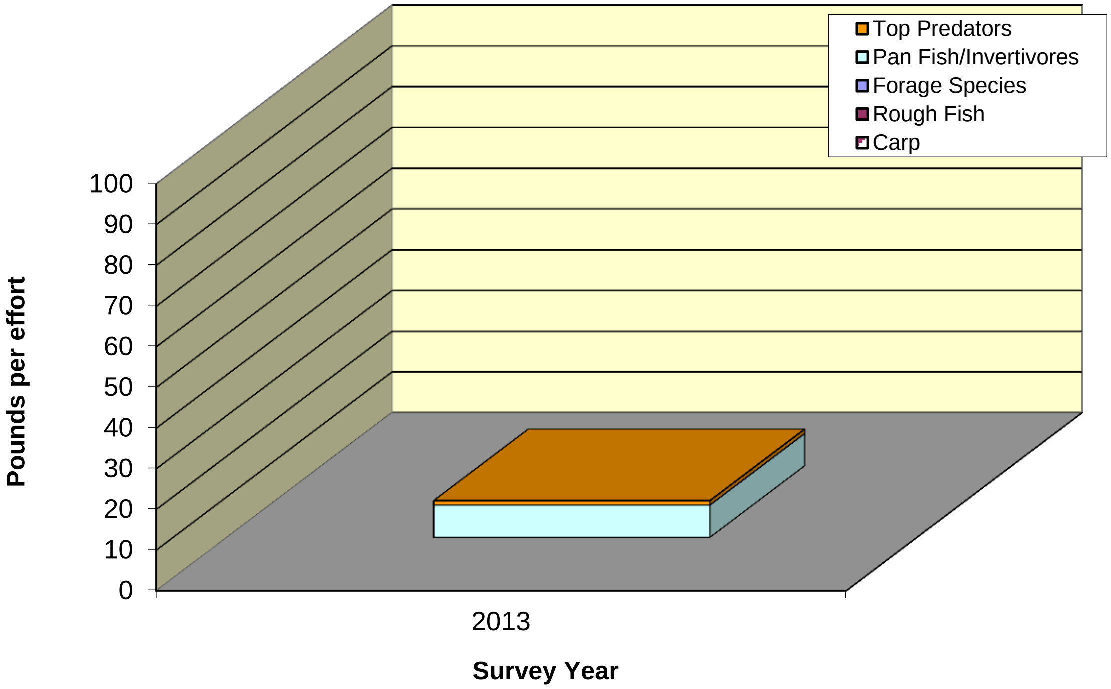
Carlson Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys



Carlson Lake Trophic Group
Historical Catch Summary for DNR Surveys

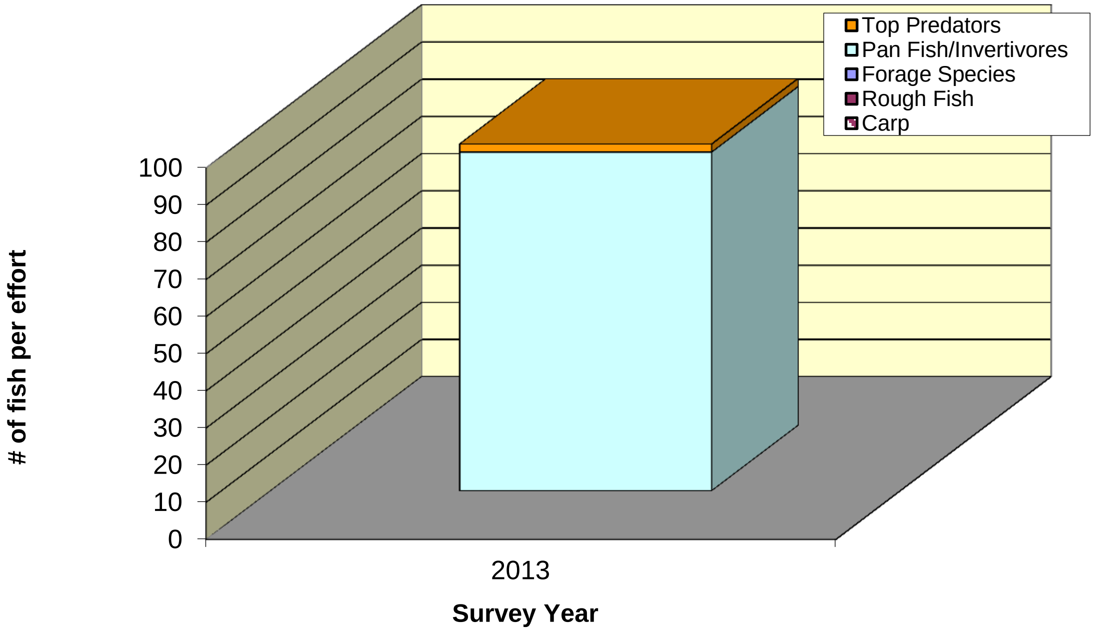


Cliff Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys



Trapnet Data Only

Cliff Lake Trophic Group
Historical Catch Summary for DNR Surveys



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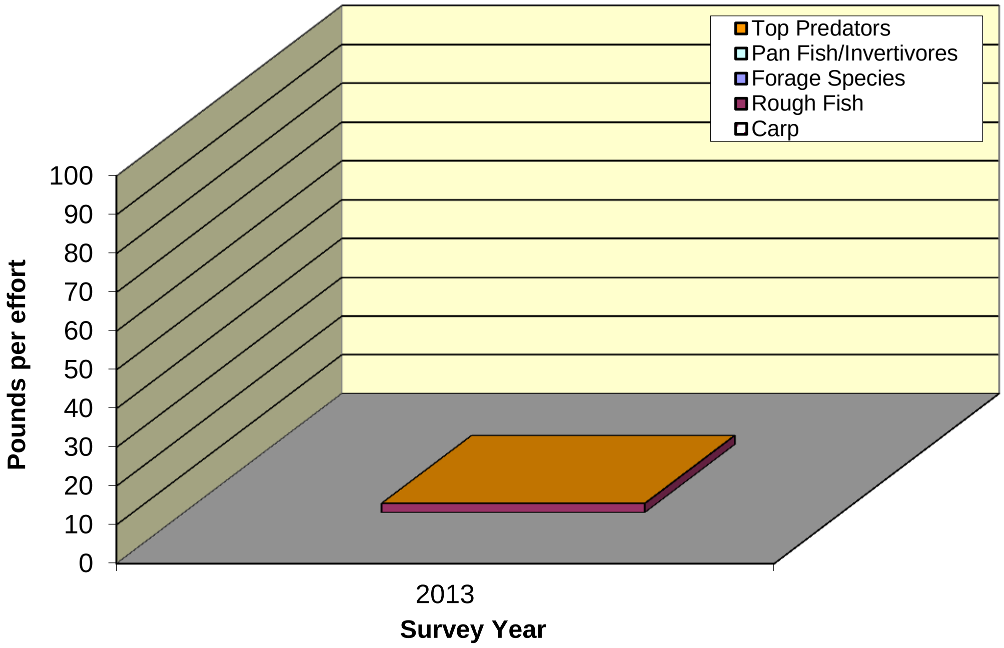
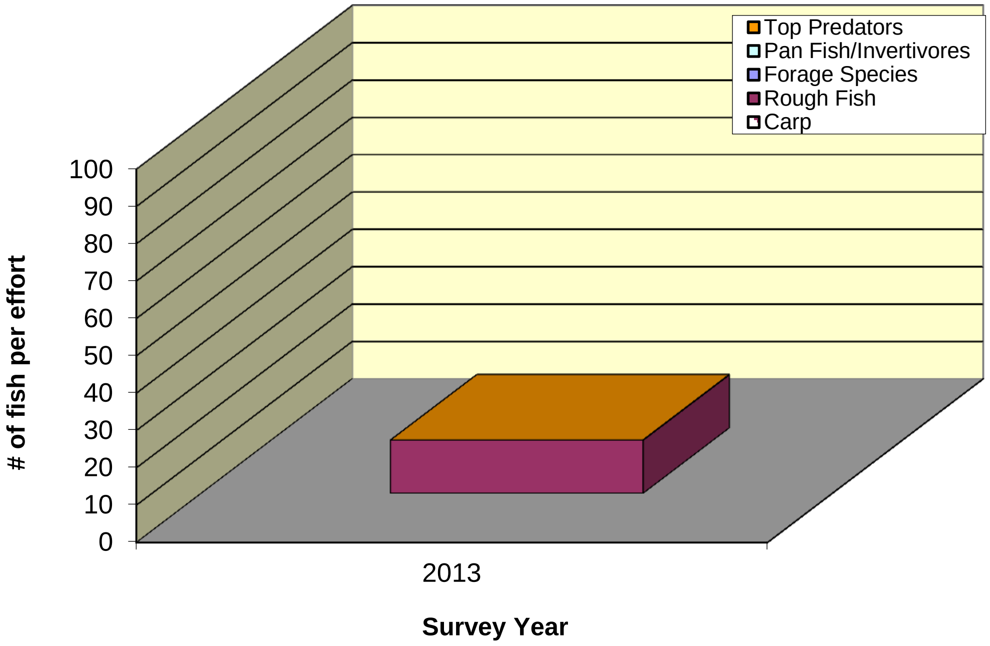


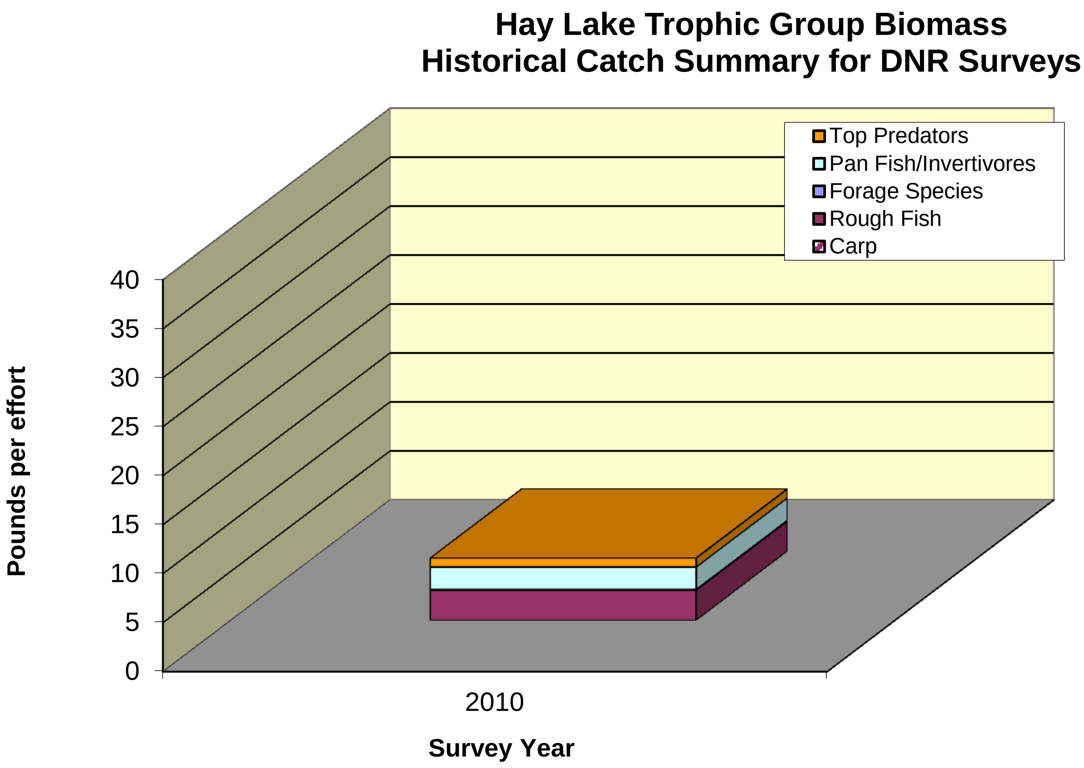
Fitz Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys

Trapned Data Only

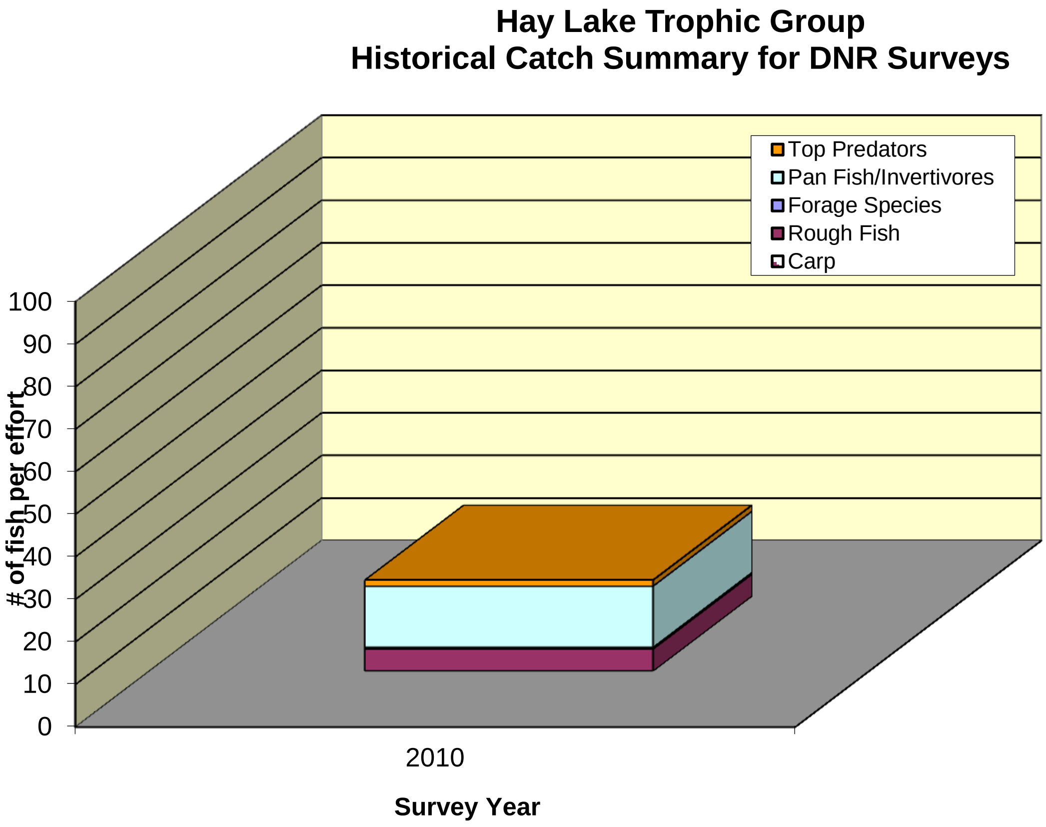


Fitz Lake Trophic Group
Historical Catch Summary for DNR Surveys

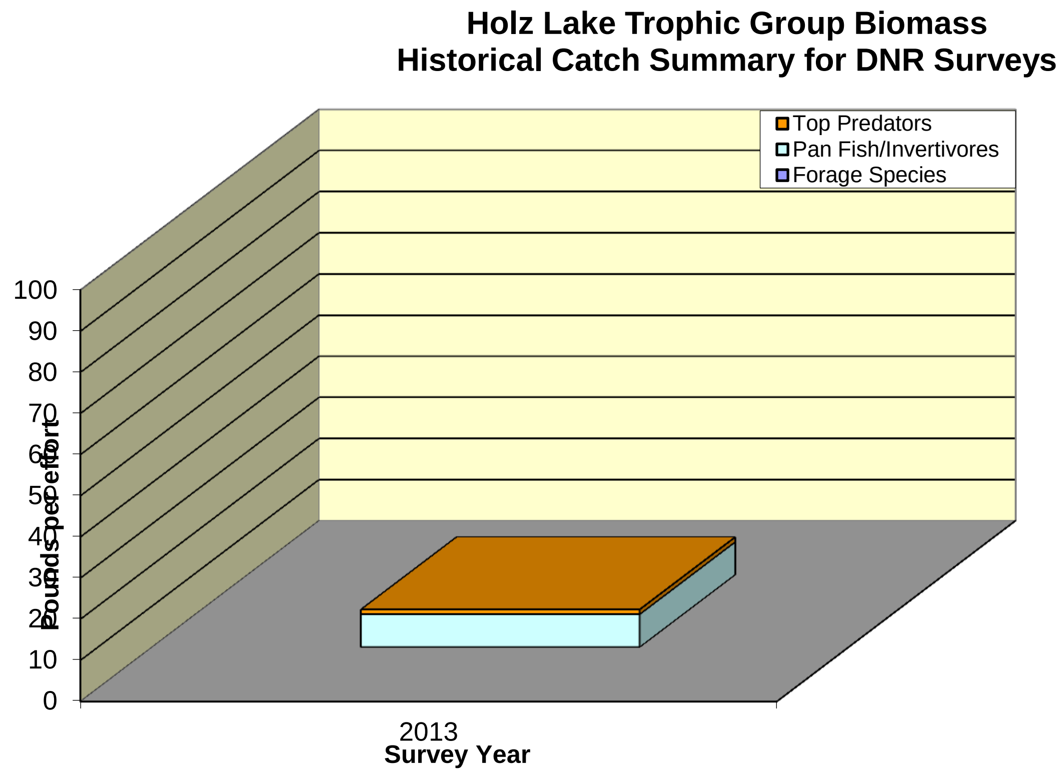
Trapnet data only



Hay Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys



Hay Lake Trophic Group
Historical Catch Summary for DNR Surveys



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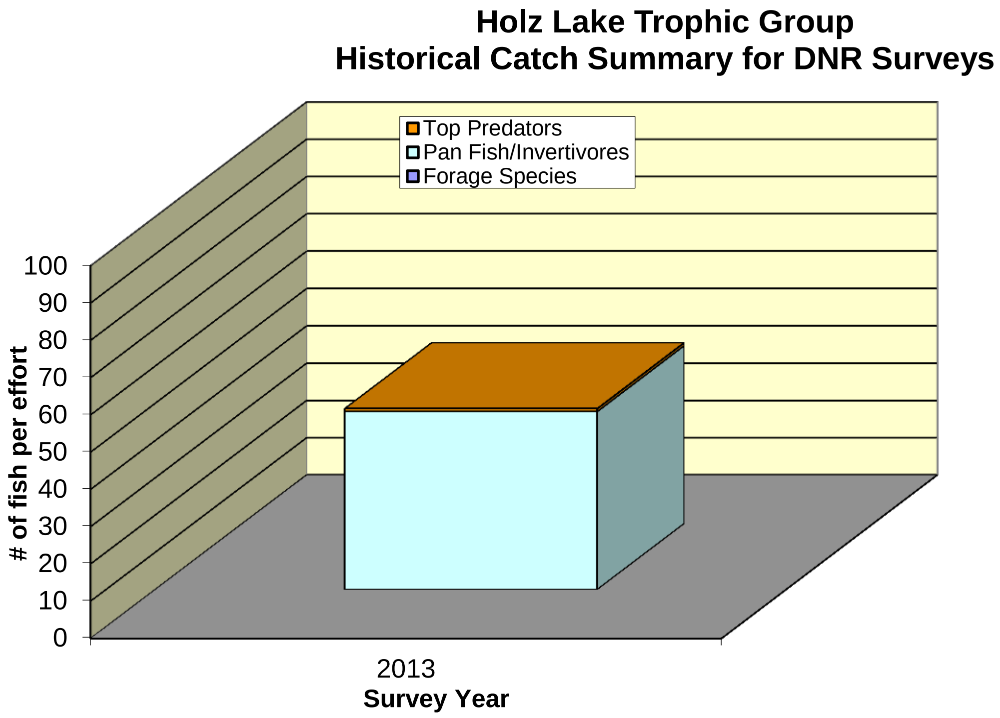
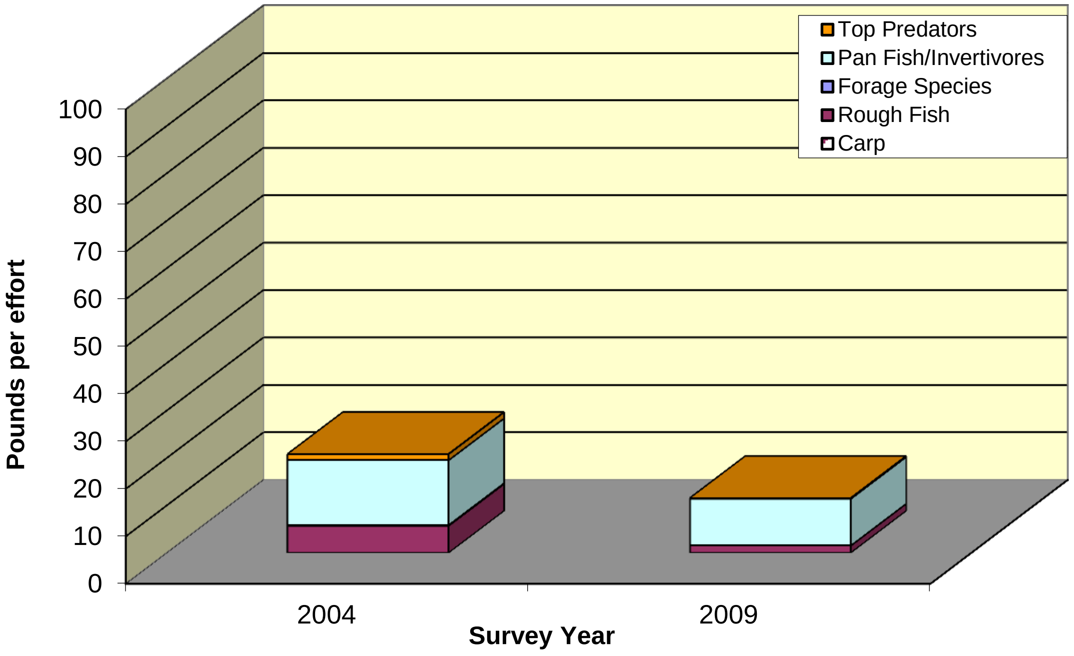
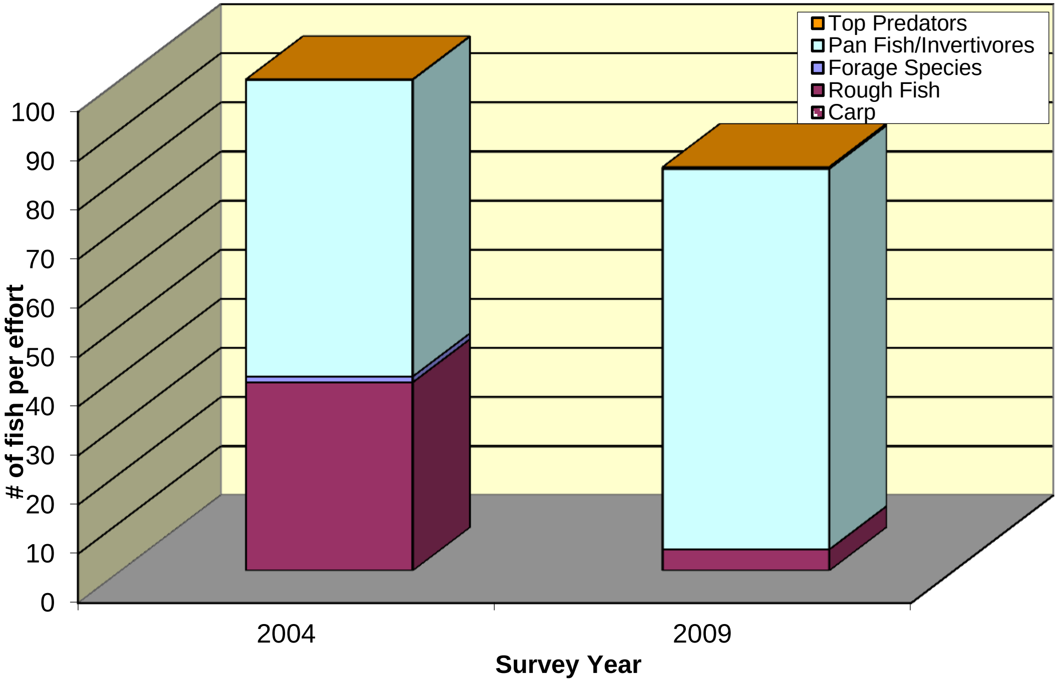


Trapnet Data Only

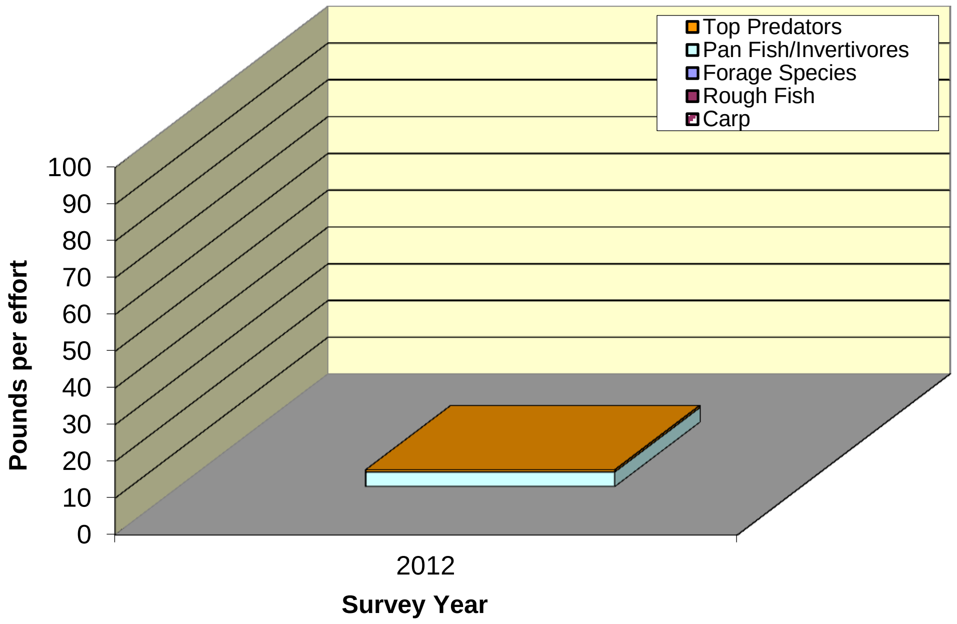
Lemay Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys



Lemay Lake Trophic Group
Historical Catch Summary for DNR Surveys

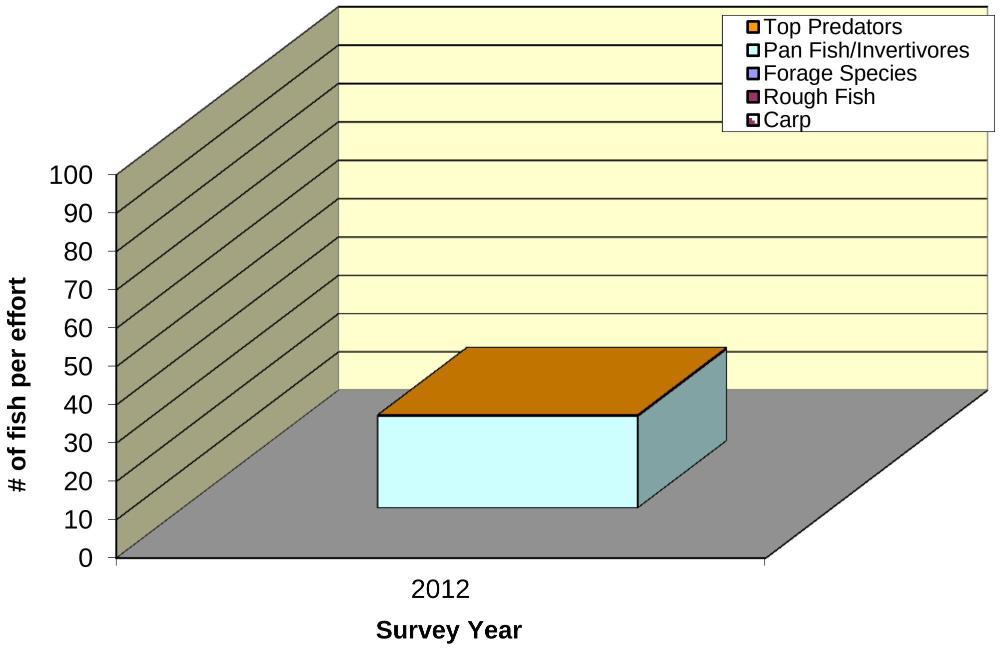


North Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys



Trapnet Data only

North Lake Trophic Group
Historical Catch Summary for DNR Surveys



Trapned Data Only

Electro Fishing Results for Bur Oaks, Cliff, and Holz Lakes

	Bluegill		**Large Mouth Bass**		**Northern Pike**	
	Count	Total Wt (lbs)	Count	Total Wt (lbs)	Count	Total Wt (lbs)
Bur Oaks	2	0.9	--	--	3	0.3
Cliff	--	--	35	4.0	--	--
Holz			61	54.0		

Appendix F

PondNET Model Preparation and Calibration

Eagan Pondnet Model Preperation and Calibration

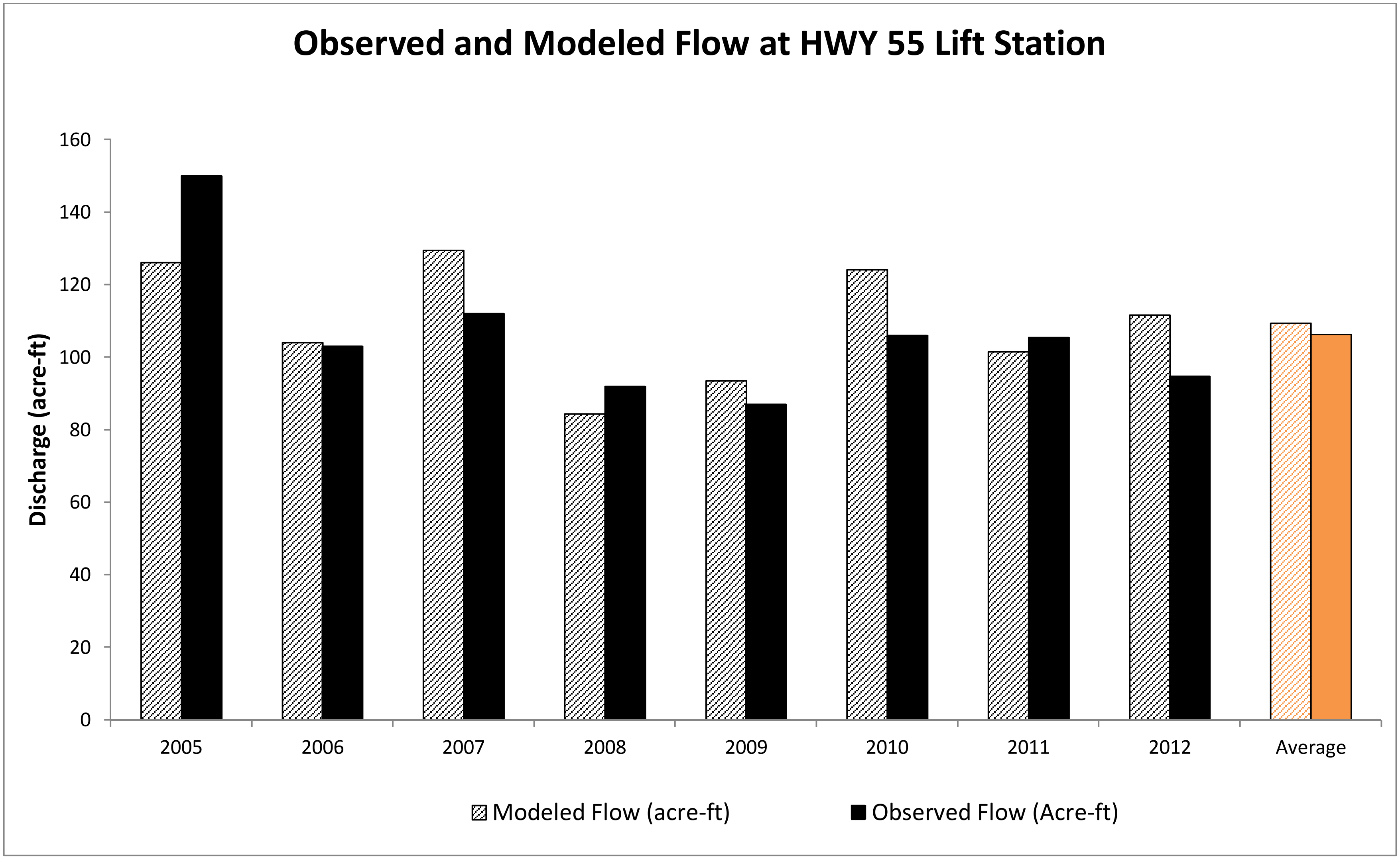
PondNET models previously constructed for a non-degradation analysis were obtained from the City of Eagan with preliminary basin area, basin volume, basin connections, and land use (Wenk, 2012). Basin connections were exhaustively verified to ensure routing was correct in each PondNET model and any changes were discussed with City of Eagan Staff. In the process of checking basin connections, pond areas were verified by the City of Eagan using GIS and field verification methods. If any pond or wetland surface areas were changed, basin volumes were subsequently updated with field verified basin volumes. Additionally, watershed bounderies in the City of Inver Grove Heights were checked and updated to ensure the pondnet models included all drainage basins.

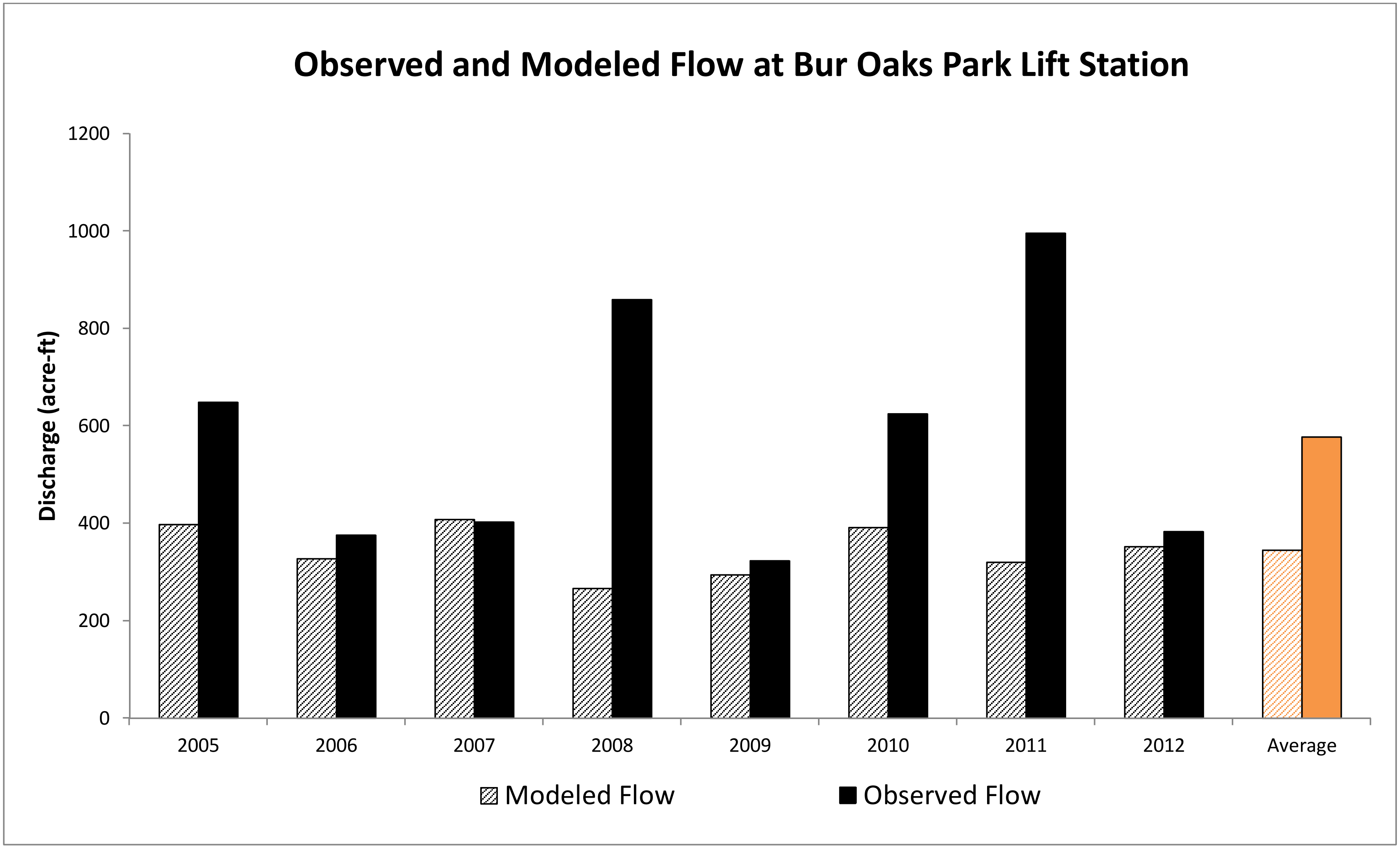
An up-to-date land use file was obtained from the City of Eagan for use in the PondNET model. This land use file was created in 2007 by the City of Eagan and has been regularly updated to reflect current land use conditions. That land use file was amended with MnDOT, Dakota County, and the City of Eagan right of way (ROW). MnDOT provided a coverage of their right-of-way in the City of Eagan while the City's was already included in the land use coverage. To estimate the County and City right-of-way, Wenck used shapefiles obtained from the 2012 non-degredation study (Wenck, 2012). Land use files were then intersected with updated basin watershed areas to obtain land use percentages for each sub-watershed. Each land use was assigned a runoff coefficient and an event mean phosphorus concentrationused to calculate runoff volume (acre-ft) and total phosphorus concentrations (µg/L) for each watershed, respectively (Table 1).

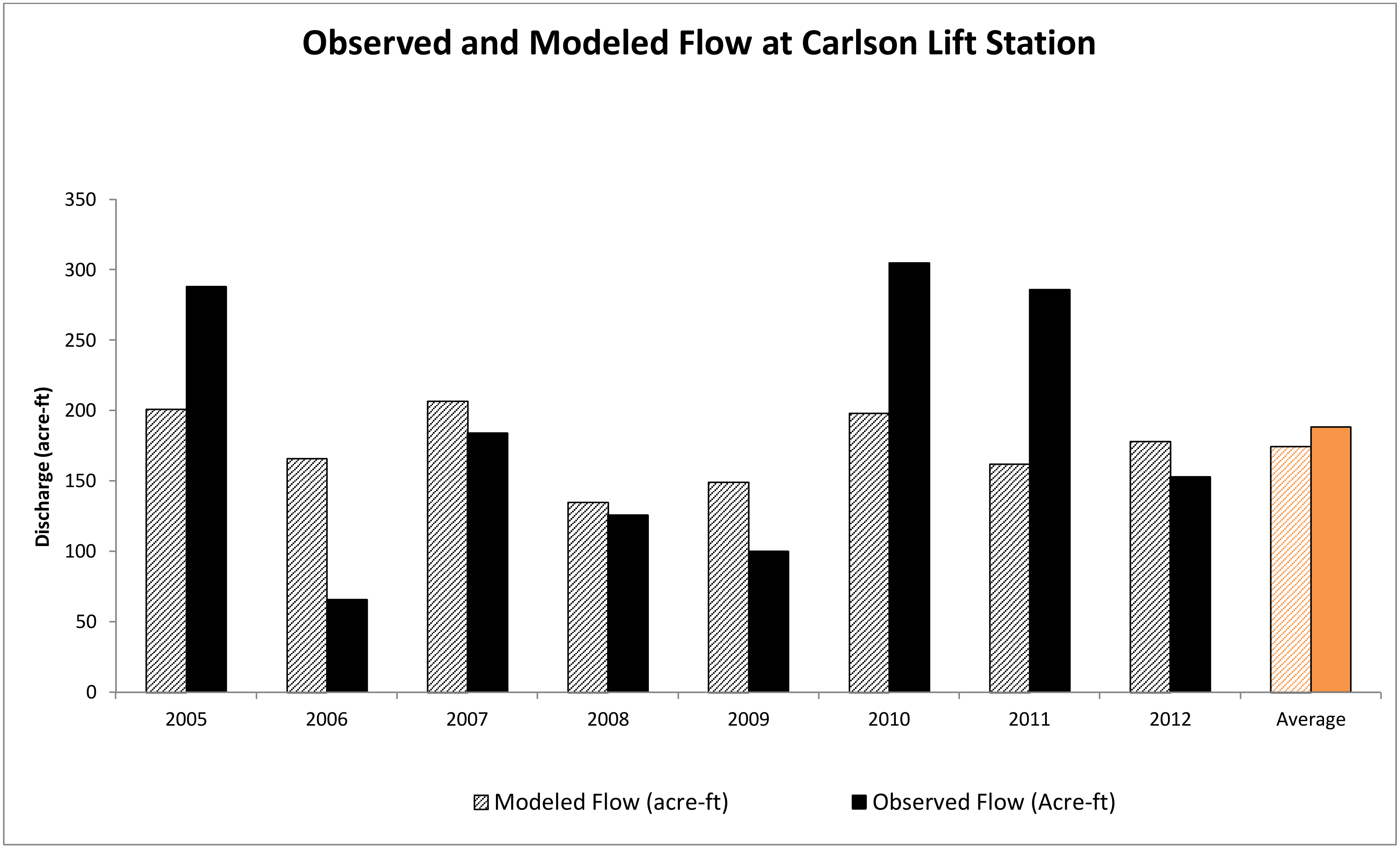
Recorded lift station discharge and measured pond total phosphorus (TP) concentrations were used for model calibration. For lift stations, total annual discharge was summed at each lift station and compared to total annual model predicted discharge. Runoff coefficients were systematically adjusted so that the average annual measured discharge was acceptbly close to PondNET modeled discharge. However, some lift stations had years with unusually high recorded discharge (Bur Oaks Park lift station 2008 and 2011; Lexington Lift Station 2010 and 2012). Consequently, average modeled discharge for Bur Oaks Park and the Lexington lift stations was lower than the average recorded discharge. Runoff calibrations resulted in a set of runoff coefficients that were used for all neighborhood lake PondNET models. There were fewer data available for total phosphorus (TP) calibration, but phosphorus coefficients were adjusted to obtain a close match to the available data. Similar to runoff coefficients, land-use-specific event mean phosphorus coefficients were applied to all pondnet models. The following tables summarize the results of the water yield and phophorus calibration of the PondNET model.

Table 1. Event mean runoff and phosphorus coefficients applied to all Eagan PondNET

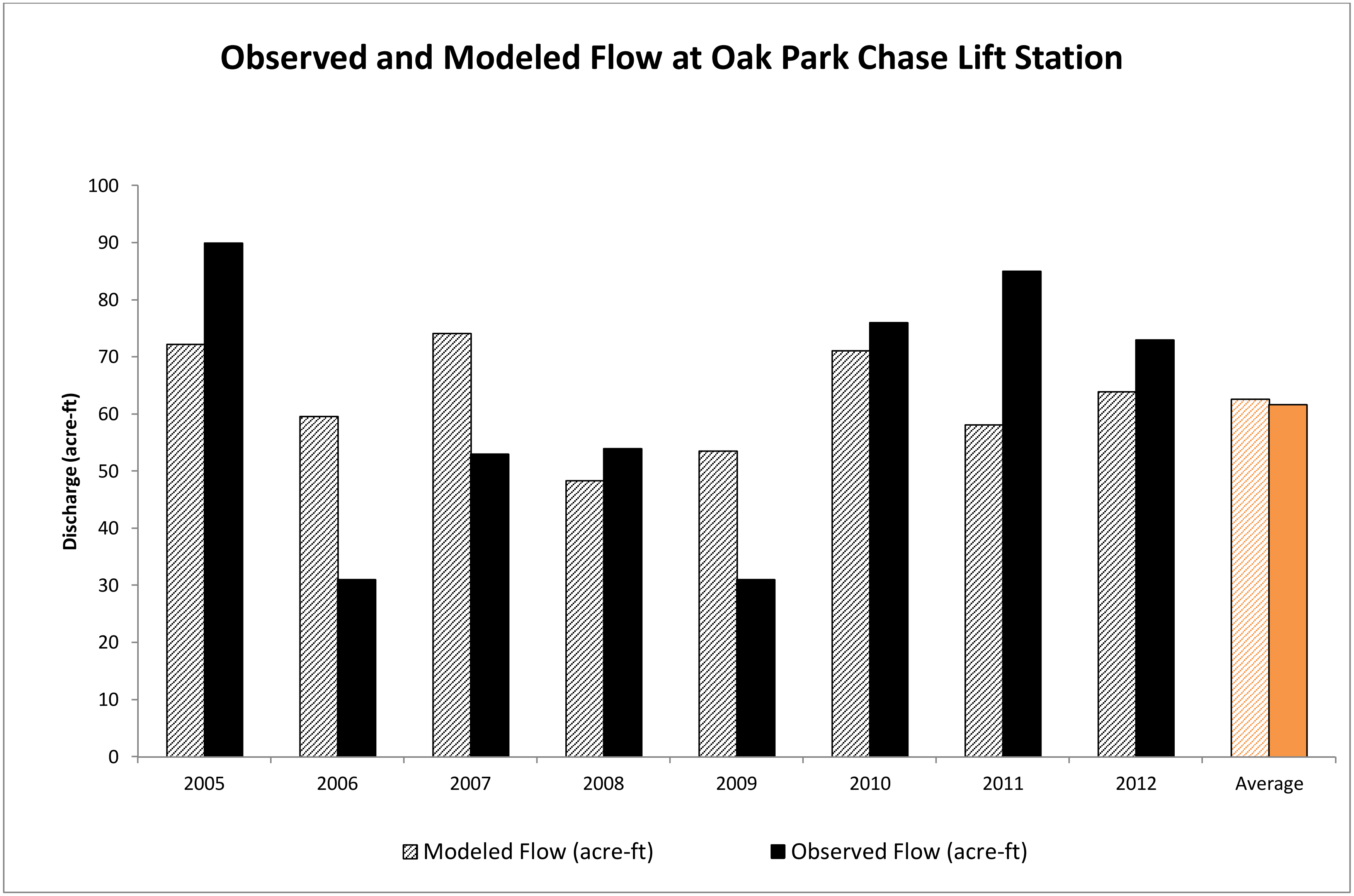
Land Use	Event Mean Phosphorus Coefficient	Runoff Coefficient
Agricultural Land	350	0.1
Industrial	300	0.3
Multi-Family Residential	250	0.17
Single Family Residential	250	0.14
Open Area	50	0.05
EAGAN ROW	300	0.14
CNTY DOT ROW	300	0.14
MN DOT ROW	300	0.14
Open Water	0	0


Observed and Modeled Flow at HWY 55 Lift Station
Discharge (acre-ft)
160
140
120
100
80
60
40
20
0
2005
2006
2007
2008
2009
2010
2011
2012
Average
▨ Modeled Flow (acre-ft)
■ Observed Flow (Acre-ft)

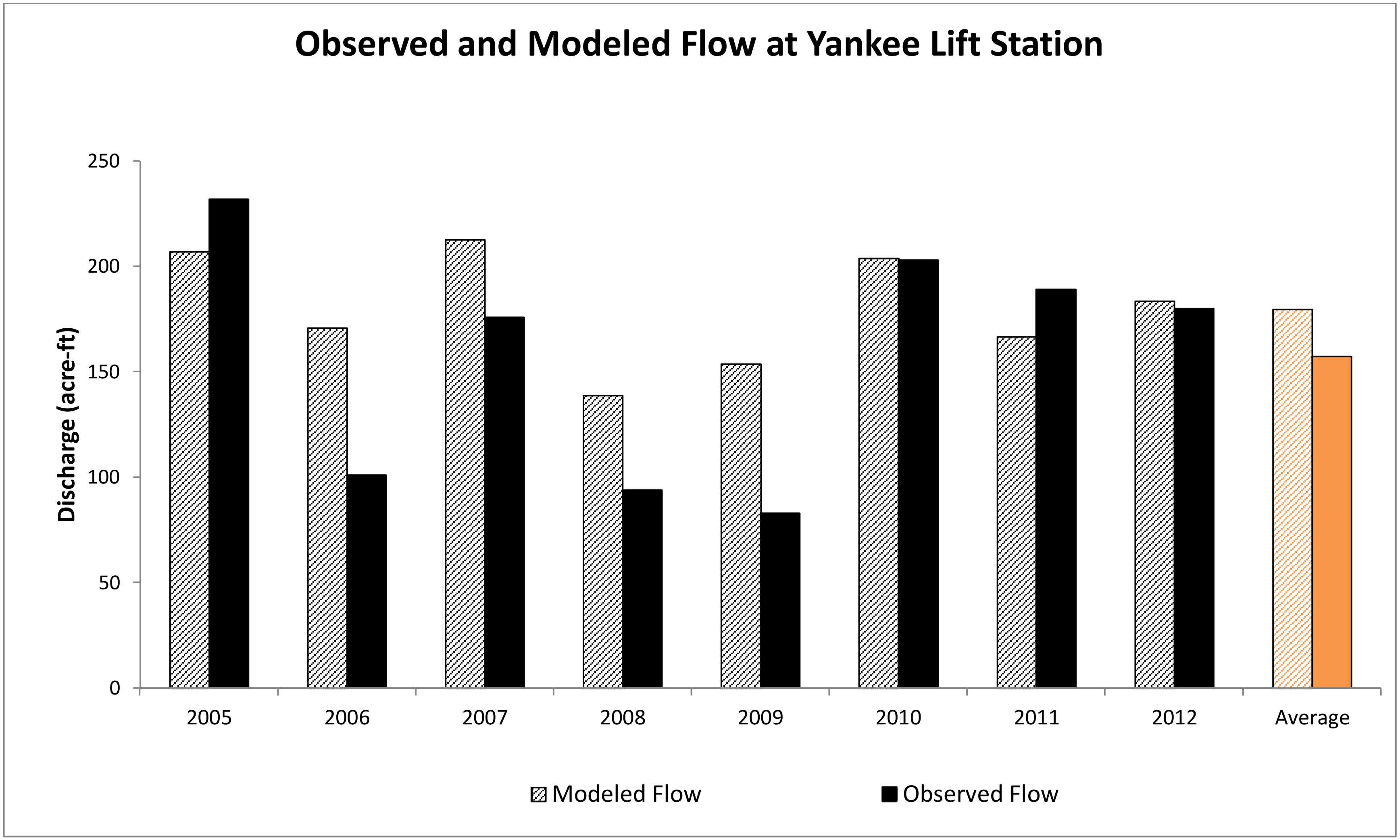

Observed and Modeled Flow at Bur Oaks Park Lift Station
Discharge (acre-ft)
1200
1000
800
600
400
200
0
2005
2006
2007
2008
2009
2010
2011
2012
Average
▨ Modeled Flow
■ Observed Flow

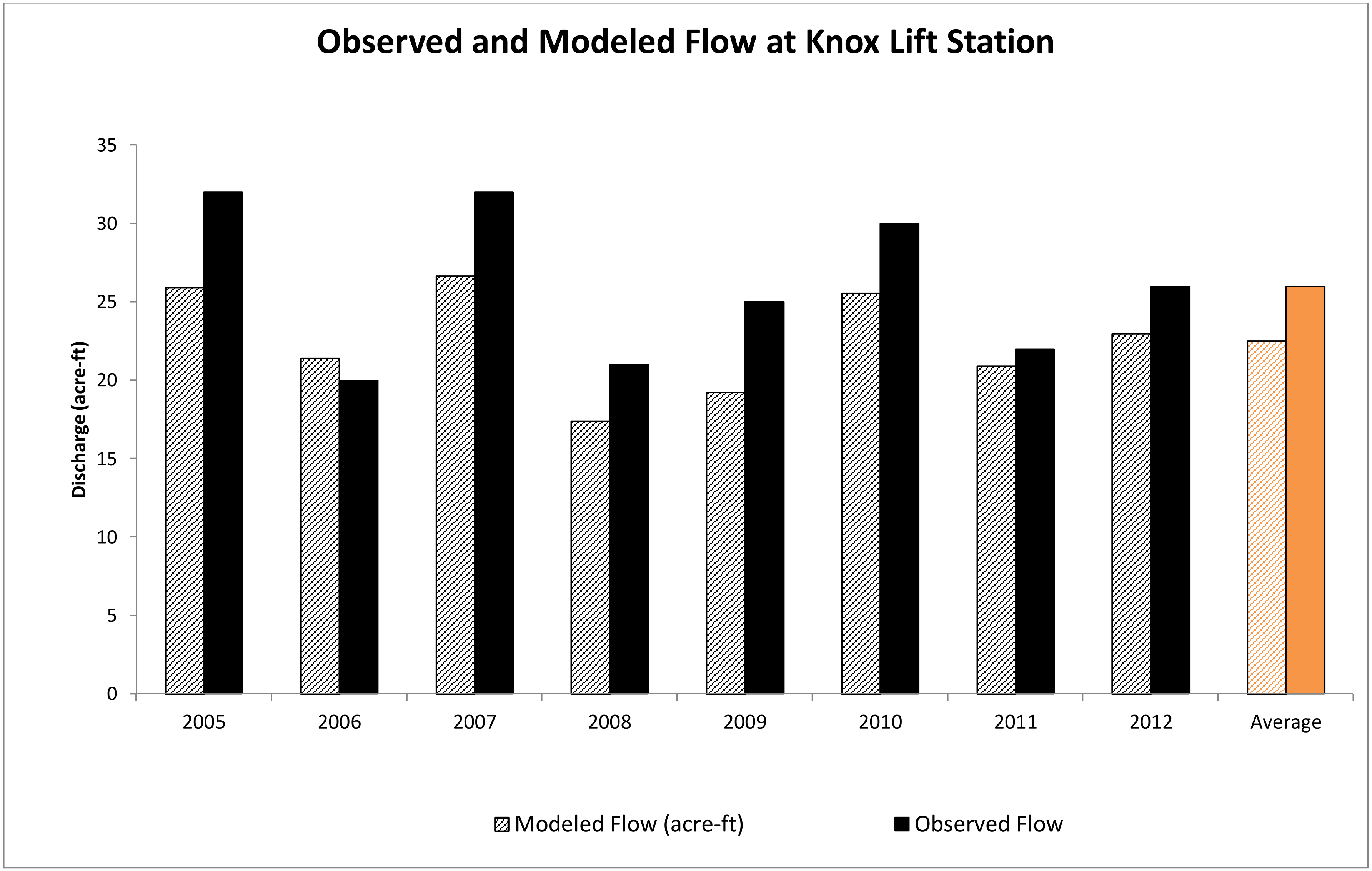


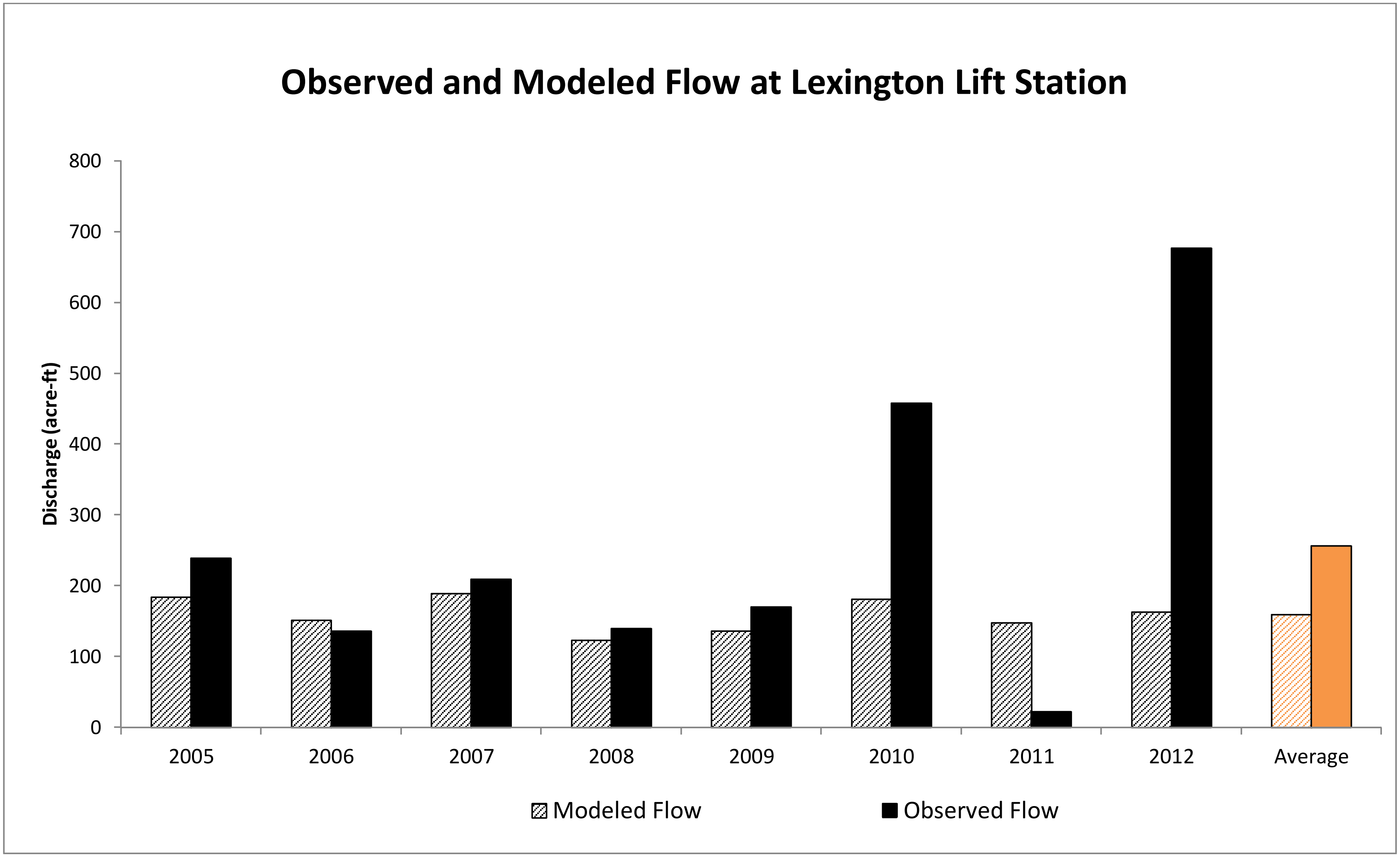
Observed and Modeled Flow at Carlson Lift Station

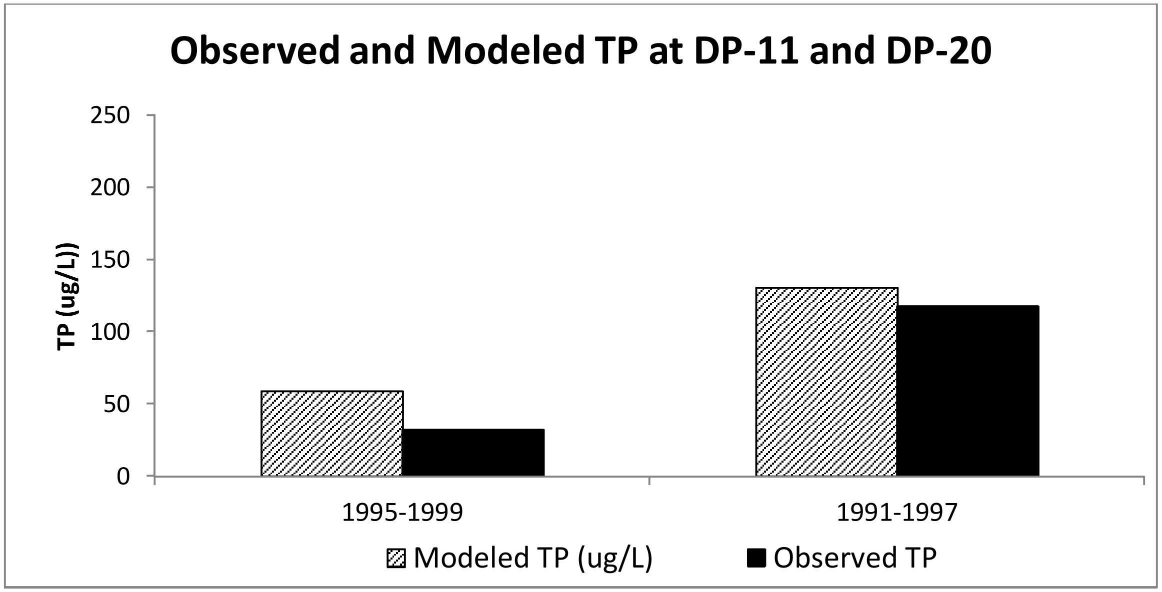


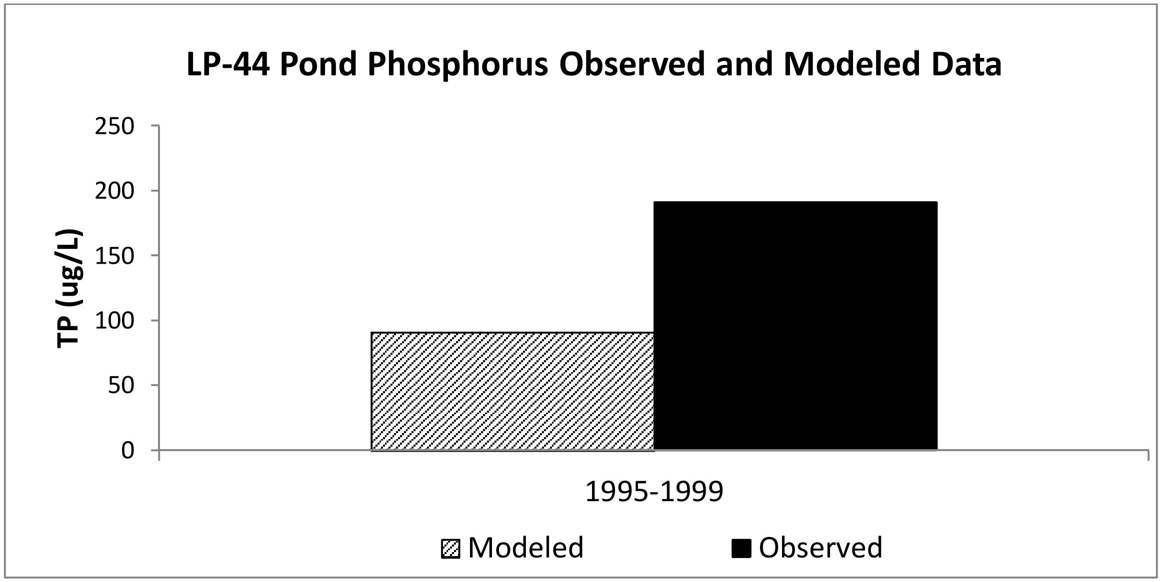
Observed and Modeled Flow at Oak Park Chase Lift Station

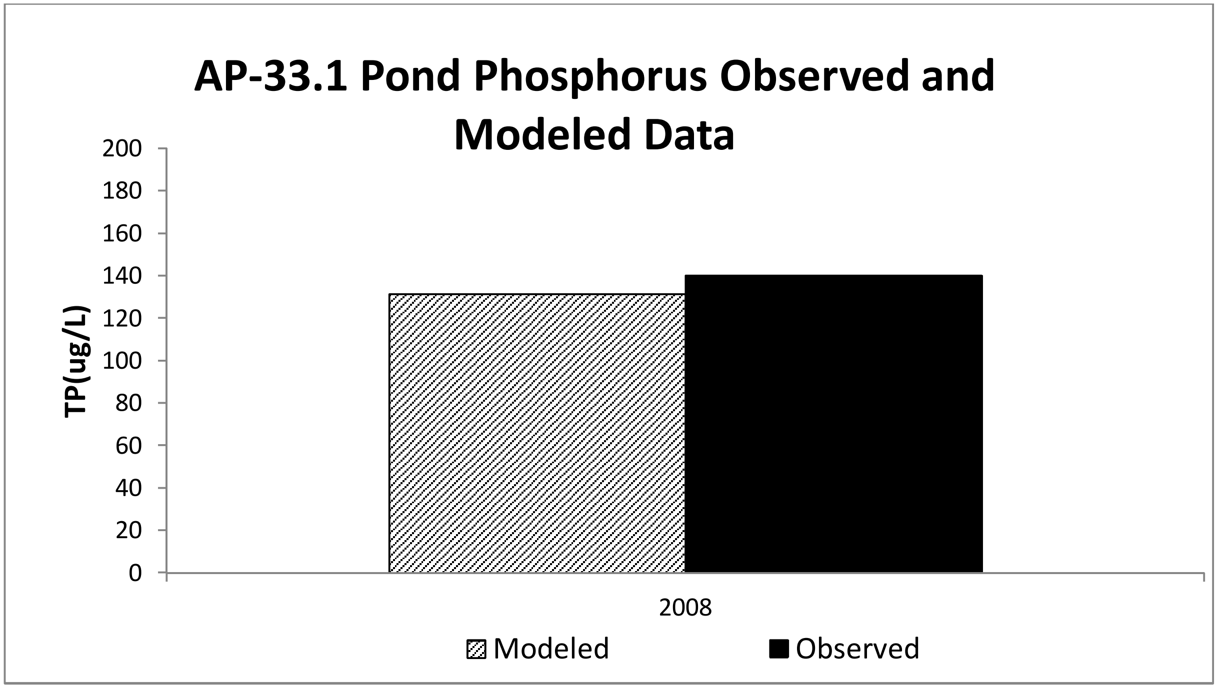

Observed and Modeled Flow at Yankee Lift Station
Discharge (acre-ft)
250
200
150
100
50
0
2005
2006
2007
2008
2009
2010
2011
2012
Average
▨ Modeled Flow
■ Observed Flow


Observed and Modeled Flow at Knox Lift Station
Discharge (acre-ft)
35
30
25
20
15
10
5
0
2005
2006
2007
2008
2009
2010
2011
2012
Average
▨ Modeled Flow (acre-ft)
■ Observed Flow


Observed and Modeled Flow at Lexington Lift Station
Discharge (acre-ft)
800
700
600
500
400
300
200
100
0
2005
2006
2007
2008
2009
2010
2011
2012
Average
▨ Modeled Flow
■ Observed Flow


Observed and Modeled TP at DP-11 and DP-20
TP (ug/L))
250
200
150
100
50
0
1995-1999
1991-1997
▨ Modeled TP (ug/L)
■ Observed TP

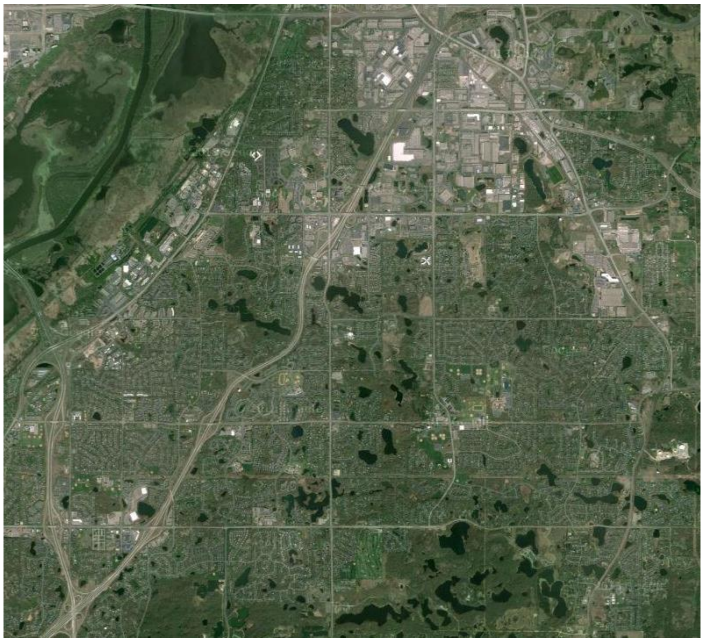

LP-44 Pond Phosphorus Observed and Modeled Data
TP (ug/L)
250
200
150
100
50
0
1995-1999
▨ Modeled
■ Observed


AP-33.1 Pond Phosphorus Observed and Modeled Data
TP(ug/L)
200
180
160
140
120
100
80
60
40
20
0
2008
▨ Modeled
■ Observed

Appendix G

Sediment Chemistry and Release Rates

Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Lakes in the City of Eagan, Minnesota



City of Eagan, MN (Google Maps, TerraMetrics)

18 February, 2015

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OBJECTIVES

The objectives of this investigation were to determine rates of phosphorus (P) release from sediments under laboratory-controlled oxic (i.e., aerobic) and anoxic (i.e., anaerobic) conditions and to quantify biologically-labile (i.e., subject to recycling) and refractory (i.e., biologically inert and subject to burial) P fractions for sediments collected from various lakes in the City of Eagan, Minnesota.

APPROACH

Laboratory-derived rates of P release from sediment under aerobic and anaerobic and anoxic conditions

Replicate sediment cores were collected by Wenck Associates from stations located in various lakes in late July-August, 2013, for determination of rates of P release from sediment under aerobic and anaerobic conditions (***Table 1***). A gravity sediment coring device (Aquatic Research Instruments, Hope ID) equipped with an acrylic core liner (6.5-cm ID and 50-cm length) was used to collect intact and undisturbed sediment cores. The core liners, containing both sediment and overlying water, were immediately sealed using rubber stoppers and stored in a covered container until analysis. Additional lake water was collected for incubation with the sediment.

Sediment cores collected for P release determination were processed within 24 h of arrival. In the laboratory, sediment cores were carefully drained of overlying water and the upper 10 cm layer was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Water collected from the lake was filtered through a glass fiber filter (Gelman A-E); 300 mL was then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems, therefore, consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers

(***Figure 1***). The sediment incubation systems were placed in a darkened environmental chamber and incubated at a constant temperature (25 ^{o}C) for up to 2 weeks or longer. The oxidation-reduction environment in each system was controlled by gently bubbling either air (aerobic) or nitrogen (anaerobic) through an air stone placed just above the sediment surface. Bubbling action ensured complete mixing of the water column but did not disrupt the sediment.

Water samples for soluble reactive phosphorus (SRP) were collected at one to three day intervals over the entire incubation period. Samples (10 mL) were collected from the center of each sediment incubation system using a syringe and immediately filtered through a 0.45 µm membrane syringe filter. The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. SRP was measured colorimetrically using the ascorbic acid method (APHA 2005). Rates of SRP release from the sediment (mg/m^2 d) were calculated as the linear change in concentration in the overlying water divided by time and the area of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment chemistry

The upper 10 cm of an additional core collected from each lake was sectioned for analysis of moisture content (%), sediment density (g/mL), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, aluminum-bound P, calcium-bound P, labile and refractory organic P, total P, total iron (Fe) and total manganese (Mn; all expressed at mg/g). Fresh sediment sections were stored in heavy-duty quart freezer bags and refrigerated until analysis. A known volume of sediment was dried at 105 ^{o}C for determination of moisture content and sediment density and burned at 500 ^{o}C for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002). Additional sediment was dried to a constant weight, ground, and digested for analysis of total P, Fe, and Mn using standard methods (Anderson 1976, APHA 2005 method 4500 P.f., EPA method 200.7).

Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), sodium hydroxide-extractable P (i.e., aluminum-bound P), and hydrochloric acid-extractable P (i.e., calcium-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P. Refractory organic P was estimated as the difference between total P and the sum of the other fractions.

The loosely-bound and iron-bound P fractions are readily mobilized at the sediment-water interface as a result of anaerobic conditions that result in desorption of P from sediment and diffusion into the overlying water column (Mortimer 1971, Boström 1984, Nürnberg 1988). The sum of the loosely-bound and iron-bound P fractions are referred to as redox-sensitive P (i.e., the P fraction that is active in P release under anaerobic and reducing conditions). In addition, labile organic P can be converted to soluble P via bacterial mineralization (Jensen and Andersen 1992) or hydrolysis of bacterial polyphosphates to soluble phosphate under anaerobic conditions (Gächter et al. 1988; Gächter and Meyer 1993; Hupfer et al. 1995). The sum of redox-sensitive P and labile organic P are collectively referred to a biologically-labile P. This fraction is generally active in recycling pathways that result in exchanges of phosphate from the sediment to the overlying water column and potential assimilation by algae. In contrast, aluminum-bound, calcium-bound, and refractory organic P fractions are more chemically inert and subject to burial rather than recycling.

RESULTS AND INTERPRETATION

Lake Sediment Characteristics

Rates of Phosphorus Release from Sediment

P mass and concentration rapidly increased in the overlying water column of sediment systems maintained under anaerobic conditions. For example, rates of P mass and concentration increase in the overlying water were approximately linear over the first six days of incubation for sediment collected in Burr Oaks Lake (***Figure 2***). Overall, mean anaerobic P release rates varied between 0.4 mg/m^2 d and 9.4 mg/m^2 d (***Table 4*** and ***Figure 3***). Mean anaerobic P release rates were greater than 5 mg/m^2 d for sediment cores collected in both deep basins of Bur Oaks Lake, the east O'Leary Lake, and North Lake. They were lowest for Hay and Quigley Lake. Nürnberg (1988) reported that anaerobic P release rates ranging between ~ 2 and 12 mg/m^2 d generally coincided with mesotrophic to eutrophic conditions. Most anaerobic P release rates in this study fell within this trophic state range. When compared to other lakes in the region, most anaerobic P release rates fell near or below the median (***Figure 4***). However, sediments collected in the south basin of Bur Oaks Lake and in East O'Leary Lake exhibited anaerobic P release rates that fell above the median and within the upper 25% quartile (***Figure 4***).

Increases in P mass and concentration were much lower in the overlying water column of sediment incubation systems under aerobic conditions, versus under anaerobic conditions (***Table 4*** and ***Figure 5***). With the exception of Quigley Lake, anaerobic P release rates were ~ 8 to 50 times greater than aerobic P release rates (***Figure 6***). While rates were generally low for Quigley Lake sediment, aerobic and anaerobic P release rates were similar at ~ 0.4 mg/m^2 d, resulting in a 1:1 anaerobic:aerobic rate ratio.

Overall, aerobic P release rates in this study fell near the median or in the lower 25% quartile compared to other lakes in the region (***Figure 4***) and rates ranged between ~0.15 mg/m^2 d (i.e., Fitz, Hay, Holz, North, and West O'Leary Lakes) and greater than 0.30 mg/m^2 d (i.e., Bald, Bur Oaks, Carlson, LeMay, East O'Leary, and Quigley Lakes; ***Table 4***). Carlson Lake sediment exhibited the highest mean aerobic P release rate at 0.56 mg/m^2 d (± 0.03 standard error; SE). Although rates were lower under aerobic compared to anaerobic conditions, they still represented a potentially important internal source of P to the water column.

Sediment Textural and Chemical Characteristics

Sediments from most lake stations generally exhibited high moisture content and low dry bulk density, indicating fined-grained flocculent sediment (***Table 5***). Moisture content exceeded 85%, while dry bulk density was less than 0.20 g/cm^3 in Bald, Bur Oaks north basin, Fitz, LeMay, East and West O'Leary, and Quigley Lake sediment, reflecting high porosity (i.e., interstitial spaces for porewater; ***Figure 7***). In contrast, sediment moisture content was less than 85% in the other lakes. In particular, Holz and North Lake sediment had the lowest sediment moisture contents at 71% and 69%, respectively. These latter patterns coincided with low organic matter content relative to the other lakes, suggesting more compacted clays and coarser-grained sediments. Organic matter content was moderate at less than 25% for most lakes (***Figure 7***). LeMay, East and West O'Leary, and Quigley Lake sediment exhibited much higher sediment organic matter content that approached or exceeded 30%.

Overall, sediment total P and the composition of P varied markedly between lakes and lake stations (***Figure 8, Table 5*** and ***6***). Sediment total P concentrations were very high and approached or exceeded 2 mg/g in Bald Lake, the north basin of Bur Oaks Lake, Hay Lake and West O'Leary Lake. Most lake stations exhibited concentrations of sediment total P exceeding 1 mg/g and fell within the upper 25% quartile or higher compared to other lakes in the region (***Figure 9***). Sediment total P concentrations were more moderate and less than 1 mg/g in the south basin of Bur Oaks Lake, LeMay Lake, and North Lake.

Biologically-labile (i.e., subject to recycling back to the overlying water column; loosely-bound P, iron-bound P, and labile organic P) P accounted for at least 38% or more of the sediment total P concentration (Range = 35.2% to 78.3%; ***Table 7*** and ***Figure 10***), suggesting the potential for internal P recycling from sediments. Iron-bound P concentrations were unusually high in many lakes (***Table 6*** and ***Figure 8***) and fell above the median concentration compared to other lakes in the region (***Figure 9***). In particular, Iron-bound P represented between approximately 20% and 84% of the biologically-labile P and concentrations exceeded 0.6 mg/g in Bald Lake, the north basin of Bur Oaks Lake, Fitz Lake, Hay Lake and West O'Leary Lake. However, there was no positive relationship between iron-bound P and anaerobic P release rates as found by others (Nürnberg 1988). This pattern may be related to lower moisture content, higher dry and wet bulk density, and lower porosity relative to flocculent sediments with high porosity (> 90%) typically found in the profundal region of deeper, stratified lakes. Lower porosity and higher dry and wet bulk density in surficial sediments would tend to limit the rate P flux by affecting (i.e. lengthening) diffusional path lengths between porewater and overlying water.

Labile organic P also represented a significant proportion of the biologically-labile P pool for most lakes (range = 14% to 81% of the biologically-labile P; ***Table 6*** and ***Figure 8***). Concentrations were greatest in Bald Lake, East and West O'Leary Lake, and Quigley Lake, exceeding 0.4 mg/g. These concentration ranges also fell well above the median concentration for lakes in the region (***Figure 9***). By comparison, concentrations of labile organic P fell below the median for sediments located in the south basin of Bur Oaks Lake, Carlson Lake, Cliff Lake, Fitz Lake, Holz Lake and North Lake (***Figure 9***).

Loosely-bound P accounted for the lowest percentage of the biologically-labile P pool at only 0.3% to 3.5% (***Table 6*** and ***Figure 8***). This fraction reflects P in the porewater and P that is loosely-adsorbed onto calcium carbonates and is typically the lowest in concentration compared to the other P fractions (***Figure 9***). Notably, concentrations were highest in sediments collected from Bald Lake (0.068 mg/g), the north basin of Bur Oaks

Lake (0.045 mg/g), and Fitz Lake (0.033 mg/g). Other lake sediments exhibited concentrations less than 0.015 mg/g.

Biologically-refractory P (i.e., aluminum-bound, calcium-bound, and refractory organic P), more inert and subject to burial rather than recycling, accounted for ~ 27% to 65% of the sediment total P for all lake stations (***Table 7*** and ***Figure 10***). Aluminum-bound P dominated the biologically-refractory P pool for sediments collected in Bald Lake (i.e., 81%) the south basin of Bur Oaks Lake (i.e., 39%), Fitz Lake (i.e., 46%), Hay Lake (i.e., 66%), and West O’Leary Lake (i.e., 49%). Calcium-bound P was the dominant refractory form in the south basin of Bur Oaks Lake (i.e., 45%), LeMay Lake (i.e., 57%), and North Lake (i.e., 56%). Refractory organic P represented the majority of the refractory P in the north basin of Bur Oaks Lake (i.e., 65%), Carlson Lake (i.e., 51%), Holz Lake (i.e., 56%), East O’Leary Lake (i.e., 50%), and Quigley Lake (i.e., 38%). The concentration of the dominant biologically-refractory P form also tended to exceed the median concentration and usually fell above the 25% quartile when compared to other lakes in the region (***Figure 9***).

Total sediment Fe concentrations for lakes in the City of Eagan were generally higher than the median and fell within or above the upper 25% quartile (***Figure 11***). In contrast, Quigley Lake and East O’Leary Lake sediment concentrations were lower at 14.97 mg/g and 18.56 mg/g, respectively (Table 8). The Fe:P ratio was relatively high for all lake stations, ranging between 9:1 and 33:1. Ratios greater than 10:1 to 15:1 have been associated with regulation of P release from sediments under oxic (aerobic) conditions (Jensen et al. 1992). Higher binding efficiency for P at higher relative concentrations of Fe are suggested explanations for patterns reported by Jensen et al. Aerobic P release rates were generally moderate to low, coinciding with Fe:P ratio near 10:1 or greater, a pattern that could be attributed to the Jensen et al. model.

Detention Pond Sediment Characteristics

Sediment physical-textual characteristics in the upper 10-cm section of various detention ponds in the Eagan area are shown in ***Table 9***. Overall, sediment moisture contents were moderate to low, ranging between 55% and 90% (***Figure 12***). This pattern may have reflected some inclusion of more compact preimpoundment soils (i.e., original soils before the start of detention pond operation) in the 10-cm sediment section. Surface sediments appeared to be flocculent, suggestive of postimpoundment deposited material. However, the lower portion of the 10-cm section was sometimes denser with visible compaction as a result of detention pond construction. Pond DP-5, DP-27, and LP-30 exhibited the lowest moisture content (< 70%) while AP-30, DP-12, and LP-44 sediments had the highest moisture content.

Sediment wet and dry bulk density reflected the opposite pattern (***Table 9***). Lower moisture content generally coincides with lower porosity (i.e., interstitial space volume), resulting in greater bulk density characteristics (***Figure 12***). Those detention ponds exhibiting the highest moisture contents had the lowest bulk densities and vice versa. Wet bulk density ranged between 1.052 g/m^3 and 1.339 g/m^3 while dry bulk density ranged between 0.109 g/m^3 and 0.616 g/m^3 (***Table 9***). Organic matter content ranged between 6% and 22% (***Table 9***) and was greatest for sediments located in AP-30, DP-12, and LP-44 (***Figure 12***). In contrast, organic matter content was less than 10% for sediments located in AP-17, DP-5, DP-27, and LP-30.

Sediment total P concentrations were modest, ranging between 0.7 and 1.1 mg/g (***Table 10***). Detention Pond sediments collected from DP-12, LP-41, and LP-44 had the greatest total P concentration (***Figure 13***). Biologically-refractory P fractions (i.e., aluminum-bound P, calcium-bound P, refractory organic P; inert and subject to burial) generally represented greater than 50% of the total P for all detention pond sediments (***Table 11*** and ***Figure 13***). However, biologically-labile P (i.e., loosely-bound P, iron-bound P, labile organic P; reactive and subject to recycling), composed primarily of iron-bound P, represented between 33% and 49% of the total P (***Table 11*** and ***Figure 14***). Loosely-bound P concentrations were typically low for all pond sediments, ranging between 0.003 mg/g and 0.023 mg/g. Iron-bound P, which has been positively correlated with rates of P release from sediments under anaerobic conditions, were modest at 0.137 mg/g to 0.477 mg/g. LP-41 sediments exhibited the highest iron-bound P concentration at 0.477 mg/g, followed by LP-30 (0.270 mg/g to 0.311 mg/g), AP-17 (0.242 mg/g), DP-27 (0.216 mg/g), and LP-44 (0.209 mg/g). Iron-bound P, expressed as µg/g FW, were relatively high due to lower moisture contents and higher sediment bulk densities (***Table 11***).

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Table 1. Lake and station sediment sampling locations and numbers of sediment cores collected for determination of rates of phosphorus (P) flux under aerobic or anaerobic conditions and biologically-labile and refractory P fractions (see Table 2).

Lake	Station location	P Flux		P fractions
		Aerobic	Anaerobic	upper 10 cm
Bald	central basin	3	3	1
Bur Oaks	north basin	3	3	1
Bur Oaks	south basin	3	3	1
Carlson	central basin	3	3	1
Cliff	central basin	3	3	1
Fitz	central basin	3	3	1
Hay	central basin	3	3	1
Holz	central basin	3	3	1
LeMay	central basin	3	3	1
North	central basin	3	3	1
O'Leary	east basin	3	3	1
O'Leary	west basin	3	3	1
Quigley	central basin	3	3	1

Table 2. Sediment physical-textural characteristics, phosphorus species, and metals variable list.

Category	Variable
Physical-textural	Moisture content
	Wet and dry sediment bulk density
	organic matter content
Phosphorus species	Loosely-bound P
	Iron-bound P
	Labile organic P
	Aluminum-bound P
	Calcium-bound P
	Refractory organic P
	Total P
Metals	Iron
	Manganese

Table 3. Sediment sequential phosphorus (P) fractionation scheme, extractants used, and definitions of recycling potential.

Variable	Extractant	Recycling Potential
Loosely-bound P	1 M Ammonium Chloride	Biologically labile; Soluble P in interstitial water and adsorbed to $CaCO_3$; Recycled via direct diffusion, eH and pH reactions, and equilibrium processes
Iron-bound P	0.11 M Sodium Bicarbonate-dithionate	Biologically labile; P adsorbed to iron oxyhydroxides (Fe(OOH); Recycled via eH and pH reactions and equilibrium processes
Labile organic P	Persulfate digestion of the NaOH extraction	Biologically labile; Recycled via bacterial mineralization of organic P and mobilization of polyphosphates stored in cells
Aluminum-bound P	0.1 N Sodium Hydroxide	Biologically refractory; Al-P minerals with a low solubility product
Calcium-bound P	0.5 N Hydrochloric Acid	Biologically refractory; Represents Ca-P minerals such as apatite with a low solubility product
Refractory organic P	Determined by subtraction of other forms from total P	Biologically refractory; Organic P that isresistant to bacterial breakdown

Table 4. Mean (1 standard error in parentheses; n = 3) rates of phosphorus (P) release under aerobic and anaerobic conditions and mean P concentration (n = 3 to 9) in the overlying water column near the end of the incubation period for intact sediment cores collected in various lakes in the Eagan, Mn area.

Station	Diffusive P flux			
	Aerobic		Anaerobic	
	(mg/m^2 d)	(mg/L)	(mg/m^2 d)	(mg/L)
Bald	0.40 (0.14)	0.125 (0.009)	3.2 (1.0)	0.364 (0.048)
Bur Oaks North	0.34 (0.02)	0.062 (0.005)	5.7 (0.5)	0.503 (0.037)
Bur Oaks South	0.31 (0.10)	0.046 (0.002)	9.4 (1.1)	0.758 (0.045)
Carlson	0.56 (0.03)	0.127 (0.048)	4.7 (0.5)	0.567 (0.053)
Cliff	0.20 (0.01)	0.032 (0.004)	4.6 (1.0)	0.322 (0.028)
Fitz	0.13 (0.02)	0.036 (0.008)	3.7 (0.1)	0.276 (0.048)
Hay	0.15 (0.02)	0.023 (0.009)	1.2 (0.1)	0.057 (0.004)
Holz	0.17 (0.02)	0.019 (0.002)	2.3 (0.8)	0.249 (0.110)
LeMay	0.27 (0.10)	0.051 (0.011)	3.4 (0.5)	0.245 (0.038)
North	0.12 (0.03)	0.041 (0.052)	6.0 (0.1)[1]	0.723 (0.001)
O'Leary East	0.30 (0.13)	0.059 (0.011)	8.8 (0.9)	1.158 (0.139)
O'Leary West	0.13 (0.02)	0.018 (0.003)	2.4 (0.6)	0.291 (0.071)
Quigley	0.36 (0.07)	0.085 (0.015)	0.4 (0.3)	0.031 (0.018)

[1] n = 2; undetected rate for rep 2

Table 5. Textural characteristics in the upper sediment layer for sediment cores collected in various lakes in the Eagan, MN area.

Station	Moisture Content (%)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Organic Matter (%)
Bald	87.9	1.063	0.130	21.0
Bur Oaks N	92.6	1.037	0.078	23.2
Bur Oaks S	80.0	1.120	0.227	13.1
Carlson	79.9	1.123	0.230	12.1
Cliff	81.8	1.106	0.205	14.7
Fitz	85.5	1.084	0.159	13.8
Hay	81.2	1.111	0.212	14.2
Holz	70.9	1.198	0.355	8.3
LeMay	90.2	1.047	0.105	28.4
North	68.7	1.209	0.387	10.5
O'Leary E	94.9	1.021	0.053	35.0
O'Leary W	84.8	1.077	0.167	23.8
Quigley	94.7	1.022	0.054	35.4

Table 6. Concentrations of biologically labile and refractory P in the upper 10-cm sediment layer for various lakes in the Eagan, MN area. DW = dry mass, FW = fresh mass.

Station	Redox-sensitive and biologically labile P				Refractory P		
	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (ug/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)	Calcium-bound P (mg/g DW)	Refractory organic P (mg/g DW)
Bald	0.068	1.316	150	0.582	1.459	0.248	0.100
Bur Oaks N	0.045	1.897	113	0.324	1.010	0.177	2.193
Bur Oaks S	0.012	0.345	73	0.126	0.167	0.196	0.069
Carlson	0.004	0.321	56	0.139	0.230	0.169	0.422
Cliff	0.011	0.403	78	0.133	0.226	0.244	0.256
Fitz	0.033	0.711	108	0.189	0.291	0.241	0.100
Hay	0.004	0.744	127	0.265	0.731	0.195	0.175
Holz	0.011	0.372	102	0.086	0.259	0.075	0.423
LeMay	0.011	0.242	41	0.189	0.121	0.261	0.077
North	0.001	0.178	61	0.094	0.123	0.283	0.097
O'Leary E	0.004	0.153	8	0.662	0.260	0.090	0.353
O'Leary W	0.004	0.835	34	0.699	0.259	0.219	0.049
Quigley	0.017	0.12	4	0.466	0.169	0.217	0.239

Table 7. Concentrations of sediment total phosphorus (P), redox-sensitive P (Redox P; the sum of the loosely-bound and iron-bound P fraction), biologically-labile P (Bio-labile P; the sum of redox-P and labile organic P), and refractory P (the sum of the aluminum-bound, calcium-bound, and refractory organic P fractions) in the upper 10-cm sediment layer for various lakes in the Eagan, MN area. DW = dry mass.

Station	Total P	Redox P		Bio-labile P		Refractory P	
	(mg/g DW)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)
Bald	3.773	1.384	36.7%	1.966	52.1%	1.807	47.9%
Bur Oaks N	5.646	1.942	34.4%	2.266	40.1%	3.38	59.9%
Bur Oaks S	0.915	0.357	39.0%	0.483	52.8%	0.432	47.2%
Carlson	1.285	0.325	25.3%	0.464	36.1%	0.821	63.9%
Cliff	1.273	0.414	32.5%	0.547	43.0%	0.726	57.0%
Fitz	1.565	0.744	47.5%	0.933	59.6%	0.632	40.4%
Hay	2.114	0.748	35.4%	1.013	47.9%	1.101	52.1%
Holz	1.226	0.383	31.2%	0.469	38.3%	0.757	61.7%
LeMay	0.901	0.253	28.1%	0.442	49.1%	0.459	50.9%
North	0.776	0.179	23.1%	0.273	35.2%	0.503	64.8%
O'Leary E	1.522	0.157	10.3%	0.819	53.8%	0.703	46.2%
O'Leary W	1.965	0.839	42.7%	1.538	78.3%	0.527	26.8%
Quigley	1.228	0.137	11.2%	0.603	49.1%	0.625	50.9%

Table 8. Concentrations of sediment total iron (Fe), total Mn, and the Fe:P ratio in the upper 10-cm sediment layer for various lakes in the Eagan, MN area. DW = dry mass.

Station	Total Fe (mg/g DW)	Total Mn (mg/g DW)	Fe:P
Bald	34.86	0.66	9.2
Bur Oaks N	50.87	2.29	9.0
Bur Oaks S	23.30	0.47	25.5
Carlson	33.17	0.50	25.8
Cliff	36.68	0.36	28.8
Fitz	31.20	0.43	19.9
Hay	44.39	1.44	21.0
Holz	32.59	0.62	26.6
LeMay	25.72	0.30	28.5
North	25.33	0.59	32.6
O'Leary E	18.56	0.30	12.2
O'Leary W	28.21	0.65	14.4
Quigley	14.97	0.27	12.2

Table 9. Textural characteristics in the upper 10-cm sediment layer for cores collected in various detention ponds in the Eagan, MN area.

Station	Moisture Content (%)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Organic Matter (%)
AP-17	73.6	1.174	0.314	8.6
AP-30	86.3	1.075	0.149	17.4
DP-5	55.2	1.339	0.616	8.1
DP-12	89.7	1.052	0.109	21.9
DP-27	67.6	1.229	0.405	6.8
LP-30-1	64.5	1.255	0.454	7.0
LP-30-2	61.7	1.283	0.501	6.4
LP-41	71.8	1.183	0.340	10.8
LP-44	84.8	1.085	0.167	16.1

Table 10. Concentrations of sediment total phosphorus (P), redox-sensitive P (Redox P; the sum of the loosely-bound and iron-bound P fraction), biologically-labile P (Bio-labile P; the sum of redox-P and labile organic P), and refractory P (the sum of the aluminum-bound, calcium-bound, and refractory organic P fractions) in the upper 10-cm sediment layer for various detention ponds in the Eagan, MN area. DW = dry mass.

Station	Total P	Redox P		Bio-labile P		Refractory P	
	(mg/g DW)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)
AP-17	0.820	0.251	30.6%	0.340	41.5%	0.569	69.4%
AP-30	0.773	0.152	19.7%	0.282	36.5%	0.622	80.5%
DP-5	0.722	0.205	28.4%	0.238	33.0%	0.517	71.6%
DP-12	1.124	0.164	14.6%	0.405	36.0%	0.96	85.4%
DP-27	0.782	0.232	29.7%	0.296	37.9%	0.55	70.3%
LP-30-1	1.000	0.314	31.4%	0.395	39.5%	0.605	60.5%
LP-30-2	1.031	0.292	28.3%	0.395	38.3%	0.636	61.7%
LP-41	1.133	0.492	43.4%	0.552	48.7%	0.641	56.6%
LP-44	1.005	0.230	22.9%	0.394	39.2%	0.775	77.1%

Table 11. Concentrations of biologically labile and refractory P in the upper 10-cm sediment layer for various detention ponds in the Eagan, MN area. DW = dry mass, FW = fresh mass.

Station	Redox-sensitive and biologically labile P				Refractory P		
	Loosely-bound P	Iron-bound P	Iron-bound P	Labile organic P	Aluminum-bound P	Calcium-bound P	Refractory organic P
	(mg/g DW)	(mg/g DW)	(ug/g FW)	(mg/g DW)	(mg/g DW)	(mg/g DW)	(mg/g DW)
AP-17	0.009	0.242	64	0.089	0.208	0.261	0.100
AP-30	0.015	0.137	19	0.130	0.252	0.231	0.139
DP-5	0.008	0.197	88	0.033	0.115	0.198	0.204
DP-12	0.023	0.141	14	0.241	0.405	0.164	0.391
DP-27	0.016	0.216	70	0.064	0.169	0.255	0.126
LP-30-1	0.003	0.311	110	0.081	0.326	0.140	0.139
LP-30-2	0.022	0.270	103	0.103	0.338	0.159	0.139
LP-41	0.015	0.477	135	0.060	0.273	0.282	0.086
LP-44	0.021	0.209	32	0.164	0.320	0.263	0.192

Figure 1. Sediment core incubation systems.

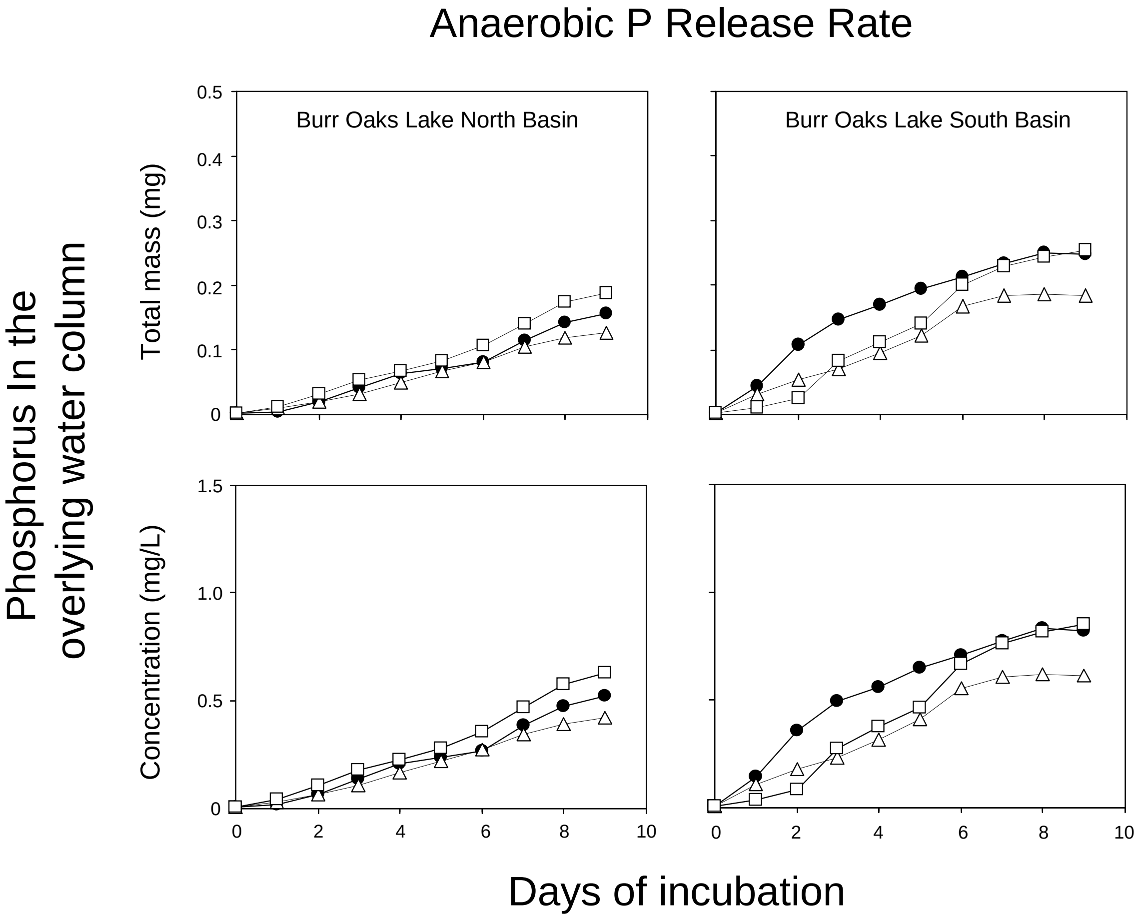


Figure 2. An example of changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column under anaerobic conditions versus time for sediment cores collected in the north basin of Bur Oaks Lake, MN.

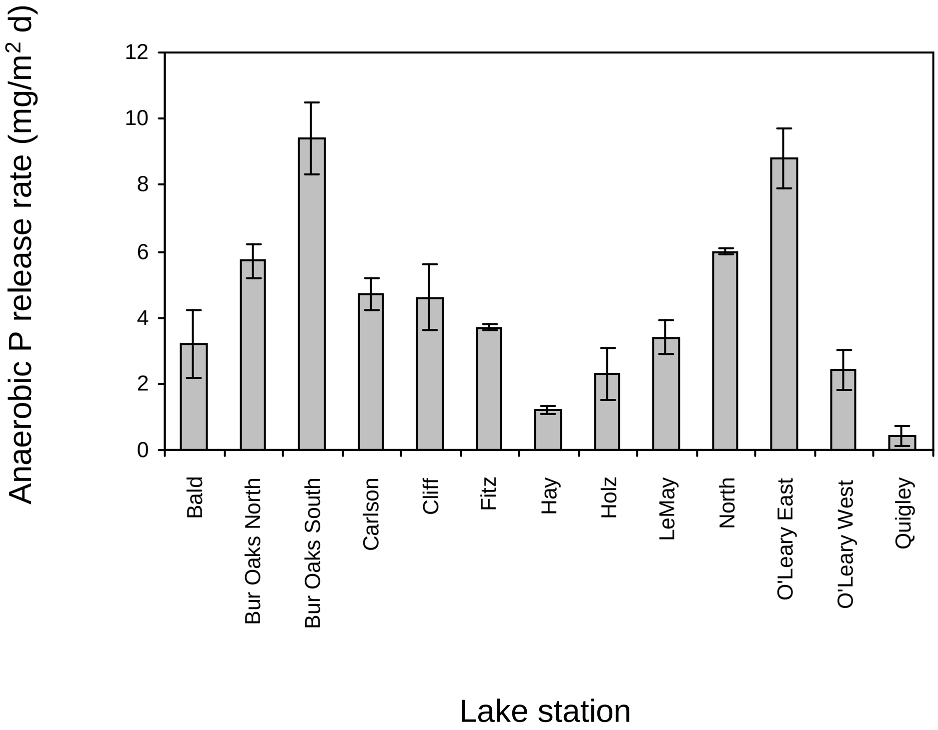


Figure 3. Mean (± 1 standard error, n = 3) rates of phosphorus (P) release from sediment under anaerobic conditions for various lake stations.

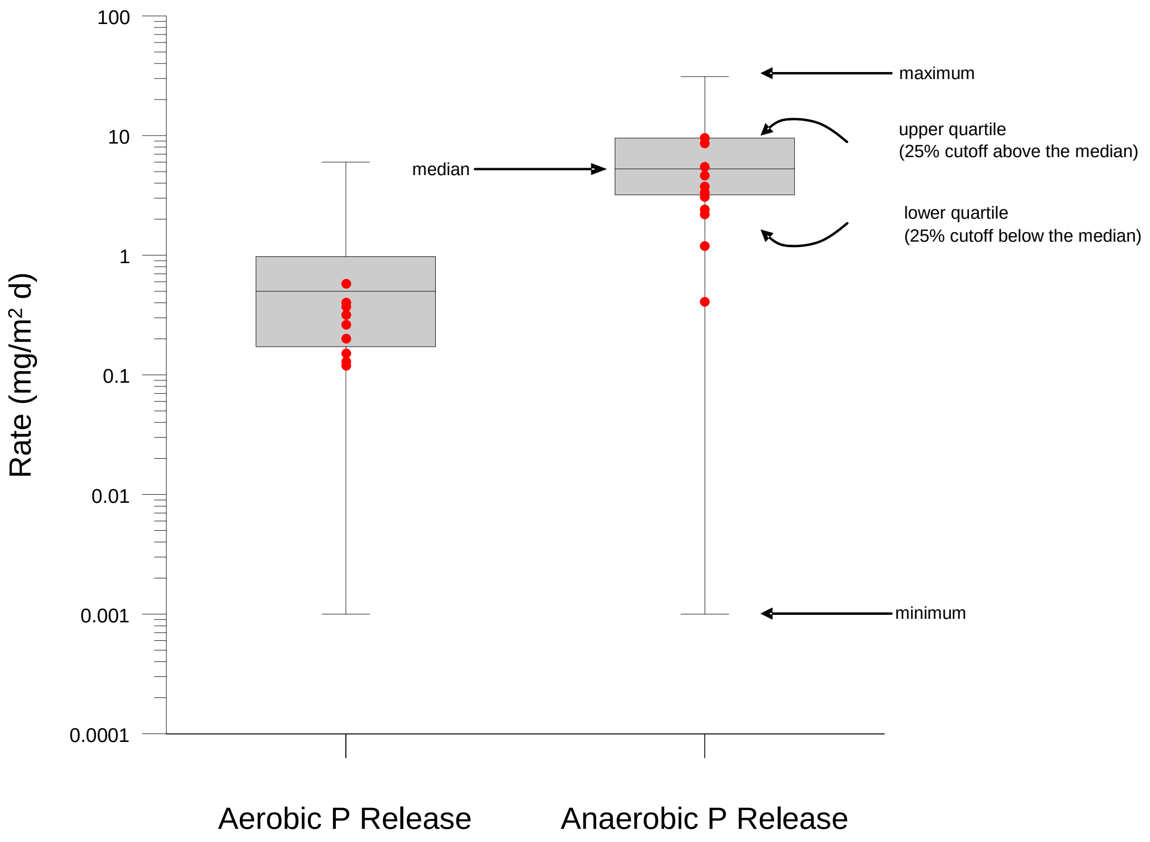


Figure 4. Box and whisker plot comparing the aerobic and anaerobic phosphorus (P) release rate measured for lakes in the Eagan, MN, area (red circles) with statistical ranges for other lakes in the region. Please note the logarithmic scale.

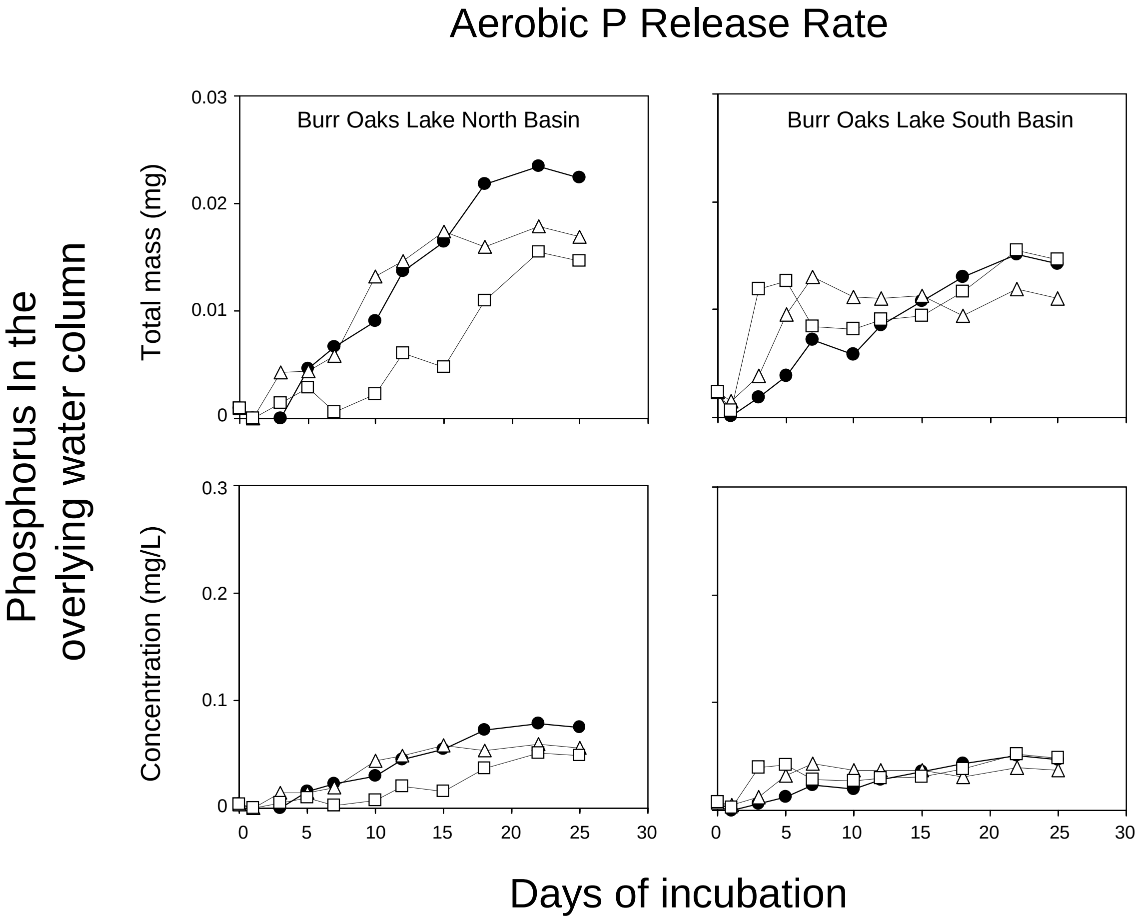


Figure 5. An example of changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column under aerobic conditions versus time for sediment cores collected in the north basin of Bur Oaks Lake, MN.

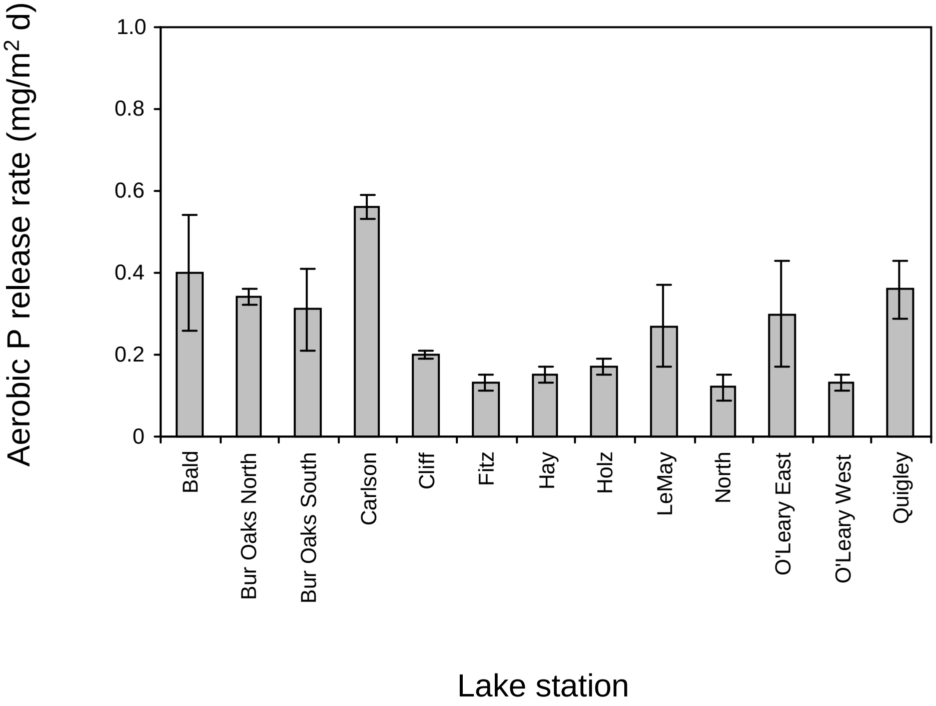


Figure 6. Mean (± 1 standard error, n = 3) rates of phosphorus (P) release from sediment under aerobic conditions for various lake stations.

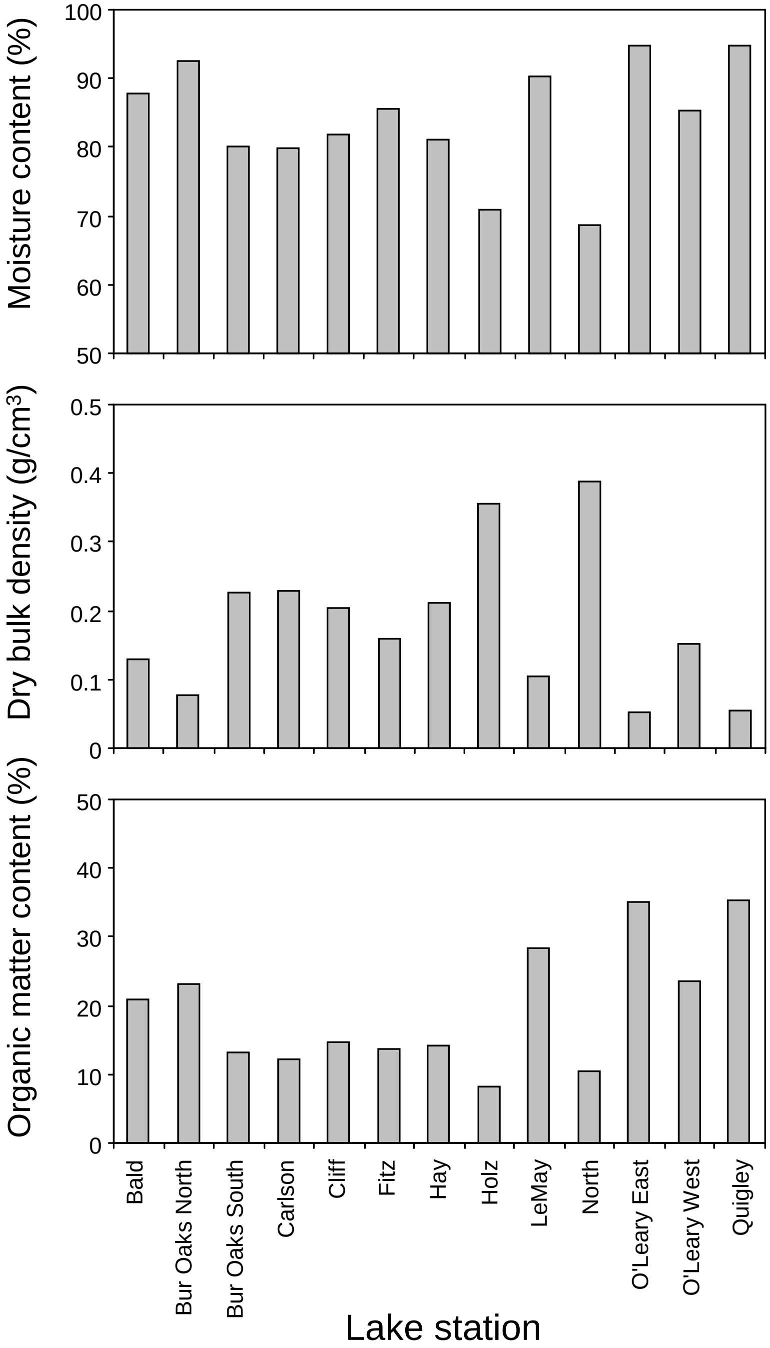


Figure 7. Sediment physical-textural characteristics for various lake stations in Eagan, MN.

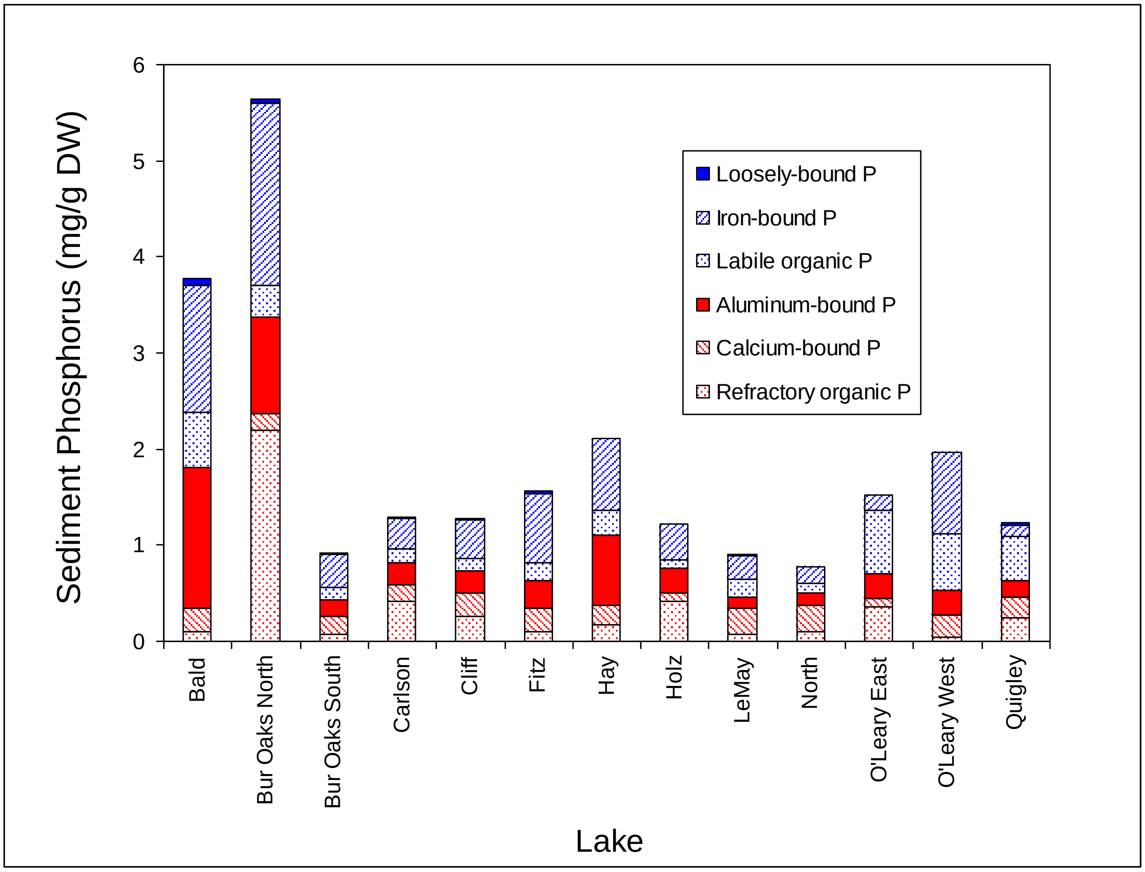


Figure 8. A comparison of sediment total phosphorus (P) composition for sediments collected from various lake stations in Eagan, MN. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial).

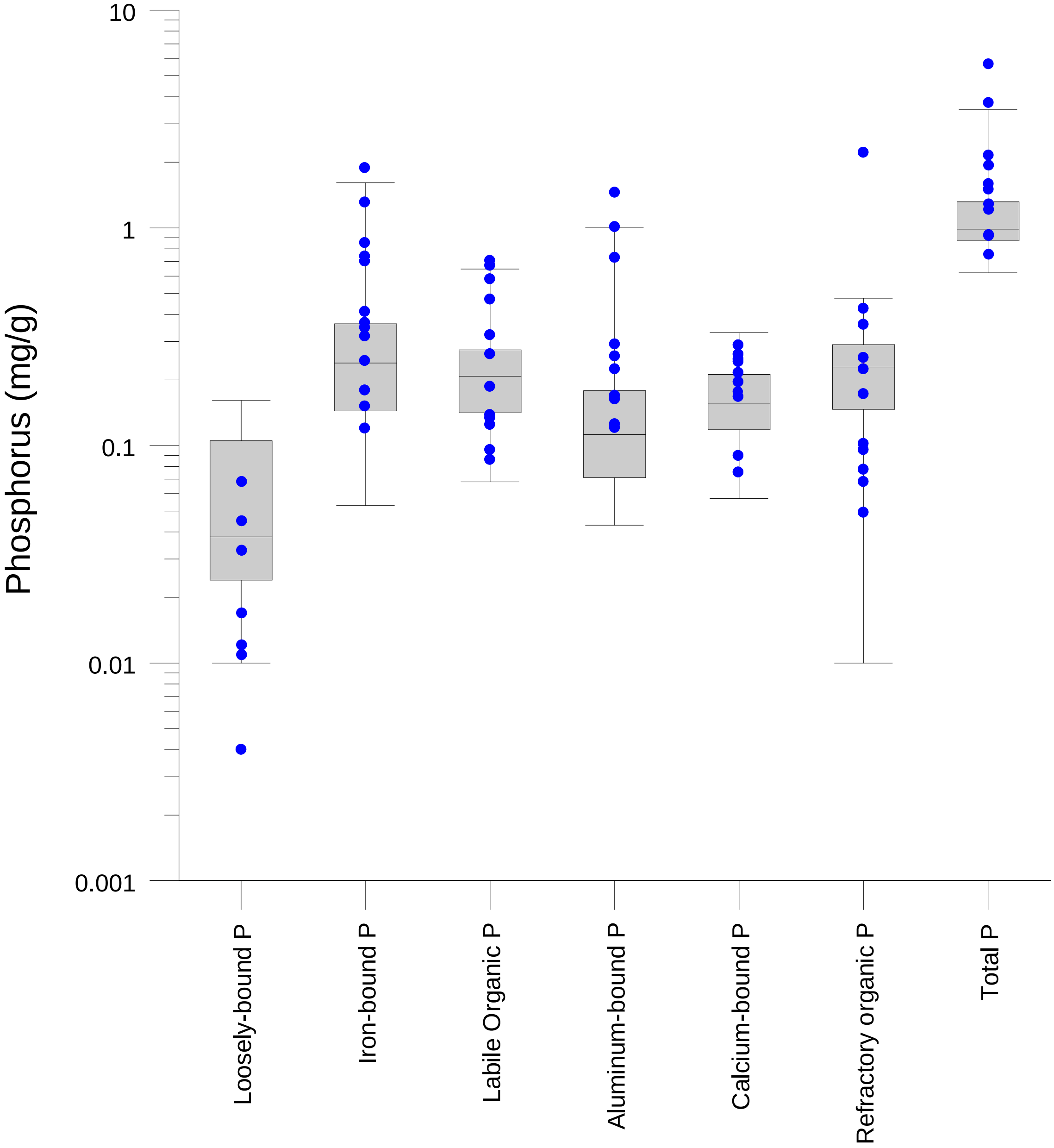


Figure 9. Box and whisker plots comparing various sediment phosphorus (P) fractions measured for lake stations in Eagan, Mn (blue circles) with statistical ranges for other lakes in the region. Loosely-bound, iron-bound, and labile organic P are biologically-labile (i.e., subject to recycling) and aluminum-bound, calcium-bound, and refractory organic P are more are more inert to transformation (i.e., subject to burial). Please note the logarithmic scale.

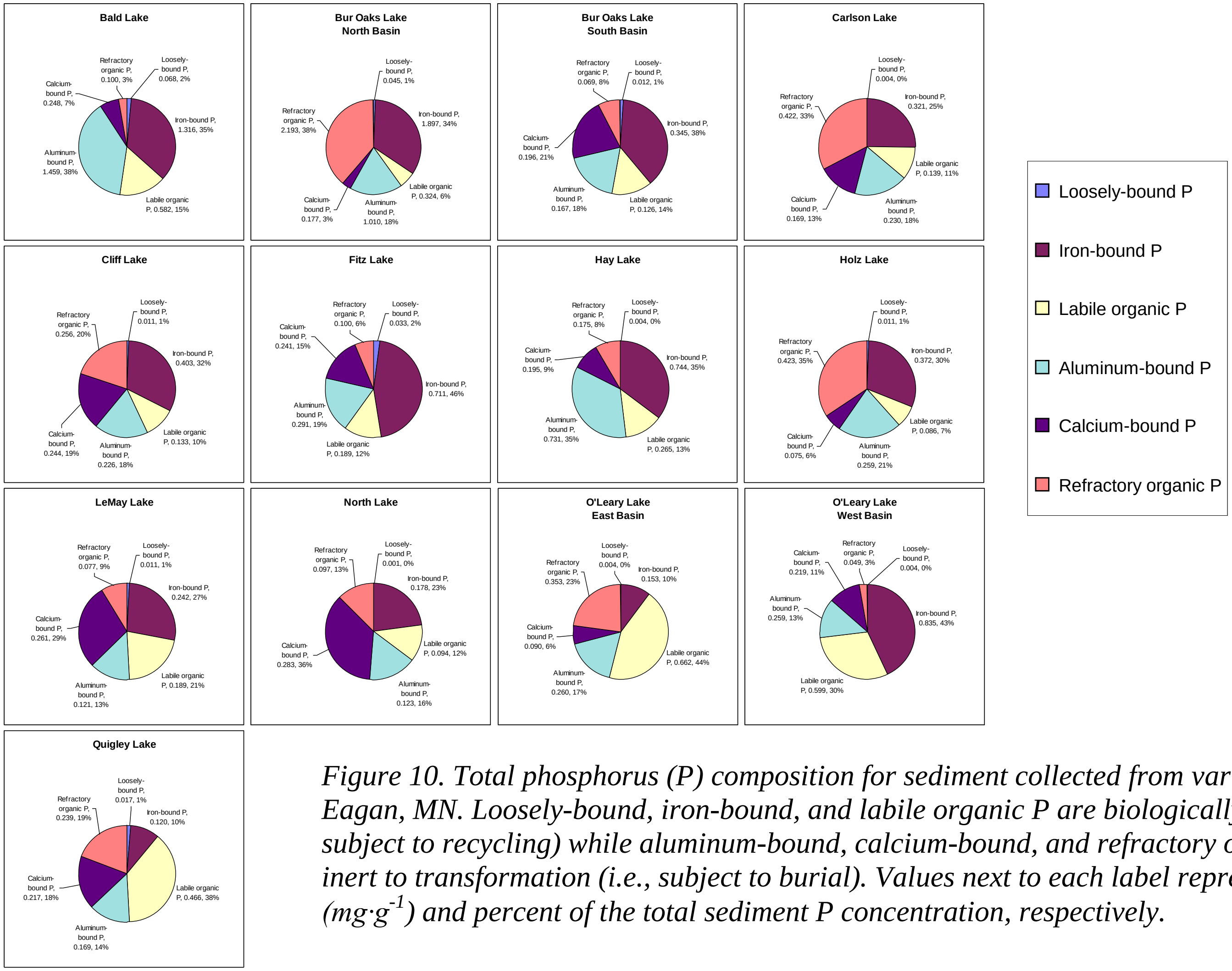


Figure 10. Total phosphorus (P) composition for sediment collected from various lake stations in Eagan, MN. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial). Values next to each label represent concentration ($mg \cdot g^{-1}$) *and percent of the total sediment P concentration, respectively.*

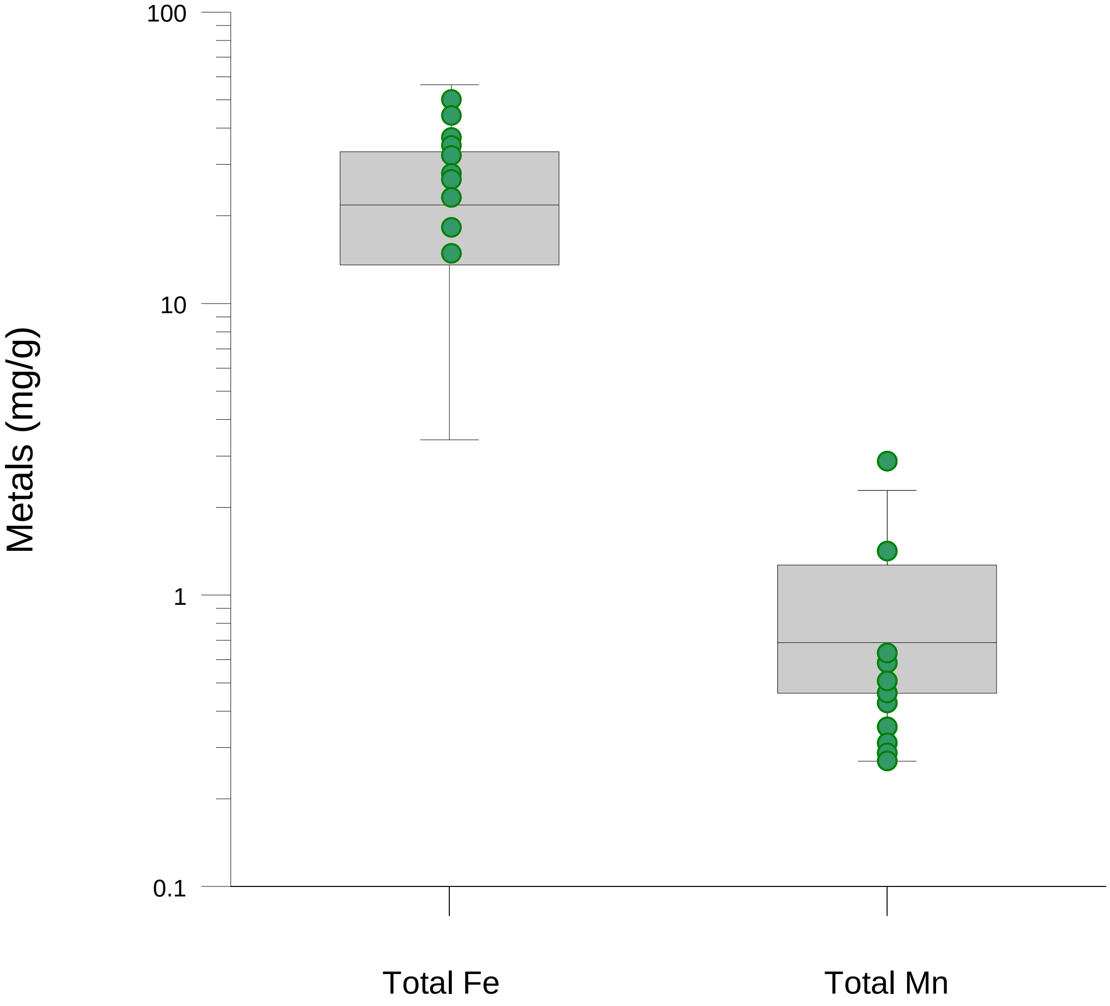


Figure 11. Box and whisker plots comparing various metal concentrations measured for lakes in the City of Eagan, MN (green circles), with statistical ranges for other lakes in the region. Please note the logarithmic scale.

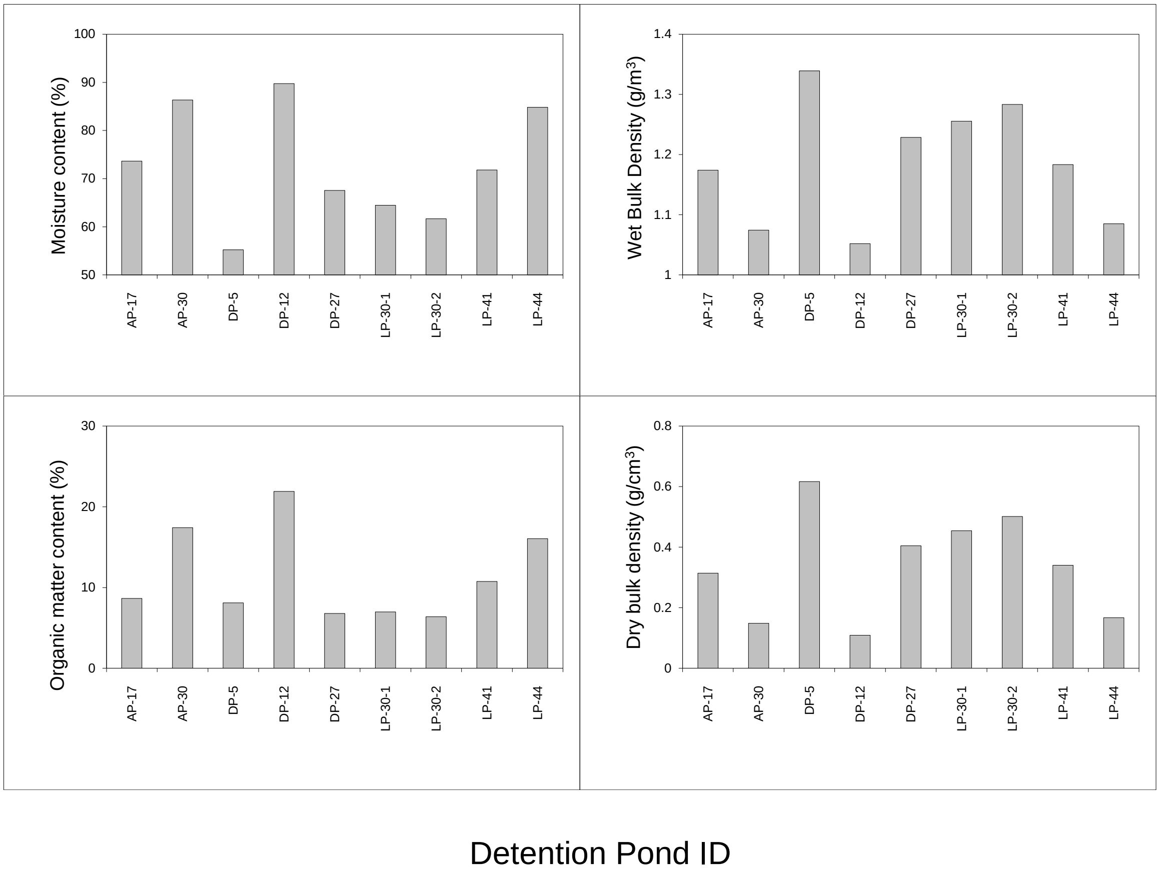


Figure 12. Sediment physical-textural characteristics for various detention ponds in Eagan, MN.

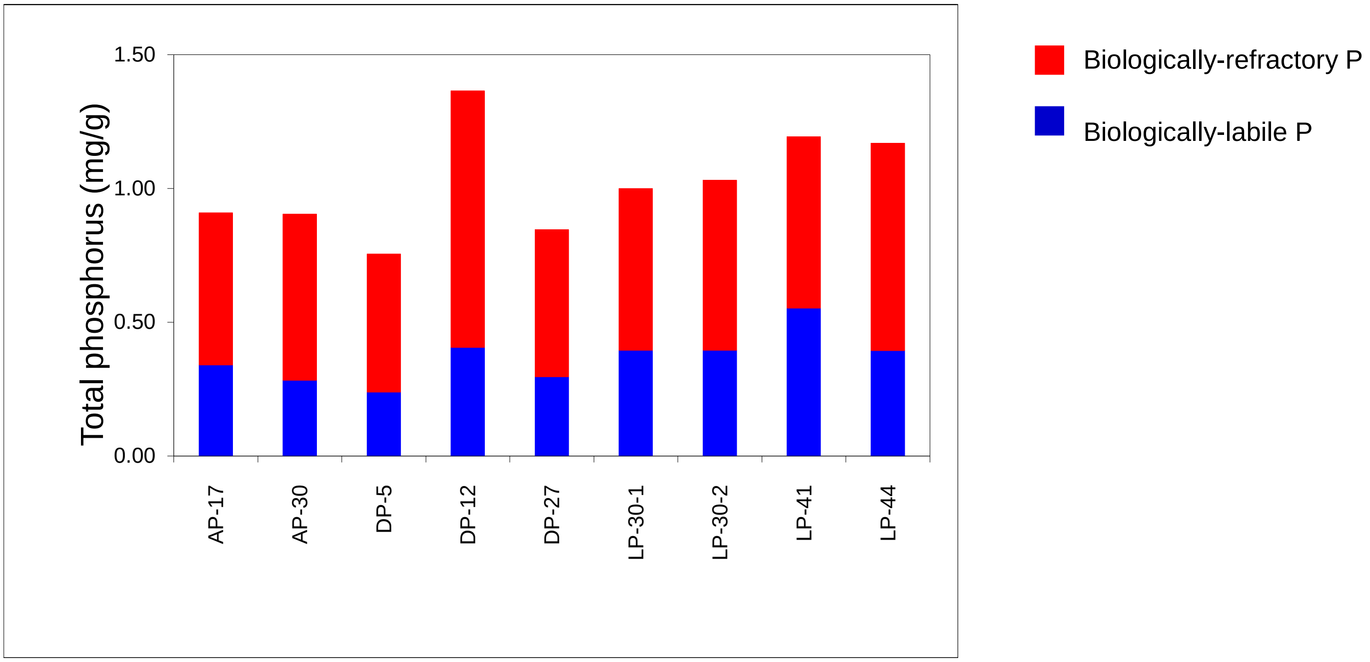


Figure 13. Total phosphorus (P) composition for sediments collected from various detention ponds in Eagan, MN. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., biologically-labile P; subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., biologically-refractory P; subject to burial).

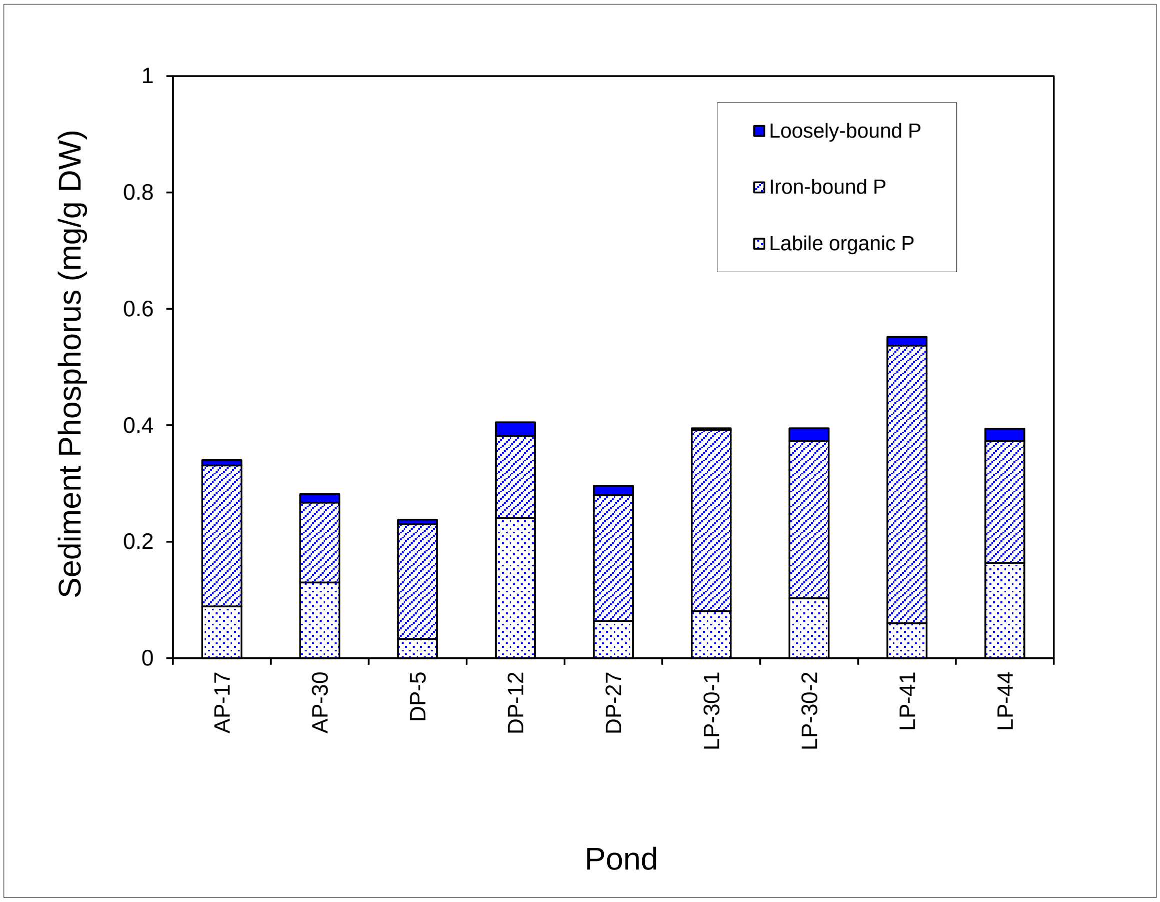
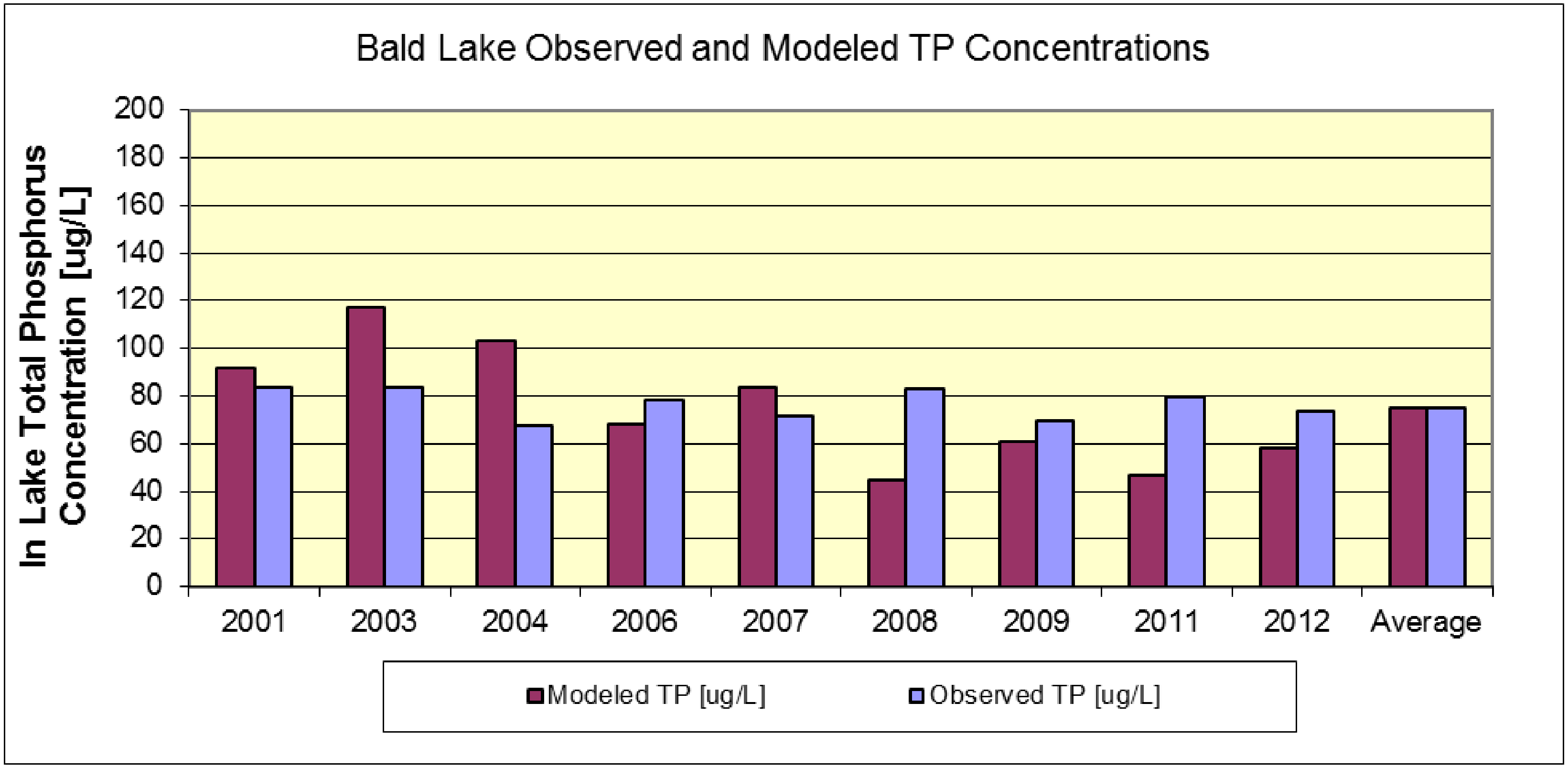


Figure 14. Composition of biologically-labile phosphorus (P) for sediments collected from various detention ponds in Eagan, MN.

Appendix H

Lake Response Model Results and Calibration


Bald Lake Observed and Modeled TP Concentrations
In Lake Total Phosphorus Concentration [ug/L]
200
180
160
140
120
100
80
60
40
20
0
2001
2003
2004
2006
2007
2008
2009
2011
2012
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Average Loading Summary for Bald Lake

Water Budgets					Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1	NorthWest	0.1	0.10	0.010	93	1.0	0.93
2	Southeast	0.2	0.07	0.013	129.4	1.0	1.66
3	Direct	0.1	0.06	0.007	146.9	1.0	1.01
4							
5							
	Summation	*0.4*	*0.23*	*0.03*			*3.61*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.04	0.77	0.77	0.00	26.80	1.0	1.07
		Dry-year total P deposition =			24.9		
		Average-year total P deposition =			26.8		
		Wet-year total P deposition =			29.0		
		(Barr Engineering 2004)					

Groundwater

Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.04						

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.04	61		Oxic	0.4	1.0	0.98
0.04	58.8		Anoxic	3.2	1.0	7.54
Summation						8.52
	Net Discharge [10^6 m^3/yr] =		**0.030**		**Net Load [kg/yr] =**	**13.2**

Average Lake Response Modeling for Bald Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.14	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	13.2	[kg/yr]
		Q (lake outflow) =	0.0298	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0735	[10^6 m^3]
		T = V/Q =	2.47	[yr]
		P_i = W/Q =	443	[µg/l]
Model Predicted In-Lake [TP]			**75.0**	**[ug/l]**
Observed In-Lake [TP]			**75.0**	**[ug/l]**

Reduction Loading Summary for Bald Lake

	Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	NorthWest	0.1	0.10	0.010	93	1.0	0.934
2	Southeast	0.2	0.07	0.013	129.4	1.0	1.66
3	Direct	0.1	0.06	0.007	146.9	1.0	1.01
4							
5							
	Summation	*0.4*	*0.23*	*0.03*			*3.61*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.04	0.77	0.77	0.0	26.80	1.0	1.07
		Dry-year total P deposition =			24.9		
		Average-year total P deposition =			26.8		
		Wet-year total P deposition =			29.0		
		(Barr Engineering 2004)					

Groundwater

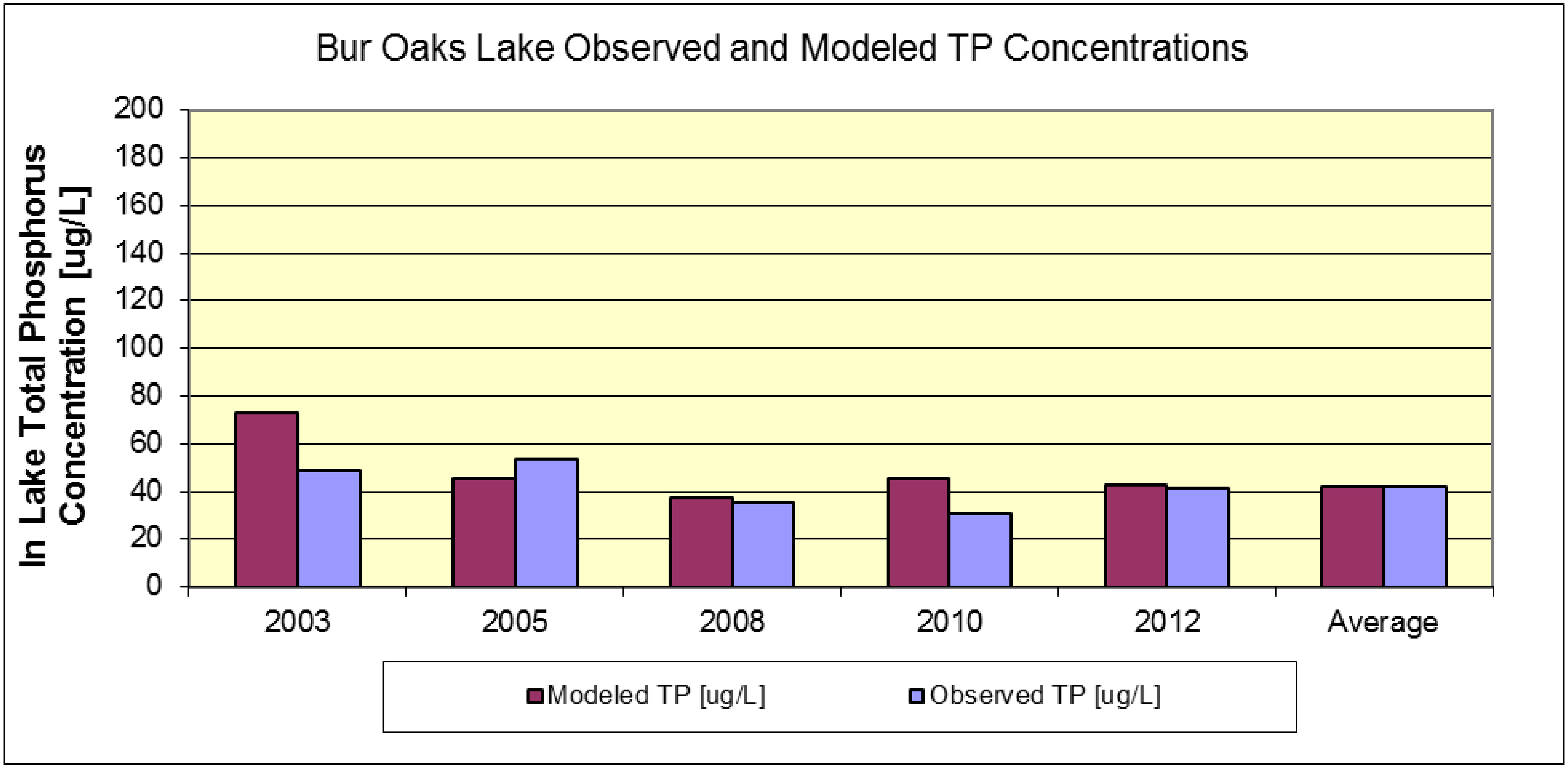
	Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
	0.04						

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
	0.04	61		Oxic	0.4	1.0	0.98
	0.04	58.8		Anoxic	1.5	1.0	3.58
	Summation						4.56
		Net Discharge [10^6 m^3/yr] =		**0.030**	**Net Load [kg/yr] =**		**9.24**

Reduction Lake Response Modeling for Bald Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.14	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	9.24	[kg/yr]
		Q (lake outflow) =	0.0298	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0735	[10^6 m^3]
		T = V/Q =	2.47	[yr]
		P_i = W/Q =	310	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**


Bur Oaks Lake Observed and Modeled TP Concentrations
In Lake Total Phosphorus Concentration [ug/L]
200
180
160
140
120
100
80
60
40
20
0
2003
2005
2008
2010
2012
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Average Loading Summary for Bur Oaks Pond (N Basin)

Inflow from Drainage Areas

	Water Budgets				**Phosphorus Loading**		
	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1	North	1.3	0.10	0.132	95	1.0	12.5
2	South	2.2	0.06	0.135	110.2	1.0	14.9
3	Direct	0.2	0.08	0.015	144.4	1.0	2.2
4							
5							
	Summation	*3.7*	*0.24*	*0.28*			*29.6*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.04	0.77	0.77	0.00	26.80	1.0	1.17
				Dry-year total P deposition =	24.9		
				Average-year total P deposition =	26.8		
				Wet-year total P deposition =	29.0		
				(Barr Engineering 2004)			

Groundwater

	Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
	0.04						

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
	0.04	0		Oxic	0.3	1.0	0.00
	0.04	13.7		Anoxic	5.7	1.0	3.40
	Summation						3.40
			Net Discharge [10^6 m^3/yr] =	**0.28**		**Net Load [kg/yr] =**	**34.2**

Average Lake Response Modeling for Bur Oaks Pond (N Basin)

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = P_i \Big/ \left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	4.24	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	34.2	[kg/yr]
		Q (lake outflow) =	0.283	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0317	[10^6 m^3]
		T = V/Q =	0.112	[yr]
		P_i = W/Q =	121	[µg/l]
Model Predicted In-Lake [TP]			**41.9**	**[ug/l]**
Observed In-Lake [TP]			**41.9**	**[ug/l]**

Reduction Loading Summary for Bur Oaks Pond (N Basin)

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1	North	1.3	0.10	0.132	94.7	1.0	12.51
2	South	2.2	0.06	0.135	110	1.0	14.89
3	Direct	0.2	0.08	0.015	144	1.0	2.23
4							
5							
	Summation	*3.7*	*0.24*	*0.28*			*29.6*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.04	0.77	0.77	0.00	26.80	1.0	1.17
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater

Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.04						0.00

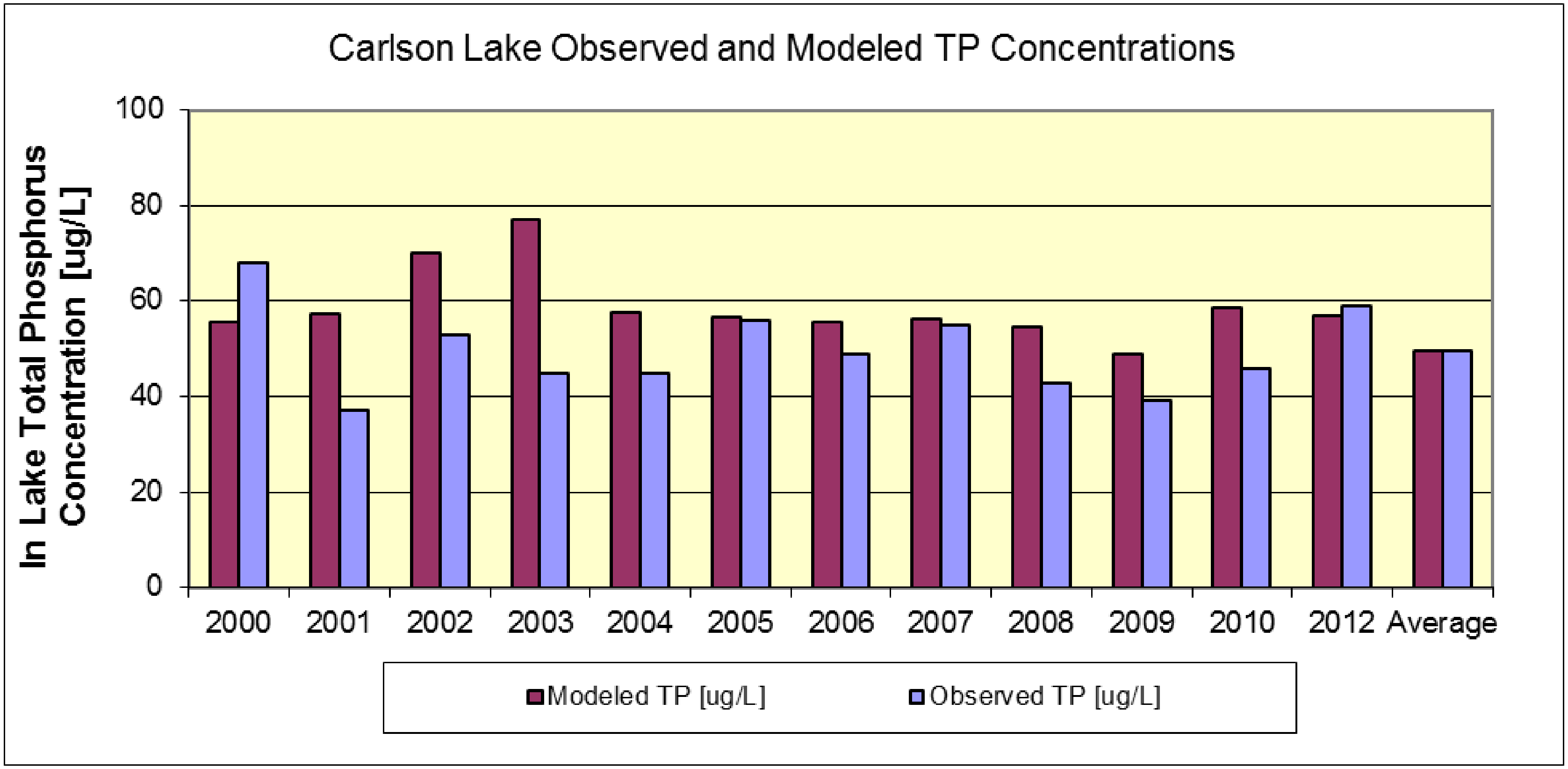
Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.04	0		Oxic	0.3	1.0	0.00
0.04	13.7		Anoxic	1.5	1.0	0.896
Summation						0.896

Net Discharge [10^6 m^3/yr] = 0.28 | **Net Load [kg/yr] = 31.7**

Reduction Lake Response Modeling for Bur Oaks Pond (N Basin)

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	4.24	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	31.7	[kg/yr]
		Q (lake outflow) =	0.283	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0317	[10^6 m^3]
		T = V/Q =	0.112	[yr]
		P_i = W/Q =	112	[µg/l]
Model Predicted In-Lake [TP]			**39.7**	**[ug/l]**
Observed In-Lake [TP]			**41.9**	**[ug/l]**



Carlson Lake Observed and Modeled TP Concentrations

Average Loading Summary for Carlson Lake

		Water Budgets			Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	South	1.1	0.09	0.097	45.1	1.0	4.38
2	North	0.4	0.10	0.045	93.1	1.0	4.18
3	Direct	0.5	0.09	0.051	231.8	1.0	11.8
4							
5							
	Summation	*2.1*	*0.28*	*0.19*			*20.4*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1	Quigley			0.03	74.8	1.0	2.08
2							
3							
	Summation			*0.03*	*74.8*		*2.08*

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.05	0.77	0.77	0.00	26.80	1.0	1.291
		Dry-year total P deposition =			24.9		
		Average-year total P deposition =			26.8		
		Wet-year total P deposition =			29.0		
		(Barr Engineering 2004)					

Groundwater

	Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
	0.05						

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
	0.05	35		Oxic	0.6	1.0	0.94
	0.05	55.8		Anoxic	4.7	0.4	5.05
	Summation						6.00
		Net Discharge [10^6 m^3/yr] =		**0.22**		**Net Load [kg/yr] =**	**29.8**

Average Lake Response Modeling for Carlson Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.54	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	29.8	[kg/yr]
		Q (lake outflow) =	0.221	[10^6 m^3/yr]
		V (modeled lake volume) =	0.124	[10^6 m^3]
		T = V/Q =	0.561	[yr]
		P_i = W/Q =	135	[µg/l]
Model Predicted In-Lake [TP]			**49.6**	**[ug/l]**
Observed In-Lake [TP]			**49.6**	**[ug/l]**

Reductions Loading Summary for Carlson Lake

Inflow from Drainage Areas

	Water Budgets				Phosphorus Loading		
	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	South	1.1	0.09	0.097	45	1.0	4.38
2	North	0.4	0.10	0.045	93.1	1.0	4.18
3	Direct	0.5	0.09	0.051	139.1	0.6	7.11
4							
5							
	Summation	*2.1*	*0.28*	*0.19*			*15.7*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1	Quigley			0.03	60.0	0.8	1.66
2							
3							
	Summation			*0.03*	*60.0*		*1.66*

Atmosphere

Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.05	0.77	0.77	0.00	26.80	1.0	1.291
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater

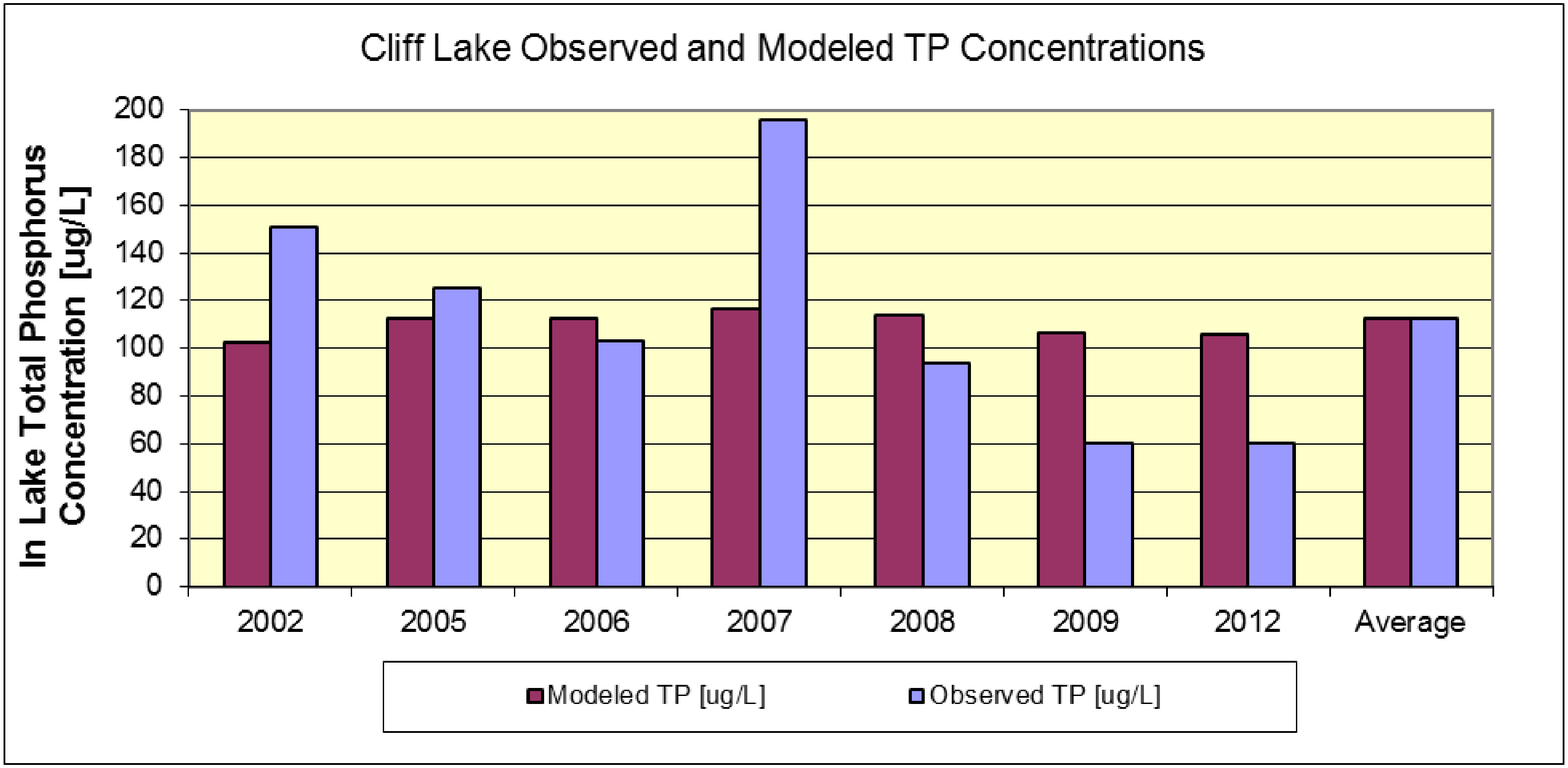
Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.05						0.00

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.05	35		Oxic	0.6	1.0	0.94
0.05	55.8		Anoxic	2.3	0.4	2.47
Summation						3.41
	Net Discharge [10^6 m^3/yr] =		**0.22**		**Net Load [kg/yr] =**	**22.0**

Reductions Lake Response Modeling for Carlson Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	1.54	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	22.0	[kg/yr]
		Q (lake outflow) =	0.221	[10^6 m^3/yr]
		V (modeled lake volume) =	0.124	[10^6 m^3]
		T = V/Q =	0.561	[yr]
		P_i = W/Q =	99.8	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**


Cliff Lake Observed and Modeled TP Concentrations
In Lake Total Phosphorus Concentration [ug/L]
200
180
160
140
120
100
80
60
40
20
0
2002
2005
2006
2007
2008
2009
2012
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Average Loading Summary for Cliff Lake

	Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	Direct	0.3	0.12	0.041	213	1.0	8.65
2	West	0.2	0.12	0.029	101.5	1.0	2.94
3	South	0.8	0.10	0.080	53.7	1.0	4.32
4							
5							
	Summation	*1.4*	*0.34*	*0.15*			*15.9*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.05	0.77	0.77	0.00	26.80	1.0	1.28
		Dry-year total P deposition =			24.9		
		Average-year total P deposition =			26.8		
		Wet-year total P deposition =			29.0		
		(Barr Engineering 2004)					

Groundwater

	Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
	0.05						

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
	0.05	122		Oxic	0.2	1.0	1.17
	0.05	59.5		Anoxic	4.6	1.0	13.1
	Summation						14.2
		Net Discharge [10^6 m^3/yr] =		**0.15**		**Net Load [kg/yr] =**	**31.4**

Average Lake Response Modeling for Cliff Lake

TOTAL IN-LAKE PHOSPHORUS CONCENTRATION

$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.937	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	31.4	[kg/yr]
		Q (lake outflow) =	0.150	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0401	[10^6 m^3]
		T = V/Q =	0.268	[yr]
		P_i = W/Q =	210	[µg/l]
Model Predicted In-Lake [TP]			**112.7**	**[ug/l]**
Observed In-Lake [TP]			**112.7**	**[ug/l]**

Reduction Loading Summary for Cliff Lake

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1	Direct	0.3	0.12	0.041	122	0.6	4.94
2	West	0.2	0.12	0.029	58	0.6	1.68
3	South	0.8	0.10	0.080	31	0.6	2.47
4							
5							
	Summation	*1.4*	*0.34*	*0.15*			*9.09*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.05	0.77	0.77	0.00	26.80	1.0	1.28
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater

Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.05						

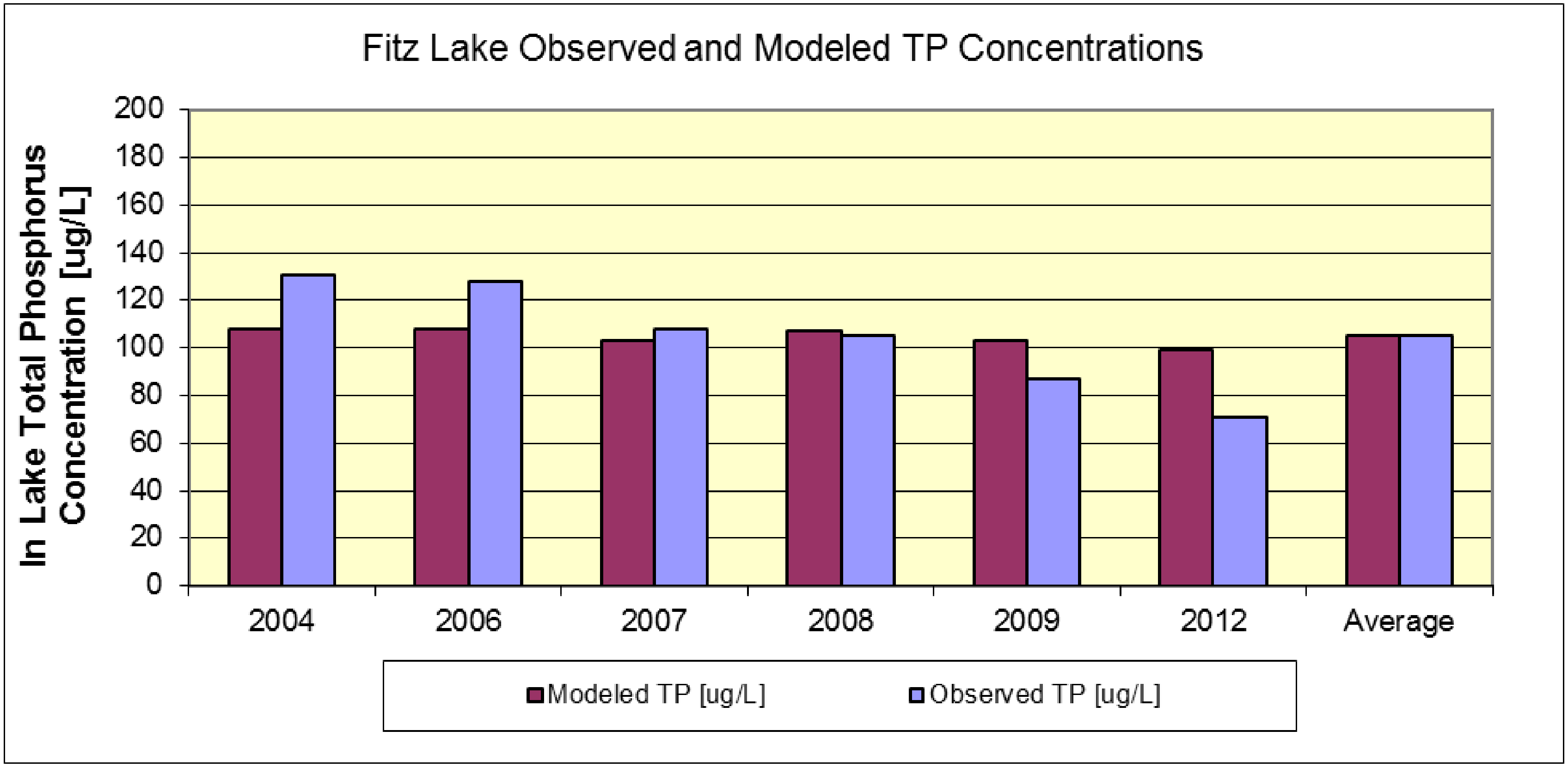
Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.05	122		Oxic	0.2	1.0	1.17
0.05	59.5		Anoxic	1.0	1.0	2.87
Summation						4.04
	Net Discharge [10^6 m^3/yr] =		**0.15**		**Net Load [kg/yr] =**	**14.4**

Reduction Lake Response Modeling for Cliff Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	0.937	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	14.4	[kg/yr]
		Q (lake outflow) =	0.150	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0401	[10^6 m^3]
		T = V/Q =	0.268	[yr]
		P_i = W/Q =	96.1	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$


Fitz Lake Observed and Modeled TP Concentrations
In Lake Total Phosphorus Concentration [ug/L]
200
180
160
140
120
100
80
60
40
20
0
2004
2006
2007
2008
2009
2012
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Average Loading Summary for Fitz lake

Water Budgets					Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	Entire Watershed	0.8	0.08	0.067	94	1.0	6.26
2							
3							
4							
5							
	Summation	*0.8*	*0.08*	*0.067*			*6.26*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.05	0.77	0.77	0.00	26.80	1.0	1.33
		Dry-year total P deposition =			24.9		
		Average-year total P deposition =			26.8		
		Wet-year total P deposition =			29.0		
		(Barr Engineering 2004)					

Groundwater

	Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
	0.05						

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
	0.05	122		Oxic	0.1	1.0	0.789
	0.05	61.6		Anoxic	3.7	1.0	11.4
	Summation						12.1
		Net Discharge [10^6 m^3/yr] =		**0.067**		**Net Load [kg/yr] =**	**19.7**

Average Lake Response Modeling for Fitz lake

TOTAL IN-LAKE PHOSPHORUS CONCENTRATION

$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$

as f(W,Q,V) from Canfield & Bachmann (1981)

Modeled Parameter	Equation	Parameters	Value	[Units]
		C_P =	0.731	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	19.7	[kg/yr]
		Q (lake outflow) =	0.0667	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0840	[10^6 m^3]
		T = V/Q =	1.26	[yr]
		P_i = W/Q =	296	[µg/l]
Model Predicted In-Lake [TP]			**105.0**	**[ug/l]**
Observed In-Lake [TP]			**105.0**	**[ug/l]**

Reduction Loading Summary for Fitz Lake

Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	Entire Watershed	0.8	0.08	0.067	61	0.7	4.07
2							
3							
4							
5							
	Summation	*0.8*	*0.08*	*0.067*			*4.07*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.05	0.77	0.77	0.00	26.80	1.0	1.33
		Dry-year total P deposition =			24.9		
		Average-year total P deposition =			26.8		
		Wet-year total P deposition =			29.0		
		(Barr Engineering 2004)					

Groundwater

	Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
	0.05						

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
	0.05	122		Oxic	0.1	1.0	0.79
	0.05	61.6		Anoxic	1.0	1.0	2.91
	Summation						3.70
		Net Discharge [10^6 m^3/yr] =		**0.067**	**Net Load [kg/yr] =**		**9.11**

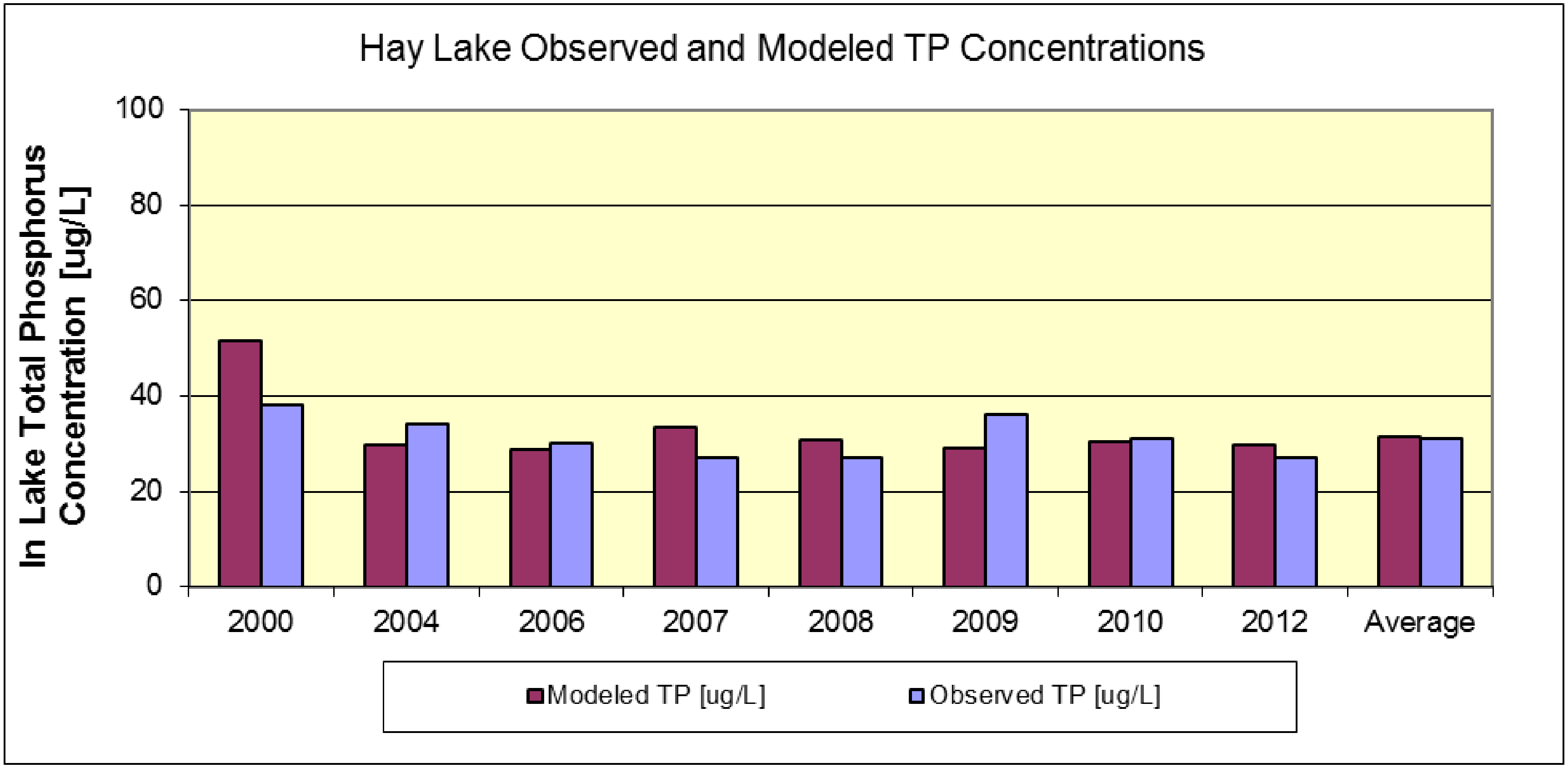
Reduction Lake Response Modeling for Fitz Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				

$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$

as f(W,Q,V) from Canfield & Bachmann (1981)

Parameters	Value	[Units]
C_P =	0.731	[--]
C_{CB} =	0.162	[--]
b =	0.458	[--]
W (total P load = inflow + atm.) =	9.11	[kg/yr]
Q (lake outflow) =	0.067	[10^6 m^3/yr]
V (modeled lake volume) =	0.084	[10^6 m^3]
T = V/Q =	1.26	[yr]
P_i = W/Q =	137	[µg/l]
Model Predicted In-Lake [TP]	**60.0**	**[ug/l]**
Observed In-Lake [TP]	**60.0**	**[ug/l]**


Hay Lake Observed and Modeled TP Concentrations
In Lake Total Phosphorus Concentration [ug/L]
100
80
60
40
20
0
2000
2004
2006
2007
2008
2009
2010
2012
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Average Loading Summary for Hay

		Water Budgets			Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1	Hay Watershed Ru	0.6	0.06	0.037	153	1.0	5.62
2							
3							
4							
5							
	Summation	*0.6*	*0.06*	*0.037*			*5.62*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1	LP-30			0.07	30.9	1.0	2.28
2	Holz			0.11	65.3	1.0	7.43
3							
	Summation			*0.19*	*48.1*		*9.72*

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.09	0.77	0.77	0.00	26.80	1.0	2.39
		Dry-year total P deposition =			24.9		
		Average-year total P deposition =			26.8		
		Wet-year total P deposition =			29.0		
		(Barr Engineering 2004)					

Groundwater

	Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
	0.09						

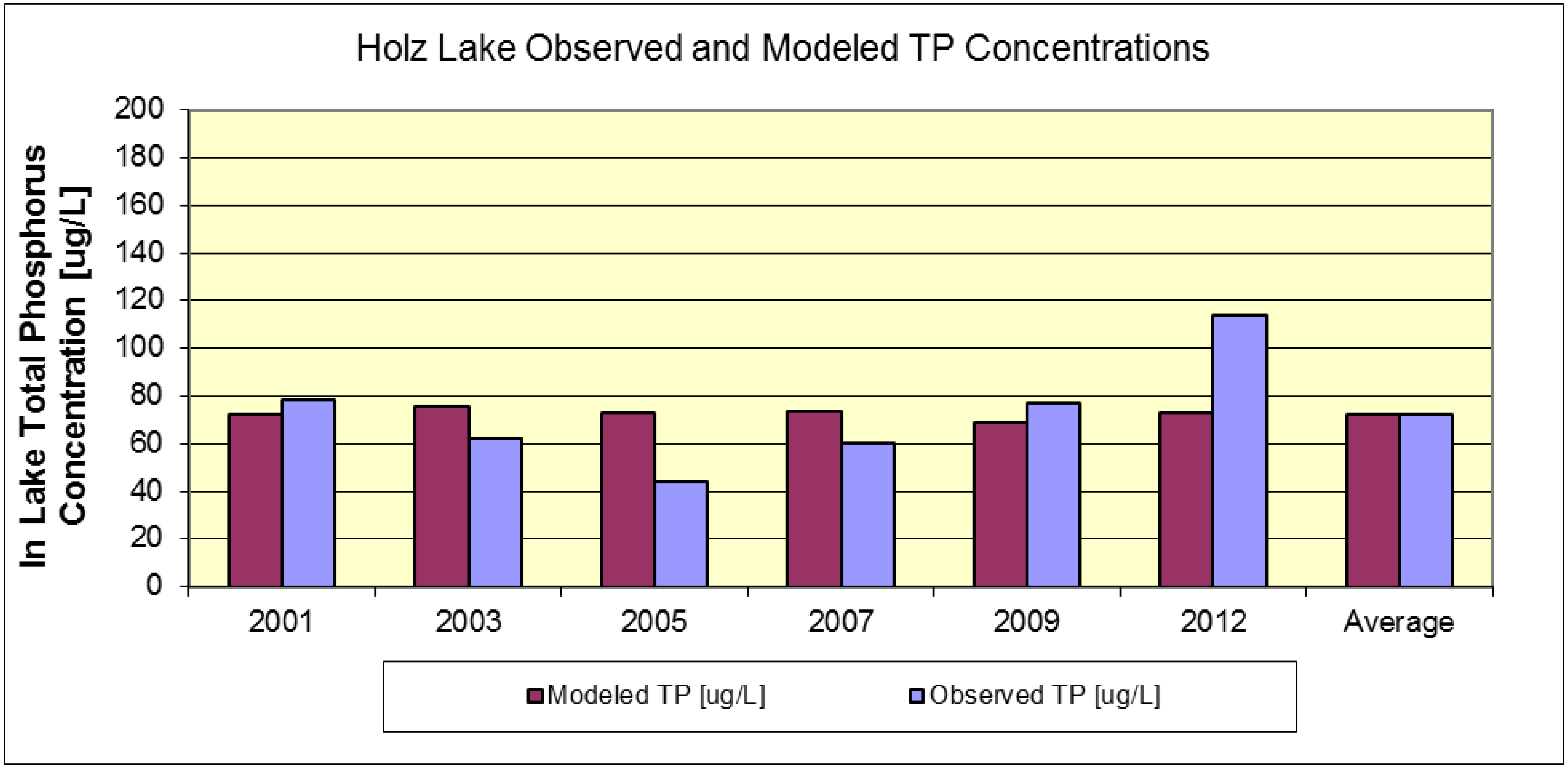
Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
	0.09			Oxic	0.2	1.0	
	0.09	31.4		Anoxic	1.2	1.0	3.35
	Summation						3.35
		Net Discharge [10^6 m^3/yr] =		**0.22**	**Net Load [kg/yr] =**		**21.1**

Average Lake Response Modeling for Hay

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	2.37	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	21.1	[kg/yr]
		Q (lake outflow) =	0.224	[10^6 m^3/yr]
		V (modeled lake volume) =	0.101	[10^6 m^3]
		T = V/Q =	0.452	[yr]
		P_i = W/Q =	94.0	[μg/l]
Model Predicted In-Lake [TP]			**31.3**	**[ug/l]**
Observed In-Lake [TP]			**31.3**	**[ug/l]**

$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$


Holz Lake Observed and Modeled TP Concentrations
In Lake Total Phosphorus Concentration [ug/L]
200
180
160
140
120
100
80
60
40
20
0
2001
2003
2005
2007
2009
2012
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Average Loading Summary for Holz

Water Budgets	Phosphorus Loading

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	Entire Watershed	0.4	0.08	0.036	129	1.0	4.66
2							
3							
4							
5							
	Summation	*0.4*	*0.08*	*0.036*			*4.66*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1	Fitz Lake			0.07	83.7	1.0	6
2							
3							
	Summation			*0.072*	*83.7*		*6.02*

Atmosphere

Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.04	0.77	0.77	0.00	26.80	1.0	1.08
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater

Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.04	61		Oxic	0.2	1.0	0.42
0.04	55.9		Anoxic	2.3	1.0	5.20
Summation						5.62
		Net Discharge [10^6 m^3/yr] =	**0.11**		**Net Load [kg/yr] =**	**17.4**

Average Lake Response Modeling for Holz

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
		as f(W,Q,V) from Canfield & Bachmann (1981)		
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	C_P =	0.905	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	17.4	[kg/yr]
		Q (lake outflow) =	0.108	[10^6 m^3/yr]
		V (modeled lake volume) =	0.073	[10^6 m^3]
		T = V/Q =	0.678	[yr]
		P_i = W/Q =	161	[µg/l]
Model Predicted In-Lake [TP]			**72.5**	**[ug/l]**
Observed In-Lake [TP]			**72.5**	**[ug/l]**

Average Loading Summary for Holz

Water Budgets					Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	Entire Watershed	0.4	0.08	0.036	129	1.0	4.66
2							
3							
4							
5							
	Summation	*0.4*	*0.08*	*0.036*			*4.66*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1	Fitz Lake			0.07	83.7	1.0	6
2							
3							
	Summation			*0.072*	*83.7*		*6.02*

Atmosphere

Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.04	0.77	0.77	0.00	26.80	1.0	1.08
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater

Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.04						

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.04	61		Oxic	0.2	1.0	0.42
0.04	55.9		Anoxic	2.3	1.0	5.20
Summation						5.62
		Net Discharge [10^6 m^3/yr] =	0.11		Net Load [kg/yr] =	17.4

Average Lake Response Modeling for Holz

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	0.905	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	17.4	[kg/yr]
		Q (lake outflow) =	0.108	[10^6 m^3/yr]
		V (modeled lake volume) =	0.073	[10^6 m^3]
		T = V/Q =	0.678	[yr]
		P_i = W/Q =	161	[µg/l]
Model Predicted In-Lake [TP]			**72.5**	**[ug/l]**
Observed In-Lake [TP]			**72.5**	**[ug/l]**

Reduction Loading Summary for Holz

	Water Budgets			Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area $[km^2]$	Runoff Depth [m/yr]	Discharge $[10^6\ m^3/yr]$	Phosphorus Concentration [ug/L]	Loading Calibration Factor $(CF)^1$ [--]	Load [kg/yr]
1	Entire Watershed	0.4	0.08	0.036	122	1.0	4.43
2							
3							
4							
5							
	Summation	*0.4*	*0.08*	*0.036*			*4.43*

Point Source Dischargers

	Name			Discharge $[10^6\ m^3/yr]$	Phosphorus Concentration [ug/L]	Loading Calibration Factor $(CF)^1$ [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge $[10^6\ m^3/yr]$	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge $[10^6\ m^3/yr]$	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1	Fitz Lake			0.07	60.0	0.7	4
2							
3							
	Summation			*0.07*	*60.0*		*4.31*

Atmosphere

Lake Area $[km^2]$	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow $[10^6\ m^3/yr]$	Aerial Loading Rate $[kg/km^2\text{-}yr]$	Calibration Factor [--]	Load [kg/yr]
0.04	0.77	0.77	0.00	26.80	1.0	1.08
		Dry-year total P deposition =		24.9		
		Average-year total P deposition =		26.8		
		Wet-year total P deposition =		29.0		
		(Barr Engineering 2004)				

Groundwater

Lake Area $[km^2]$	Groundwater Flux [m/yr]		Net Inflow $[10^6\ m^3/yr]$	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.04						

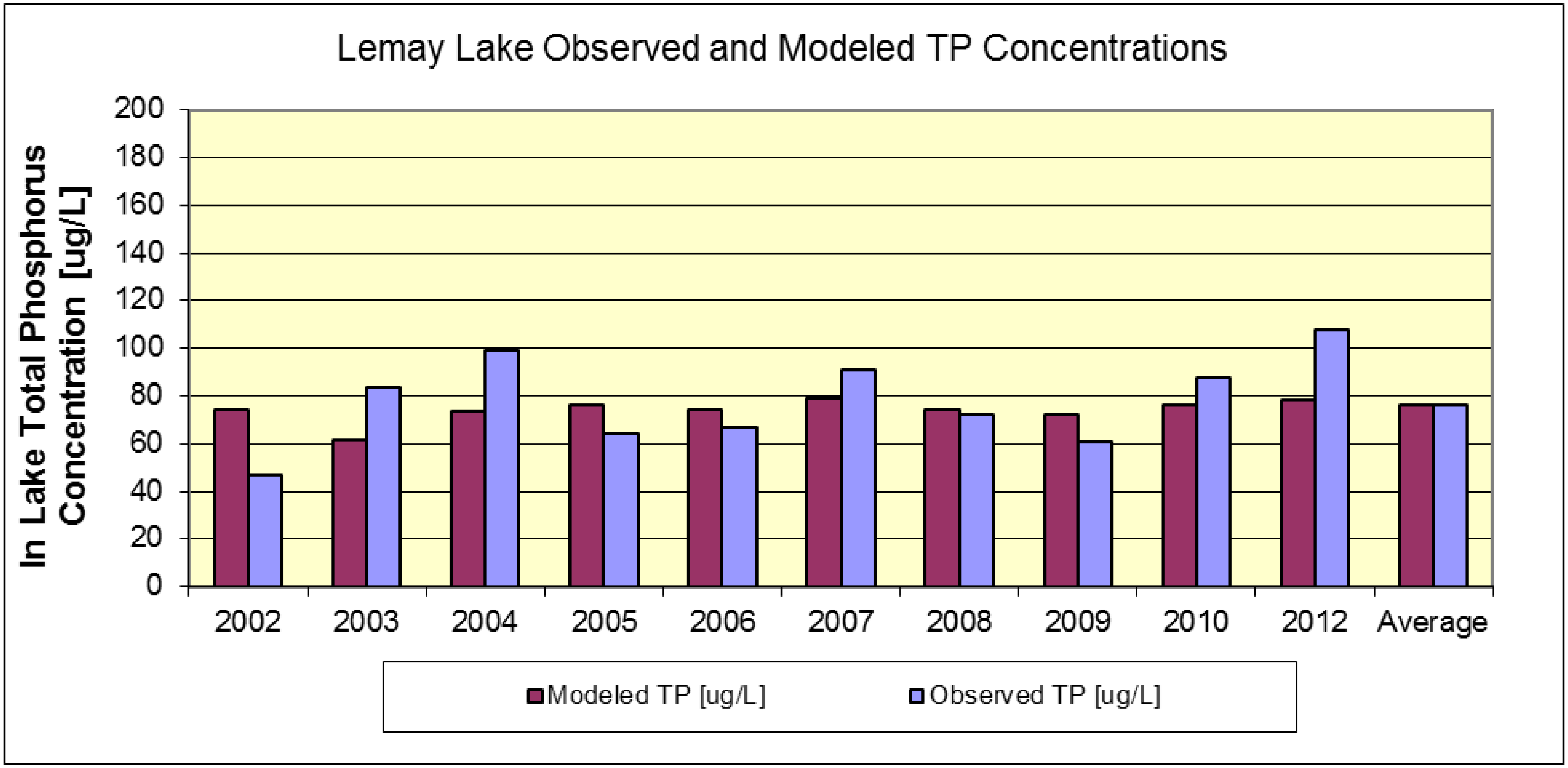
Internal

Lake Area $[km^2]$	Anoxic Factor [days]			Release Rate $[mg/m^2\text{-}day]$	Calibration Factor [--]	Load [kg/yr]
0.04	61		Oxic	0.2	1.0	0.42
0.04	55.9		Anoxic	1.5	1.0	3.28
Summation						3.70
	Net Discharge $[10^6\ m^3/yr]$ =		**0.11**		**Net Load [kg/yr] =**	**13.5**

Reduction Lake Response Modeling for Holz

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.905	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	13.5	[kg/yr]
		Q (lake outflow) =	0.108	$[10^6\ m^3/yr]$
		V (modeled lake volume) =	0.0733	$[10^6\ m^3]$
		T = V/Q =	0.678	[yr]
		P_i = W/Q =	125	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$


Lemay Lake Observed and Modeled TP Concentrations
In Lake Total Phosphorus Concentration [ug/L]
200
180
160
140
120
100
80
60
40
20
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2012
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Average Loading Summary for Lemay

Water Budgets	Phosphorus Loading

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	Northern	1.2	0.17	0.198	104	1.0	20.5
2	Southern	2.9	0.13	0.375	52	1.0	19.4
3	Direct	1.0	0.14	0.145	213	1.0	30.8
4							
5							
	Summation	*5.1*	*0.44*	*0.718*			*70.8*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.13	0.77	0.77	0.00	26.80	1.0	3.44
		Dry-year total P deposition =			24.9		
		Average-year total P deposition =			26.8		
		Wet-year total P deposition =			29.0		
		(Barr Engineering 2004)					

Groundwater

	Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
	0.13						

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
	0.13	61		Oxic	0.3	1.0	2.11
	0.13	15.8		Anoxic	3.4	1.0	6.91
	Summation						9.02
	Net Discharge [10^6 m^3/yr] =			**0.718**	**Net Load [kg/yr] =**		**83.2**

Average Lake Response Modeling for Lemay

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = P_i \bigg/ \left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.717	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	83.2	[kg/yr]
		Q (lake outflow) =	0.718	[10^6 m^3/yr]
		V (modeled lake volume) =	0.207	[10^6 m^3]
		T = V/Q =	0.288	[yr]
		P_i = W/Q =	116	[µg/l]
Model Predicted In-Lake [TP]			**76.2**	**[ug/l]**
Observed In-Lake [TP]			**76.2**	**[ug/l]**

Reductions Loading Summary for Lemay

Water Budgets	Phosphorus Loading

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1	Northern	1.2	0.17	0.198	81	0.8	16.0
2	Southern	2.9	0.13	0.375	40.3	0.8	15.1
3	Direct	1.0	0.14	0.145	165.6	0.8	24.0
4							
5							
	Summation	*5.1*	*0.44*	*0.718*			*55.0*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.13	0.77	0.77	0.00	26.80	1.0	3.44
		Dry-year total P deposition =			24.9		
		Average-year total P deposition =			26.8		
		Wet-year total P deposition =			29.0		
		(Barr Engineering 2004)					

Groundwater

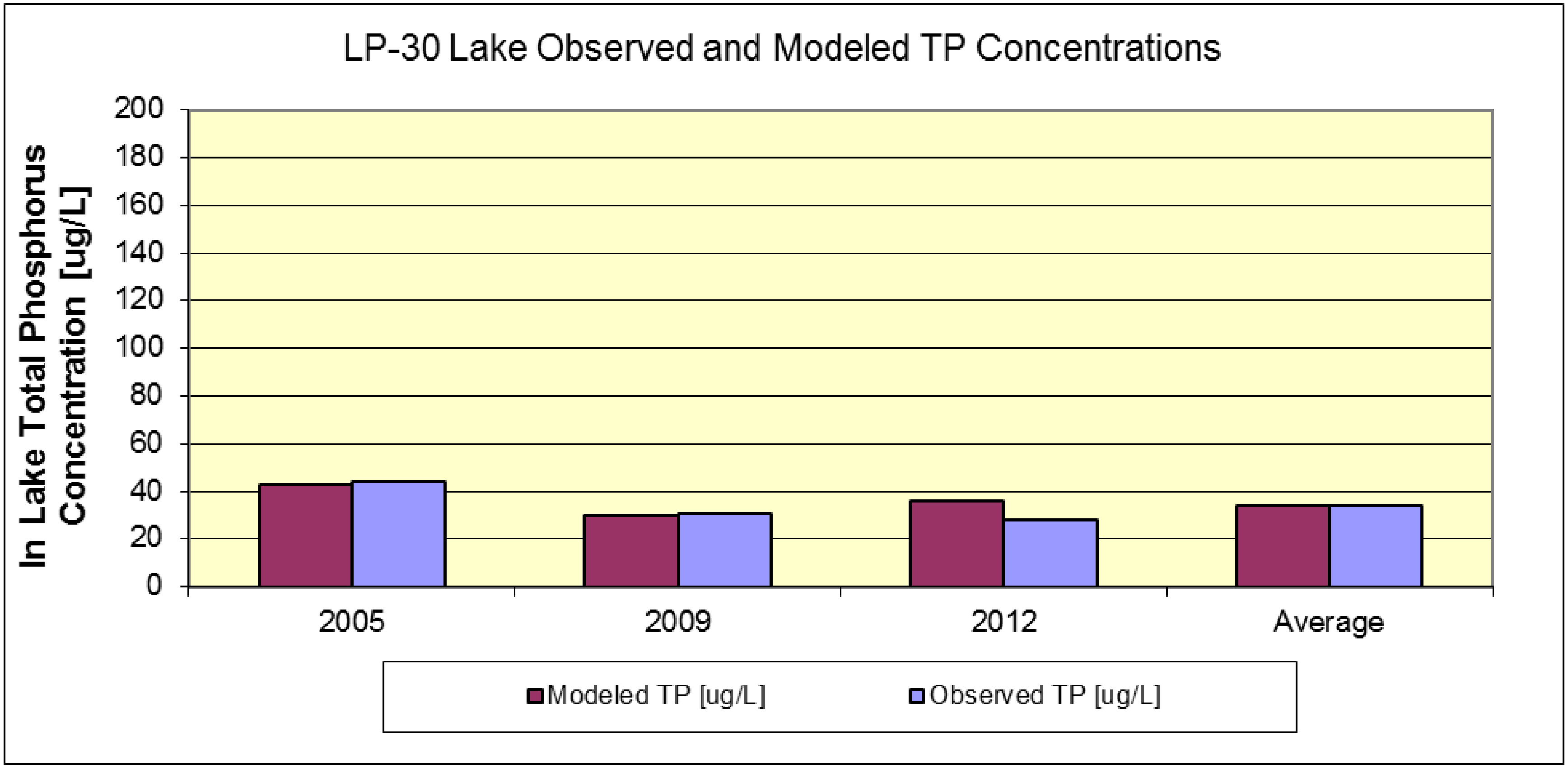
	Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
	0.13	0.0		0.00	0	1.0	0.00

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
	0.13	61		Oxic	0.3	1.0	2.11
	0.13	15.8		Anoxic	1.1	1.0	2.21
	Summation						4.33
		Net Discharge [10^6 m^3/yr] =		**0.718**	**Net Load [kg/yr] =**		**62.8**

Reductions Lake Response Modeling for Lemay

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.717	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	62.8	[kg/yr]
		Q (lake outflow) =	0.718	[10^6 m^3/yr]
		V (modeled lake volume) =	0.207	[10^6 m^3]
		T = V/Q =	0.288	[yr]
		P_i = W/Q =	87.5	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**


LP-30 Lake Observed and Modeled TP Concentrations
In Lake Total Phosphorus Concentration [ug/L]
200
180
160
140
120
100
80
60
40
20
0
2005
2009
2012
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Average Loading Summary for LP-30

	Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	Entire Watershed	1.4	0.05	0.074	83	1.0	6.17
2							
3							
4							
5							
	Summation	*1.4*	*0.05*	*0.074*			*6.17*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.04	0.77	0.77	0.00	26.80	1.0	1.02
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater

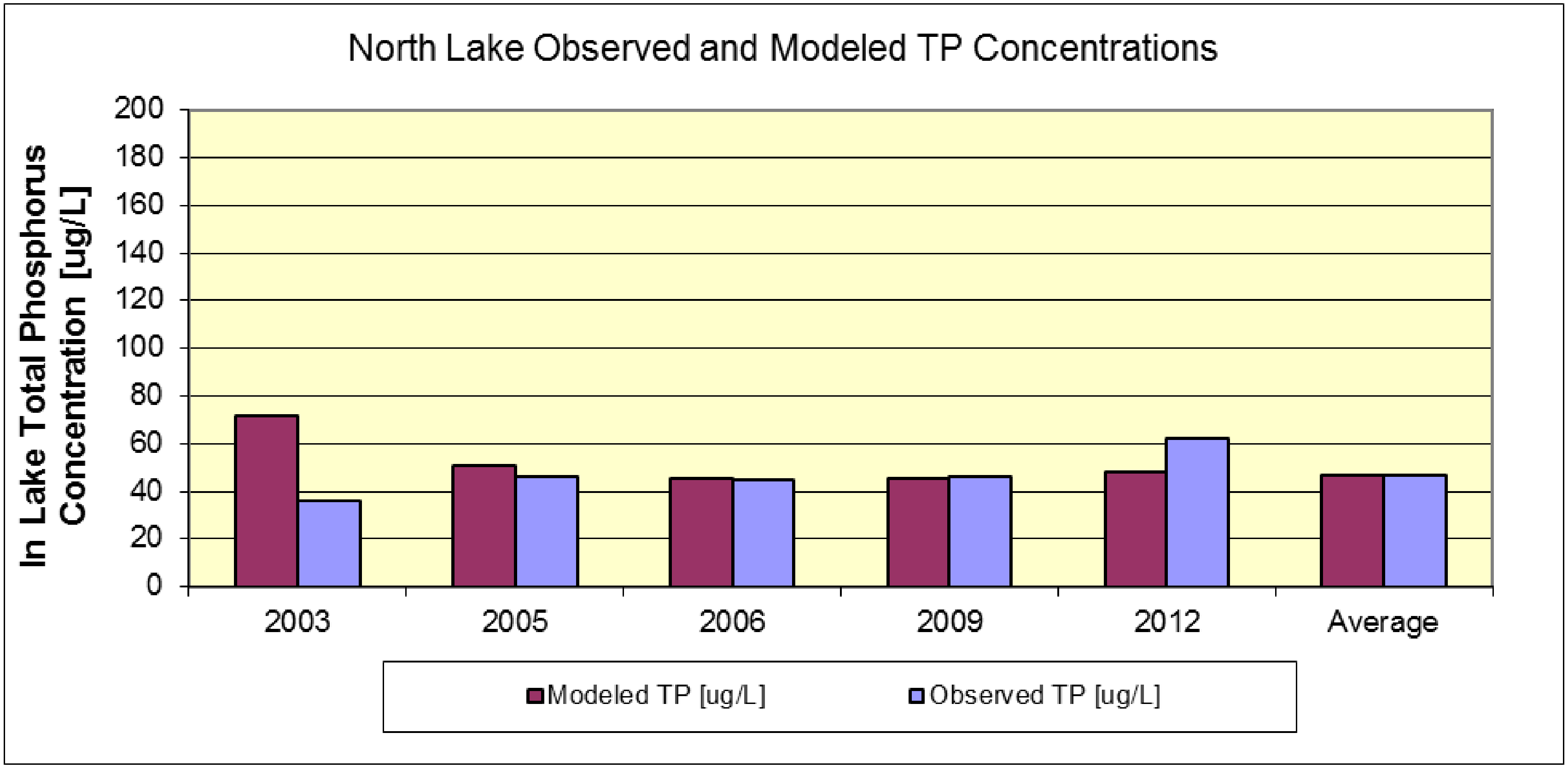
Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.04						

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.04			Oxic	0.2	1.0	
0.04	11.0		Anoxic	2.6	1.0	1.08
Summation						1.08
		Net Discharge [10^6 m^3/yr] =	**0.07**		**Net Load [kg/yr] =**	**8.27**

Average Lake Response Modeling for LP-30

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = P_i \bigg/ \left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.26	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	8.271	[kg/yr]
		Q (lake outflow) =	0.074	[10^6 m^3/yr]
		V (modeled lake volume) =	0.116	[10^6 m^3]
		T = V/Q =	1.57	[yr]
		P_i = W/Q =	112	[µg/l]
Model Predicted In-Lake [TP]			**34.3**	**[ug/l]**
Observed In-Lake [TP]			**34.3**	**[ug/l]**



North Lake Observed and Modeled TP Concentrations

Average Loading Summary for North Lake

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	South Watershed	0.2	0.23	0.050	173	1.0	8.74
2	North Watershed	0.4	0.24	0.096	112	1.0	10.8
3	Direct	0.9	0.18	0.169	198	1.0	33.6
4							
5							
	Summation	*1.5*	*0.7*	*0.316*			*53.1*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1	Bur Oaks			0.28	42.0	1.0	11.6
2							
3							
	Summation			*0.28*	*42.0*		*11.6*

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.06	0.77	0.77	0.00	26.80	1.0	1.74
				Dry-year total P deposition =	24.9		
				Average-year total P deposition =	26.8		
				Wet-year total P deposition =	29.0		
				(Barr Engineering 2004)			

Groundwater

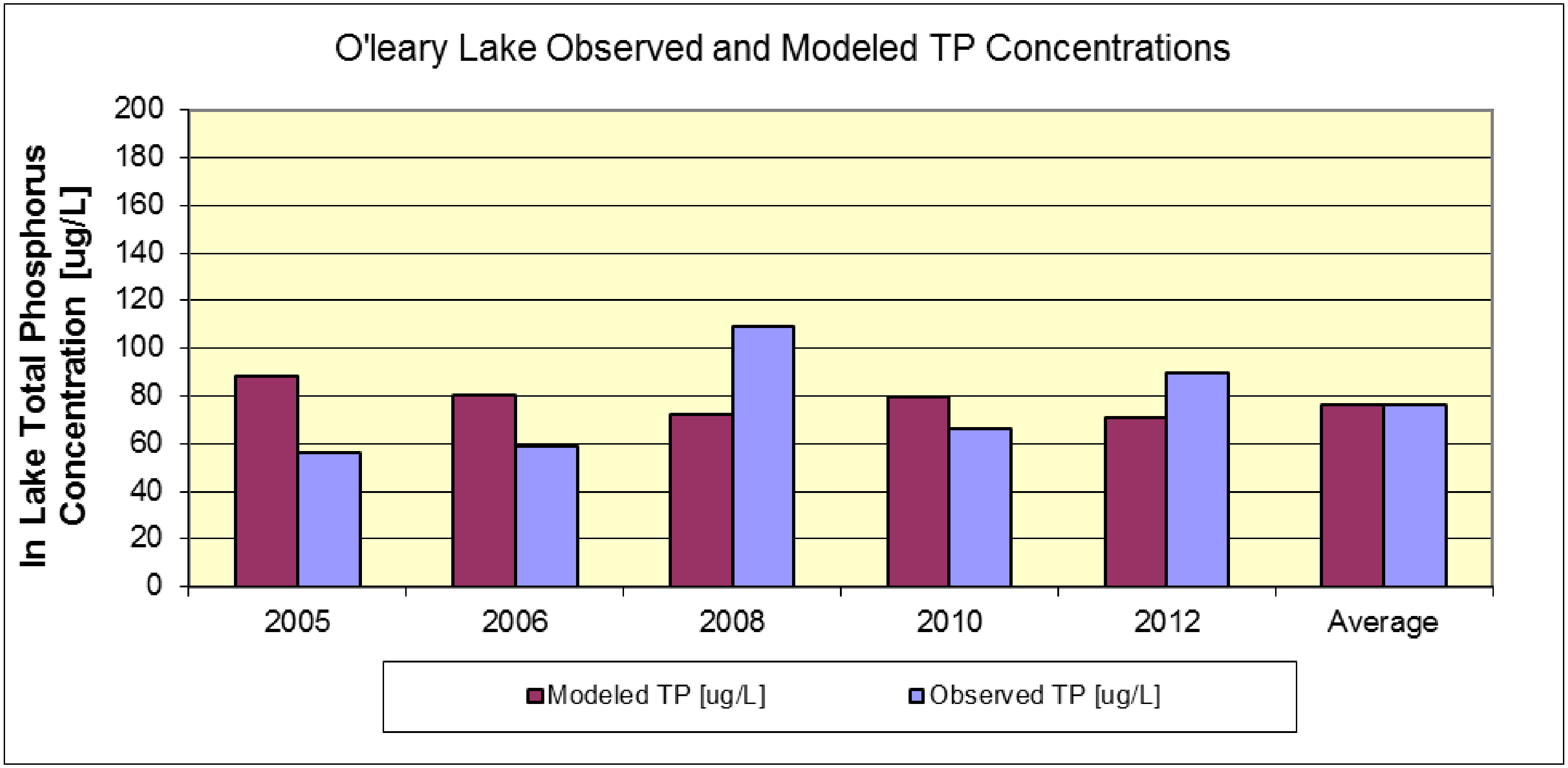
Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.06						

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.06			Oxic	0.1	1.0	
0.06	17.0		Anoxic	6.0	1.0	6.61
Summation						6.61
	Net Discharge [10^6 m^3/yr] =		**0.59**		**Net Load [kg/yr] =**	**73.0**

Average Lake Response Modeling for North Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	2.97	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	73.0	[kg/yr]
		Q (lake outflow) =	0.592	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0953	[10^6 m^3]
		T = V/Q =	0.161	[yr]
		P_i = W/Q =	123	[µg/l]
Model Predicted In-Lake [TP]			**47.0**	**[ug/l]**
Observed In-Lake [TP]			**47.0**	**[ug/l]**


O'leary Lake Observed and Modeled TP Concentrations
In Lake Total Phosphorus Concentration [ug/L]
200
180
160
140
120
100
80
60
40
20
0
2005
2006
2008
2010
2012
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Average Loading Summary for O'Leary West Basin

	Water Budgets				**Phosphorus Loading**		

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1	Oleary Watershed	0.2	0.11	0.022	137	1.0	3.03
2							
3							
4							
5							
	Summation	*0.2*	*0.11*	*0.022*			*3.03*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.04	0.77	0.77	0.00	26.80	1.0	1.01
				Dry-year total P deposition =	24.9		
				Average-year total P deposition =	26.8		
				Wet-year total P deposition =	29.0		
				(Barr Engineering 2004)			

Groundwater

	Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
	0.04						

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
	0.04	61		Oxic	0.1	1.0	0.30
	0.04	17.1		Anoxic	2.4	1.0	1.54
	Summation						1.84
		Net Discharge [10^6 m^3/yr] =		**0.022**	**Net Load [kg/yr] =**		**5.88**

Average Lake Response Modeling for O'Leary West Basin

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = P_i \Big/ \left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.964	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	5.88	[kg/yr]
		Q (lake outflow) =	0.0221	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0329	[10^6 m^3]
		T = V/Q =	1.49	[yr]
		P_i = W/Q =	266	[µg/l]
Model Predicted In-Lake [TP]			**76.0**	**[ug/l]**
Observed In-Lake [TP]			**76.0**	**[ug/l]**

eductions Loading Summary for O'Leary West Basin

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	Oleary Watershed	0.2	0.11	0.022	100	0.7	2.21
2							
3							
4							
5							
	Summation	*0.2*	*0.11*	*0.022*			*2.21*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.04	0.77	0.77	0.00	26.80	1.0	1.01
				Dry-year total P deposition =	24.9		
				Average-year total P deposition =	26.8		
				Wet-year total P deposition =	29.0		
				(Barr Engineering 2004)			

Groundwater

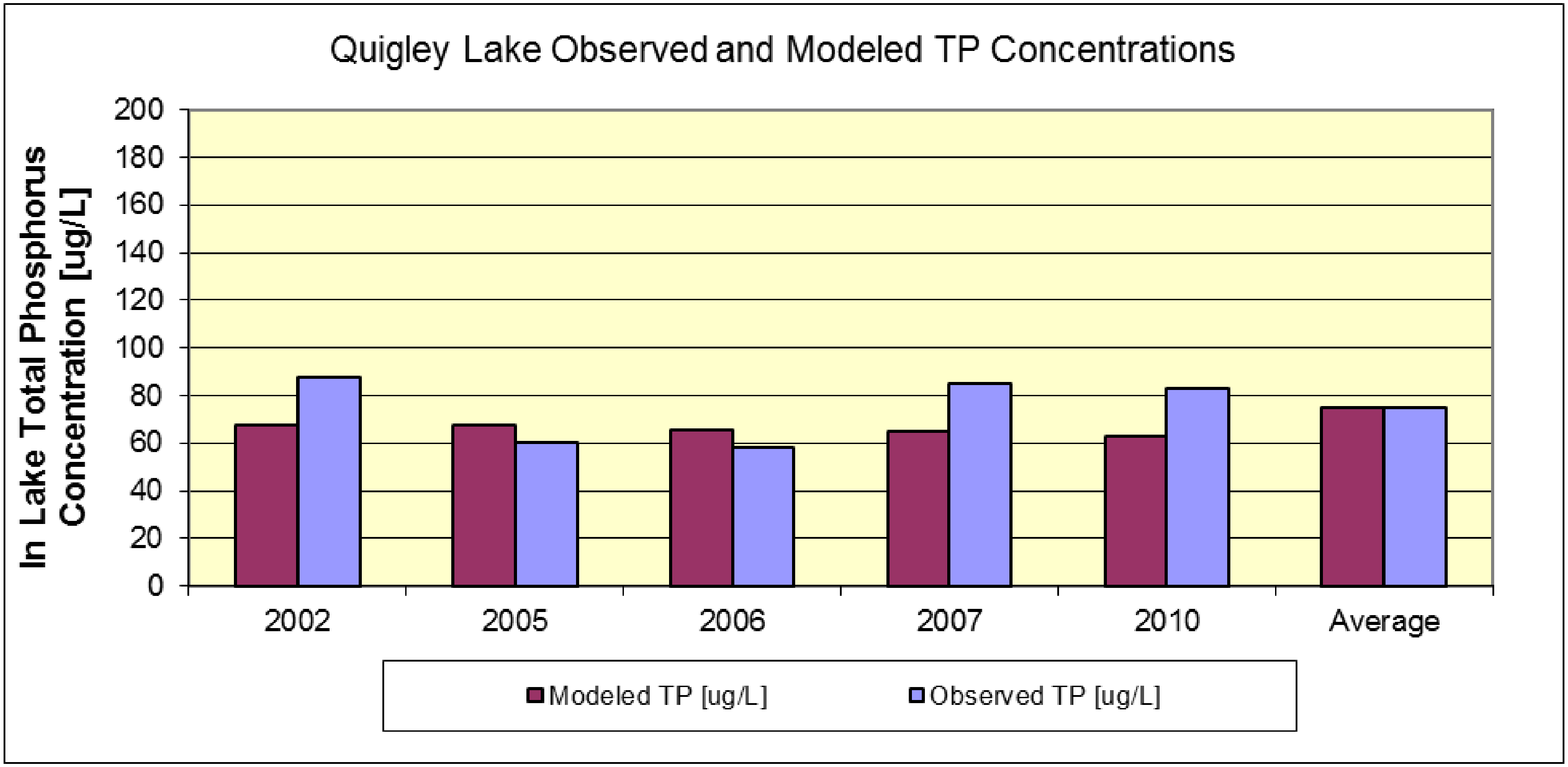
Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.04						

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
	0.04	61		Oxic	0.1	1.0	0.298
	0.04	17.1		Anoxic	1.0	1.0	0.643
	Summation						0.942
		Net Discharge [10^6 m^3/yr] =		**0.022**		**Net Load [kg/yr] =**	**4.16**

Reductions Lake Response Modeling for O'Leary West Basin

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.964	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	4.16	[kg/yr]
		Q (lake outflow) =	0.0221	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0329	[10^6 m^3]
		T = V/Q =	1.49	[yr]
		P_i = W/Q =	188	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**


Quigley Lake Observed and Modeled TP Concentrations
In Lake Total Phosphorus Concentration [ug/L]
200
180
160
140
120
100
80
60
40
20
0
2002
2005
2006
2007
2010
Average
Modeled TP [ug/L]
Observed TP [ug/L]

Average Loading Summary for Quigley Lake

Water Budgets	Phosphorus Loading

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1	Direct	0.4	0.08	0.032	79	1.0	2.53
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*0.4*	*0.08*	*0.032*			*2.53*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.06	0.77	0.77	0.00	26.80	1.0	1.65
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater

Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.06						

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.06	122		Oxic	0.4	1.0	2.70
0.06	47.3		Anoxic	0.4	1.0	1.16
Summation						3.86
	Net Discharge [10^6 m^3/yr] =		**0.032**		**Net Load [kg/yr] =**	**8.05**

Average Lake Response Modeling for Quigley Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.83	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	8.05	[kg/yr]
		Q (lake outflow) =	0.0322	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0586	[10^6 m^3]
		T = V/Q =	1.82	[yr]
		P_i = W/Q =	250	[µg/l]
Model Predicted In-Lake [TP]			**74.8**	**[ug/l]**
Observed In-Lake [TP]			**74.8**	**[ug/l]**

Reductions Loading Summary for Quigley Lake

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1	Direct	0.4	0.08	0.032	49	0.6	1.59
2							
3							
4							
5							
	Summation	*0.4*	*0.08*	*0.032*			*1.59*

Point Source Dischargers

	Name			Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [10^6 m^3/yr]	Failure [%]		Load [kg/yr]
1							
2							
3							
4							
5							
	Summation						

Inflow from Upstream Lakes

	Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1							
2							
3							
	Summation						

Atmosphere

	Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
	0.06	0.77	0.77	0.00	26.80	1.0	1.65
		Dry-year total P deposition =			24.9		
		Average-year total P deposition =			26.8		
		Wet-year total P deposition =			29.0		
		(Barr Engineering 2004)					

Groundwater

	Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
	0.06						

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
	0.06	65		Oxic	0.4	1.0	1.44
	0.06	47.3		Anoxic	0.4	1.0	1.16
	Summation						2.60
		Net Discharge [10^6 m^3/yr] =		**0.032**	**Net Load [kg/yr] =**		**5.84**

Reductions Lake Response Modeling for Quigley Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	0.834	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	5.84	[kg/yr]
		Q (lake outflow) =	0.0322	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0586	[10^6 m^3]
		T = V/Q =	1.82	[yr]
		P_i = W/Q =	181	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$

Appendix I

Cost Analysis

This appendix summarizes the cost analysis used for this project. The analysis consisted of two components: a unit cost analysis/estimate and a 30 year lifecycle cost analysis. The unit cost analysis represents itemized present value unit costs for each project using prices that are relevant in today's construction industry. Tables 1 through Table 31 are the assumed unit costs for each project based on a preliminary analysis of the system.

For the 30 year lifecycle component of the analysis, present value operation and maintenance costs were assumed for each project and accounted for over a 30 year period. Table 33 summarizes the assumed present value operation and maintenance costs for each project. Future costs within the 30 year life cycle are adjusted using an assumed inflation rate of 2.3%, then using a discount rate of 3.5% the adjusted present value of the project is represented by the following equation.

$$\boldsymbol{PV = C_o + \sum_{n=1}^{m} R * \frac{\left(1 + i_{inf}\right)^n}{(1 + i_{dis})^n}}$$

Where:

PV = Present value cost

C_o = Total unit cost for each project

R = Maintenance cost per period

i_{inf} = Inflation rate

i_{dis} = Discount rate

n = period

m = number of periods (30 years)

Table 1. DP-3 present value unit cost estimate for an iron enhanced filtration system with outlet modification.

DP-3 OPTION 1 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
CLEARING AND GRUBBING	ACRE	0.2	$5,000	$1,000
CONSTRUCT FILTERBENCH	SQ FT	9,775	$2	$19,550
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
OUTLET MODIFICATION	EACH	1	$2,000	$2,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	2,000	$8	$16,000
INSTALL COARSE FILTER AGREGATE	CU YD	360	$45	$16,200
INSTALL CLEAN SAND	CY	545	$35	$19,075
INSTALL IRON FILINGS	TON	41	$800	$32,800
Construction Cost Estimate				$147,125
Contingency (20 %Construction Cost)				$29,425
Total Construction Cost				$176,550
Construction Management Services (5%)				$8,828
Design Fee (15 %)				$22,069
Preliminary Cost Estimate				**$207,446**

Table 2. DP-3 present value unit cost estimate for just the basin expansion.

DP-3 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
WETLAND MITIGATION COSTS	SF	28,825	$2	$57,650
COMMON EXCAVATION OFF SITE	CU YD	10,310	$20	$206,200
CLEARING AND GRUBBING	ACRE	1.0	$5,000	$5,000
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL FORCE MAIN	LIN FT	320	$35	$11,200
Construction Cost Estimate				$320,550
Contingency (20 %Construction Cost)				$64,110
Total Construction Cost				$384,660
Construction Management Services (5%)				$19,233
Design Fee (15 %)				$48,083
Preliminary Cost Estimate				**$451,976**

Table 3. DP-3 Present value unit cost estimate for an iron enhanced filtration system with outlet modification and a basin expansion.

DP-3 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
WETLAND MITIGATION COSTS	SF	28,825	$2	$57,650
COMMON EXCAVATION OFF SITE	CU YD	10,310	$20	$206,200
CLEARING AND GRUBBING	ACRE	1.2	$5,000	$6,000
CONSTRUCT FILTERBENCH	SQ FT	9,775	$2	$19,550
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL FORCE MAIN	LIN FT	320	$35	$11,200
OUTLET MODIFICATION	EACH	1	$2,000	$2,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	2,000	$8	$16,000
INSTALL COARSE FILTER AGREGATE	CU YD	360	$45	$16,200
INSTALL CLEAN SAND	CY	545	$35	$19,075
INSTALL IRON FILINGS	TON	41	$800	$32,800
Construction Cost Estimate				$427,175
Contingency (20 %Construction Cost)				$85,435
Total Construction Cost				$512,610
Construction Management Services (5%)				$25,631
Design Fee (15 %)				$64,076
Preliminary Cost Estimate				**$602,317**

Table 4. DP-4.2 present value unit cost estimate for an iron enhanced filtration system with outlet modification.

DP-4.2 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
CONSTRUCT FILTERBENCH	SQ FT	6,600	$2	$13,200
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
OUTLET MODIFICATION	EACH	1	$2,000	$2,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	880	$8	$7,040
INSTALL SHEET PILE	SQ FT	2,880	$30	$86,400
INSTALL COARSE FILTER AGREGATE	CU YD	245	$45	$11,025
INSTALL CLEAN SAND	CY	370	$35	$12,950
INSTALL IRON FILINGS	TON	18	$800	$14,400
Construction Cost Estimate				$182,515
Contingency (20 %Construction Cost)				$36,503
Total Construction Cost				$219,018
Construction Management Services (5%)				$10,951
Design Fee (15 %)				$27,377
Preliminary Cost Estimate				**$257,346**

Table 5. DP 2.3 present value unit cost estimate for a basin expansion and an iron enhanced filtration system with outlet modification.

DP-2.3 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$1,000	$1,000
COMMON EXCAVATION OFF SITE	CU YD	485	$20	$9,700
CLEARING AND GRUBBING	ACRE	0.1	$5,000	$500
CONSTRUCT INFILTRATION BASIN	SQ FT	4,355	$2	$8,710
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL RIPRAP CLASS II	CU YD	6	$125	$750
INSTALL 24" RC PIPE SEWER	LIN FT	90	$48	$4,320
OUTLET MODIFICATION	EACH	1	$2,000	$2,000
CONNECT TO EXISTING MH	EACH	1	$1,000	$1,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	50	$8	$400
INSTALL COARSE FILTER AGREGATE	CU YD	37	$45	$1,665
INSTALL CLEAN SAND	CY	55	$35	$1,925
INSTALL IRON FILINGS	TON	3	$800	$2,400
Construction Cost Estimate				$62,870
Contingency (20 %Construction Cost)				$12,574
Total Construction Cost				$75,444
Construction Management Services (5%)				$3,772
Design Fee (15 %)				$9,431
Preliminary Cost Estimate				**$88,647**

Table 6. DP-4A_2 present value unit cost estimate for a stormwater reroute with proposed basin and iron enhanced filtration system.

DP-4A_2 COST ESTIMATE

Item	Unit	Quantity	Unit Cost	Total Cost
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
TRAFFIC DETOUR	LUMP SUM	1	$3,500	$3,500
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$1,000	$1,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION OFF SITE	CU YD	4,460	$20	$89,200
CLEARING AND GRUBBING	ACRE	0.2	$5,000	$1,000
CONSTRUCT INFILTRATION BASIN	SQ FT	16,850	$2	$33,700
CONSTRUCT FILTERBENCH	SQ FT	1,130	$2	$2,260
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL RIPRAP CLASS II	CU YD	15	$125	$1,875
INSTALL 15" RC PIPE SEWER	LIN FT	500	$30	$15,000
INSTALL DRAINAGE STRUCTURE - 4' DIA CBMH	EACH	4	$2,000	$8,000
CONNECT TO EXISTING MH	EACH	1	$1,000	$1,000
INSTALL CURB AND GUTTER	LIN FT	350	$20	$7,000
BITUMINOUS INSTALATION	TON	100	$75	$7,500
INSTALL AGGREGATE BASE CLASS V	TON	100	$20	$2,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	115	$8	$920
INSTALL COARSE FILTER AGREGATE	CU YD	40	$45	$1,800
INSTALL CLEAN SAND	CY	65	$35	$2,275
INSTALL IRON FILINGS	TON	5	$800	$4,000
BTIUMINOUS REMOVAL	SQ YD	305	$4	$1,068
REMOVE MANHOLE OR CATCHBASIN	EACH	4	$500	$2,000
REMOVE RC PIPE SEWER	LIN FT	450	$10	$4,500
REMOVE CURB AND GUTTER	LIN FT	350	$5	$1,750
Construction Cost Estimate				$232,848
Contingency (20 %Construction Cost)				$46,570
Total Construction Cost				$279,417
Construction Management Services (5%)				$13,971
Design Fee (15 %)				$34,927
Preliminary Cost Estimate				**$328,315**

Table 7. DP-4A_2 present value unit cost estimate for two underground storage areas with iron enhanced filtration systems.

DP-4A_2 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
TRAFFIC DETOUR	LUMP SUM	1	$3,500	$3,500
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$1,000	$1,000
COMMON EXCAVATION OFF SITE	CU YD	2,615	$20	$52,300
CONSTRUCT INFILTRATION BASIN	SQ FT	17,425	$2	$34,850
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
CONNECT TO EXISTING MH	EACH	4	$1,000	$4,000
INSTALL CURB AND GUTTER	LIN FT	70	$20	$1,400
BITUMINOUS INSTALATION	TON	845	$75	$63,375
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	150	$8	$1,200
INSTALL COARSE FILTER AGREGATE	CU YD	3,875	$45	$174,375
INSTALL CLEAN SAND	CY	255	$35	$8,925
INSTALL IRON FILINGS	TON	19	$800	$15,200
BTIUMINOUS REMOVAL	SQ YD	1,935	$4	$6,773
Construction Cost Estimate				$392,898
Contingency (20 %Construction Cost)				$78,580
Total Construction Cost				$471,477
Construction Management Services (5%)				$23,574
Design Fee (15 %)				$58,935
Preliminary Cost Estimate				**$553,985**

Table 8. DP-4A, 4B, and 26 present value unit cost estimate for an iron enhanced sand filtration bench and outlet modification.

DP-4A, 4B, 26 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION OFF SITE	CU YD	7,740	$20	$154,800
CLEARING AND GRUBBING	ACRE	0.2	$5,000	$1,000
CONSTRUCT FILTERBENCH	SQ FT	23,152	$2	$46,304
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
OUTLET MODIFICATION	EACH	1	$2,000	$2,000
CONNECT TO EXISTING MH	EACH	1	$1,000	$1,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	11,575	$8	$92,600
INSTALL SHEET PILE	SQ FT	10,800	$30	$324,000
INSTALL COARSE FILTER AGREGATE	CU YD	860	$45	$38,700
INSTALL CLEAN SAND	CY	1,290	$35	$45,150
INSTALL IRON FILINGS	TON	97	$800	$77,600
Construction Cost Estimate				$823,654
Contingency (20 %Construction Cost)				$164,731
Total Construction Cost				$988,385
Construction Management Services (5%)				$49,419
Design Fee (15 %)				$123,548
Preliminary Cost Estimate				**$1,161,352**

Table 9. DP-2 present value unit cost estimate for a low flow bypass diversion weir, gravity drainage pipes, and an above ground iron enhanced filtration system along the east side of LeMay Lake.

DP-2 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION ON SITE	CU YD	1,670	$6	$10,020
COMMON EXCAVATION OFF SITE	CU YD	21,300	$20	$426,000
CLEARING AND GRUBBING	ACRE	1.5	$5,000	$7,500
CONSTRUCT INFILTRATION BASIN	SQ FT	43,560	$2	$87,120
CONSTRUCT FILTERBENCH	SQ FT	8,100	$2	$16,200
CONSTRUCT POURED CONCRETE STRUCTURE	CU YD	155	$750	$116,250
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL RIPRAP CLASS II	CU YD	35	$125	$4,375
INSTALL 36" RC PIPE SEWER	LIN FT	1,050	$72	$75,600
INSTALL FORCE MAIN	LIN FT	450	$35	$15,750
PUMP CONTROLS	EACH	2	$2,000	$4,000
PUMPS	EACH	2	$10,000	$20,000
INSTALL DRAINAGE STRUCTURE - 6' DIA MH	EACH	2	$7,500	$15,000
CONNECT TO EXISTING MH	EACH	4	$1,000	$4,000
CONSTRUCT BYPASS SPLITTER	EACH	1	$1,000	$1,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	800	$8	$6,400
INSTALL COARSE FILTER AGREGATE	CU YD	300	$45	$13,500
INSTALL CLEAN SAND	CY	450	$35	$15,750
INSTALL IRON FILINGS	TON	34	$800	$27,200
REMOVE MANHOLE OR CATCHBASIN	EACH	1	$500	$500
Construction Cost Estimate				$902,665
Contingency (20 %Construction Cost)				$180,533
Total Construction Cost				$1,083,198
Construction Management Services (5%)				$54,160
Design Fee (15 %)				$135,400
Preliminary Cost Estimate				**$1,272,758**

Table 10. DP-2 present value unit cost estimate for a low flow bypass diversion weir, gravity drainage pipes, lift station, and a clarifier system for alum injection.

DP-2 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION ON SITE	CU YD	1,805	$6	$10,830
COMMON EXCAVATION OFF SITE	CU YD	4,550	$20	$91,000
CLEARING AND GRUBBING	ACRE	1.5	$5,000	$7,500
CONSTRUCT INFILTRATION BASIN	SQ FT	43,560	$2	$87,120
CONSTRUCT FILTERBENCH	SQ FT	8,100	$2	$16,200
CONSTRUCT POURED CONCRETE STRUCTURE	CU YD	465	$750	$348,750
CLARIFIER INTERNALS	FT-DIA	77	$2,000	$154,000
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL RIPRAP CLASS II	CU YD	35	$125	$4,375
INSTALL 84" RC PIPE SEWER	LIN FT	500	$168	$84,000
INSTALL 36" RC PIPE SEWER	LIN FT	55	$72	$3,960
INSTALL 12" RC PIPE SEWER	LIN FT	35	$24	$840
INSTALL FORCE MAIN	LIN FT	690	$35	$24,150
PUMP CONTROLS	EACH	4	$2,000	$8,000
PUMPS	EACH	4	$10,000	$40,000
INSTALL DRAINAGE STRUCTURE - 6' DIA MH	EACH	2	$7,500	$15,000
SLUDGE PUMP STRUCTURE	LUMP SUM	1	$30,000	$30,000
ALUM TREATMENT BUILDING	SF	150	$75	$11,250
CHEMICAL FEED SYSTEM AND CONTROLS	LUMP SUM	1	$40,000	$40,000
CONNECT TO EXISTING MH	EACH	4	$1,000	$4,000
CONSTRUCT BYPASS SPLITTER	EACH	1	$1,000	$1,000
REMOVE MANHOLE OR CATCHBASIN	EACH	1	$500	$500
Construction Cost Estimate				$1,018,975
Contingency (20 %Construction Cost)				$203,795
Total Construction Cost				$1,222,770
Construction Management Services (5%)				$61,139
Design Fee (15 %)				$152,846
Preliminary Cost Estimate				**$1,436,755**

Table 11. JP-20.1 and 20.2 present value unit cost estimate for a stormwater reuse system.

JP-20.1 & 20.2 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$1,000	$1,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION OFF SITE	CU YD	2,440	$20	$48,800
INSTALL 15" RC PIPE SEWER	LIN FT	400	$30	$12,000
INSTALL IRRIGATION SYSTEM	SQ FT	54,000	$1	$54,000
INSTALL IRRIGATION WELL	EACH	1	$7,500	$7,500
INSTALL DRAINAGE STRUCTURE - 6' DIA MH	EACH	1	$7,500	$7,500
INSTALL COARSE FILTER AGREGATE	CU YD	2,100	$45	$94,500
Construction Cost Estimate				$254,300
Contingency (20 %Construction Cost)				$50,860
Total Construction Cost				$305,160
Construction Management Services (5%)				$15,258
Design Fee (15 %)				$38,145
Preliminary Cost Estimate				**$358,563**

Table 12. JP-20.5 present value unit cost estimates for an iron enhanced filtration system with outlet modification.

JP-20.5 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
CLEARING AND GRUBBING	ACRE	0.2	$5,000	$1,000
CONSTRUCT FILTERBENCH	SQ FT	400	$2	$800
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	80	$8	$640
INSTALL COARSE FILTER AGREGATE	CU YD	15	$45	$675
INSTALL CLEAN SAND	CY	23	$35	$805
INSTALL IRON FILINGS	TON	2	$800	$1,360
Construction Cost Estimate				$40,780
Contingency (20 %Construction Cost)				$8,156
Total Construction Cost				$48,936
Construction Management Services (5%)				$2,447
Design Fee (15 %)				$6,117
Preliminary Cost Estimate				**$57,500**

Table 13. GP-5 present value unit cost estimates for an iron enhanced filtration system and outlet modification.

GP-5 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$1,000	$1,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION ON SITE	CU YD	1,480	$6	$8,880
COMMON EXCAVATION OFF SITE	CU YD	2,600	$20	$52,000
CLEARING AND GRUBBING	ACRE	0.5	$5,000	$2,500
CONSTRUCT FILTERBENCH	SQ FT	18,600	$2	$37,200
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL 12" RC PIPE SEWER	LIN FT	400	$24	$9,600
OUTLET MODIFICATION	EACH	1	$2,000	$2,000
INSTALL DRAINAGE STRUCTURE - 4' DIA CBMH	EACH	2	$2,000	$4,000
CONNECT TO EXISTING MH	EACH	1	$1,000	$1,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	3,100	$8	$24,800
INSTALL COARSE FILTER AGREGATE	CU YD	690	$45	$31,050
INSTALL CLEAN SAND	CY	1,035	$35	$36,225
INSTALL IRON FILINGS	TON	78	$800	$62,400
Construction Cost Estimate				$309,155
Contingency (20 %Construction Cost)				$61,831
Total Construction Cost				$370,986
Construction Management Services (5%)				$18,549
Design Fee (15 %)				$46,373
Preliminary Cost Estimate				**$435,909**

Table 14. GP-1.2 present value unit cost estimate for an iron enhanced filter bench and outlet modification.

GP-1.2 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION OFF SITE	CU YD	1,450	$20	$29,000
CLEARING AND GRUBBING	ACRE	0.2	$5,000	$750
CONSTRUCT FILTERBENCH	SQ FT	6,450	$2	$12,900
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL RIPRAP CLASS II	CU YD	30	$125	$3,750
INSTALL 12" RC PIPE SEWER	LIN FT	100	$24	$2,400
INSTALL DRAINAGE STRUCTURE - 5' DIA MH	EACH	1	$6,000	$6,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	860	$8	$6,880
INSTALL COARSE FILTER AGREGATE	CU YD	240	$45	$10,800
INSTALL CLEAN SAND	CY	360	$35	$12,600
INSTALL IRON FILINGS	TON	27	$800	$21,600
Construction Cost Estimate				$142,180
Contingency (20 %Construction Cost)				$28,436
Total Construction Cost				$170,616
Construction Management Services (5%)				$8,531
Design Fee (15 %)				$21,327
Preliminary Cost Estimate				**$200,474**

Table 15. GP-1.2 present value unit cost estimate for just a basin expansion.

GP-1.2 COST ESTIMATE

Item	Unit	Quantity	Unit Cost	Total Cost
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION ON SITE	CU YD	1,400	$6	$8,400
COMMON EXCAVATION OFF SITE	CU YD	16,140	$20	$322,800
CLEARING AND GRUBBING	ACRE	1.0	$5,000	$5,000
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL RIPRAP CLASS II	CU YD	30	$125	$3,750
INSTALL DRAINAGE STRUCTURE - 5' DIA MH	EACH	1	$6,000	$6,000
Construction Cost Estimate				$381,450
Contingency (20 %Construction Cost)				$76,290
Total Construction Cost				$457,740
Construction Management Services (5%)				$22,887
Design Fee (15 %)				$57,218
Preliminary Cost Estimate				**$537,845**

Table 16. GP-1.2 present value unit costs for a basin expansion and an iron enhanced sand filter bench with outlet modification.

GP-1.2 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION ON SITE	CU YD	1,400	$6	$8,400
COMMON EXCAVATION OFF SITE	CU YD	16,140	$20	$322,800
CLEARING AND GRUBBING	ACRE	1.0	$5,000	$5,000
CONSTRUCT FILTERBENCH	SQ FT	12,800	$2	$25,600
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL RIPRAP CLASS II	CU YD	30	$125	$3,750
INSTALL 12" RC PIPE SEWER	LIN FT	100	$24	$2,400
INSTALL DRAINAGE STRUCTURE - 5' DIA MH	EACH	1	$6,000	$6,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	2,240	$8	$17,920
INSTALL COARSE FILTER AGREGATE	CU YD	475	$45	$21,375
INSTALL CLEAN SAND	CY	710	$35	$24,850
INSTALL IRON FILINGS	TON	54	$800	$43,200
Construction Cost Estimate				$516,795
Contingency (20 %Construction Cost)				$103,359
Total Construction Cost				$620,154
Construction Management Services (5%)				$31,008
Design Fee (15 %)				$77,519
Preliminary Cost Estimate				**$728,681**

Table 17. EP-2.4_2 present value unit costs for an iron enhanced filtration system.

EP-2.4_2 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
CLEARING AND GRUBBING	ACRE	0.2	$5,000	$750
CONSTRUCT FILTERBENCH	SQ FT	2,175	$2	$4,350
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL 12" RC PIPE SEWER	LIN FT	20	$24	$480
OUTLET MODIFICATION	EACH	1	$2,000	$2,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	145	$8	$1,160
INSTALL COARSE FILTER AGREGATE	CU YD	80	$45	$3,600
INSTALL CLEAN SAND	CY	120	$35	$4,200
INSTALL IRON FILINGS	TON	9	$800	$7,200
Construction Cost Estimate				$64,240
Contingency (20 %Construction Cost)				$12,848
Total Construction Cost				$77,088
Construction Management Services (5%)				$3,854
Design Fee (15 %)				$9,636
Preliminary Cost Estimate				**$90,578**

Table 18. EP-2.91 present value unit costs for a basin expansion.

EP-2.91 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$2,500	$2,500
EROSION CONTROL	LUMP SUM	1	$2,500	$2,500
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$500	$500
COMMON EXCAVATION OFF SITE	CU YD	485	$20	$9,700
SITE GRADING	LUMP SUM	1	$1,250	$1,250
SITE RESTORATION	LUMP SUM	1	$2,500	$2,500
Construction Cost Estimate				$18,950
Contingency (20 %Construction Cost)				$3,790
Total Construction Cost				$22,740
Construction Management Services (5%)				$1,137
Design Fee (15 %)				$2,843
Preliminary Cost Estimate				**$26,720**

Table 19. EP-2.92 present value unit costs for a basin expansion.

EP-2.92 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$2,500	$2,500
EROSION CONTROL	LUMP SUM	1	$2,500	$2,500
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$500	$500
COMMON EXCAVATION OFF SITE	CU YD	1,450	$20	$29,000
SITE GRADING	LUMP SUM	1	$1,250	$1,250
SITE RESTORATION	LUMP SUM	1	$2,500	$2,500
Construction Cost Estimate				$38,250
Contingency (20 %Construction Cost)				$7,650
Total Construction Cost				$45,900
Construction Management Services (5%)				$2,295
Design Fee (15 %)				$5,738
Preliminary Cost Estimate				**$53,933**

Table 20. LP-42 present value unit costs for a stormwater reroute and underground filtration system.

LP-42 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
TRAFFIC DETOUR	LUMP SUM	1	$3,500	$3,500
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$1,000	$1,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION ON SITE	CU YD	625	$6	$3,750
COMMON EXCAVATION OFF SITE	CU YD	810	$20	$16,200
CONSTRUCT INFILTRATION BASIN	SQ FT	5,000	$2	$10,000
CONSTRUCT POURED CONCRETE STRUCTURE	CU YD	450	$750	$337,500
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SALVAGE AND REINSTALL TOPSOIL	LUMP SUM	1	$5,000	$5,000
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL 36" RC PIPE SEWER	LIN FT	550	$72	$39,600
INSTALL DRAINAGE STRUCTURE - 4' DIA CBMH	EACH	4	$2,000	$8,000
CONNECT TO EXISTING MH	EACH	1	$1,000	$1,000
INSTALL CURB AND GUTTER	LIN FT	420	$20	$8,400
BITUMINOUS INSTALATION	TON	105	$75	$7,875
INSTALL AGGREGATE BASE CLASS V	TON	105	$20	$2,100
INSTALL COARSE FILTER AGREGATE	CU YD	185	$45	$8,325
INSTALL CLEAN SAND	CY	280	$35	$9,800
INSTALL IRON FILINGS	TON	21	$800	$16,800
BTIUMINOUS REMOVAL	SQ YD	350	$4	$1,225
REMOVE MANHOLE OR CATCHBASIN	EACH	3	$500	$1,500
REMOVE RC PIPE SEWER	LIN FT	550	$10	$5,500
REMOVE CURB AND GUTTER	LIN FT	420	$5	$2,100
Construction Cost Estimate				$530,675
Contingency (20 %Construction Cost)				$106,135
Total Construction Cost				$636,810
Construction Management Services (5%)				$31,841
Design Fee (15 %)				$79,601
Preliminary Cost Estimate				**$748,252**

Table 21. LP-53 present value unit costs for a stormwater reroute and an above ground iron enhanced filtration system.

LP-53 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
TRAFFIC DETOUR	LUMP SUM	1	$3,500	$3,500
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$1,000	$1,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION OFF SITE	CU YD	5,925	$20	$118,500
CONSTRUCT INFILTRATION BASIN	SQ FT	17,250	$2	$34,500
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL RIPRAP CLASS II	CU YD	60	$125	$7,500
INSTALL 15" RC PIPE SEWER	LIN FT	300	$30	$9,000
INSTALL FORCE MAIN	LIN FT	300	$35	$10,500
PUMP CONTROLS	EACH	2	$2,000	$4,000
PUMPS	EACH	2	$10,000	$20,000
INSTALL DRAINAGE STRUCTURE - 5' DIA MH	EACH	1	$6,000	$6,000
CONNECT TO EXISTING MH	EACH	1	$1,000	$1,000
INSTALL CURB AND GUTTER	LIN FT	15	$20	$300
BITUMINOUS INSTALATION	TON	65	$75	$4,875
INSTALL SIDEWALK	SQ FT	50	$5	$250
INSTALL AGGREGATE BASE CLASS V	TON	65	$20	$1,300
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	1,500	$8	$12,000
INSTALL COARSE FILTER AGREGATE	CU YD	640	$45	$28,800
INSTALL CLEAN SAND	CY	960	$35	$33,600
INSTALL IRON FILINGS	TON	72	$800	$57,600
BTIUMINOUS REMOVAL	SQ YD	200	$4	$700
REMOVE MANHOLE OR CATCHBASIN	EACH	1	$500	$500
REMOVE SIDEWALK	SQ FT	50	$1	$50
REMOVE CURB AND GUTTER	LIN FT	15	$5	$75
Construction Cost Estimate				$397,050
Contingency (20 %Construction Cost)				$79,410
Total Construction Cost				$476,460
Construction Management Services (5%)				$23,823
Design Fee (15 %)				$59,558
Preliminary Cost Estimate				**$559,841**

Table 22. LP-53 present value unit costs for a stormwater reroute and an underground iron enhanced filtration system.

LP-53 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
TRAFFIC DETOUR	LUMP SUM	1	$3,500	$3,500
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$1,000	$1,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION ON SITE	CU YD	495	$6	$2,970
COMMON EXCAVATION OFF SITE	CU YD	5,430	$20	$108,600
CONSTRUCT INFILTRATION BASIN	SQ FT	17,250	$2	$34,500
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SALVAGE AND REINSTALL TOPSOIL	LUMP SUM	1	$5,000	$5,000
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL 15" RC PIPE SEWER	LIN FT	300	$30	$9,000
INSTALL FORCE MAIN	LIN FT	300	$35	$10,500
PUMP CONTROLS	EACH	2	$2,000	$4,000
PUMPS	EACH	2	$10,000	$20,000
INSTALL DRAINAGE STRUCTURE - 5' DIA MH	EACH	1	$6,000	$6,000
CONNECT TO EXISTING MH	EACH	1	$1,000	$1,000
INSTALL CURB AND GUTTER	LIN FT	15	$20	$300
BITUMINOUS INSTALATION	TON	65	$75	$4,875
INSTALL SIDEWALK	SQ FT	50	$5	$250
INSTALL AGGREGATE BASE CLASS V	TON	65	$20	$1,300
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	1,500	$8	$12,000
INSTALL COARSE FILTER AGREGATE	CU YD	2,405	$45	$108,225
INSTALL CLEAN SAND	CY	960	$35	$33,600
INSTALL IRON FILINGS	TON	72	$800	$57,600
STORM TECH STORAGE SYSTEM	EACH	310	$600	$186,000
BTIUMINOUS REMOVAL	SQ YD	200	$4	$700
REMOVE MANHOLE OR CATCHBASIN	EACH	1	$500	$500
REMOVE SIDEWALK	SQ FT	50	$1	$50
REMOVE CURB AND GUTTER	LIN FT	15	$5	$75
Construction Cost Estimate				$653,045
Contingency (20 %Construction Cost)				$130,609
Total Construction Cost				$783,654
Construction Management Services (5%)				$39,183
Design Fee (15 %)				$97,957
Preliminary Cost Estimate				**$920,793**

Table 23. LP-70 present value unit costs for an iron enhanced filtration system.

LP-70 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
CLEARING AND GRUBBING	ACRE	0.2	$5,000	$1,000
CONSTRUCT FILTERBENCH	SQ FT	3,300	$2	$6,600
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL RIPRAP CLASS II	CU YD	87	$125	$10,875
INSTALL 15" RC PIPE SEWER	LIN FT	45	$30	$1,350
INSTALL DRAINAGE STRUCTURE - 5' DIA MH	EACH	1	$6,000	$6,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	220	$8	$1,760
INSTALL COARSE FILTER AGREGATE	CU YD	125	$45	$5,625
INSTALL CLEAN SAND	CY	185	$35	$6,475
INSTALL IRON FILINGS	TON	14	$800	$11,200
Construction Cost Estimate				$86,385
Contingency (20 %Construction Cost)				$17,277
Total Construction Cost				$103,662
Construction Management Services (5%)				$5,183
Design Fee (15 %)				$12,958
Preliminary Cost Estimate				**$121,803**

Table 24. AP-42 present value unit costs for a basin expansion and iron enhanced filter bench.

AP-42 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
TRAFFIC DETOUR	LUMP SUM	1	$3,500	$3,500
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$1,000	$1,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION ON SITE	CU YD	1,139	$6	$6,834
COMMON EXCAVATION OFF SITE	CU YD	2,596	$20	$51,920
CLEARING AND GRUBBING	ACRE	1.6	$5,000	$8,000
CONSTRUCT FILTERBENCH	SQ FT	4,220	$2	$8,440
SITE GRADING	LUMP SUM	1	$2,500	$2,500
OUTLET MODIFICATION	EACH	1	$2,000	$2,000
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
INSTALL RIPRAP CLASS II	CU YD	20	$125	$2,500
CONNECT TO EXISTING MH	EACH	1	$1,000	$1,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	422	$8	$3,376
INSTALL COARSE FILTER AGREGATE	CU YD	157	$45	$7,065
INSTALL CLEAN SAND	CY	226	$35	$7,910
INSTALL IRON FILINGS	TON	18	$800	$14,080
Construction Cost Estimate				$159,125
Contingency (20 %Construction Cost)				$31,825
Total Construction Cost				$190,950
Construction Management Services (5%)				$9,548
Design Fee (15 %)				$23,869
Preliminary Cost Estimate				**$224,366**

Table 25. AP-44 present value unit costs for an iron enhanced filter bench and outlet modification.

AP-44 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
TRAFFIC DETOUR	LUMP SUM	1	$3,500	$3,500
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$1,000	$1,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
OUTLET MODIFICATION	EACH	1	$2,000	$2,000
COMMON EXCAVATION OFF SITE	CU YD	3,143	$20	$62,860
CLEARING AND GRUBBING	ACRE	0.5	$5,000	$2,500
CONSTRUCT FILTERBENCH	SQ FT	1,640	$2	$3,280
SITE GRADING	LUMP SUM	1	$2,500	$2,500
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
CONNECT TO EXISTING MH	EACH	1	$1,000	$1,000
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	82	$8	$656
INSTALL COARSE FILTER AGREGATE	CU YD	61	$45	$2,745
INSTALL CLEAN SAND	CY	88	$35	$3,080
INSTALL IRON FILINGS	TON	7	$800	$5,600
Construction Cost Estimate				$129,721
Contingency (20 %Construction Cost)				$25,944
Total Construction Cost				$155,665
Construction Management Services (5%)				$7,783
Design Fee (15 %)				$19,458
Preliminary Cost Estimate				**$182,907**

Table 26. AP-42 present value unit costs for rain garden and other commercial BMPs.

AP-42 COMMERCIAL COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
TRAFFIC DETOUR	LUMP SUM	1	$3,500	$3,500
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$1,000	$1,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION OFF SITE	CU YD	469	$20	$9,380
CLEARING AND GRUBBING	ACRE	0.29	$5,000	$1,458
CONSTRUCT RAIN GARDEN	SQ FT	12,700	$2	$25,400
CONSTRUCT CURB CUT	EACH	15	$200	$3,000
Construction Cost Estimate				$77,738
Contingency (20 %Construction Cost)				$15,548
Total Construction Cost				$93,285
Construction Management Services (5%)				$4,664
Design Fee (15 %)				$11,661
Preliminary Cost Estimate				**$109,610**

Table 27. LP-26.3 present value unit costs for a stormwater reroute from basins 27 and 27.1, a basin expansion of 26.3 with an integrated iron enhanced filtration system.

LP-26.3 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
TRAFFIC DETOUR	LUMP SUM	1	$3,500	$3,500
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
UTILITY LOCATE	LUMP SUM	1	$1,000	$1,000
UNKNOWN WATER MAIN CROSSINGS	EACH	1	$1,000	$1,000
VEGETATION PLAN	LUMP SUM	1	$13,000	$13,000
COMMON EXCAVATION OFF SITE	CU YD	2,162	$20	$43,240
CLEARING AND GRUBBING	ACRE	0.2	$5,000	$1,000
CONSTRUCT FILTERBENCH	SQ FT	1,050	$2	$2,100
INSTALL 12" RC PIPE SEWER	LIN FT	1,083	$24	$25,992
JACK OR AUGER PIPE W/CASING	LIN FT	50	$550	$27,500
PUMPS	EACH	2	$10,000	$20,000
PUMP CONTROLS	EACH	1	$2,000	$2,000
INSTALL DRAINAGE STRUCTURE - 4' DIA CBMH	EACH	2	$2,000	$4,000
INSTALL DRAINAGE STRUCTURE - 6' DIA MH	EACH	1	$7,500	$7,500
CONNECT TO EXISTING MH	EACH	1	$1,000	$1,000
CONSTRUCT BYPASS SPLITTER	EACH	1	$1,000	$1,000
BITUMINOUS INSTALATION	TON	27	$75	$1,992
INSTALL AGGREGATE BASE CLASS V	TON	87	$20	$1,742
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	70	$8	$560
INSTALL COARSE FILTER AGREGATE	CU YD	35	$45	$1,575
INSTALL CLEAN SAND	CY	51	$35	$1,785
INSTALL IRON FILINGS	TON	4	$800	$3,200
BTIUMINOUS REMOVAL	SQ YD	132	$4	$462
Construction Cost Estimate				$185,149
Contingency (20 %Construction Cost)				$37,030
Total Construction Cost				$222,179
Construction Management Services (5%)				$11,109
Design Fee (15 %)				$27,772
Preliminary Cost Estimate				**$261,060**

Table 28. LP-26.4 present value unit costs for an iron enhanced filtration system and outlet modification.

LP-26.4 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
OUTLET MODIFICATION	EACH	1	$2,000	$2,000
COMMON EXCAVATION ON SITE	CU YD	1,000	$6	$6,000
CLEARING AND GRUBBING	ACRE	0.2	$5,000	$1,000
CONSTRUCT FILTERBENCH	SQ FT	300	$2	$600
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	30	$8	$240
INSTALL COARSE FILTER AGREGATE	CU YD	11	$45	$495
INSTALL CLEAN SAND	CY	17	$35	$595
INSTALL IRON FILINGS	TON	1.3	$800	$1,040
Construction Cost Estimate				$31,970
Contingency (20 %Construction Cost)				$6,394
Total Construction Cost				$38,364
Construction Management Services (5%)				$1,918
Design Fee (15 %)				$4,796
Preliminary Cost Estimate				**$45,078**

Table 29. LP-26.5 present value unit costs for an iron enhanced filtration system and outlet modification.

LP-26.5 COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
OUTLET MODIFICATION	EACH	1	$2,000	$2,000
COMMON EXCAVATION ON SITE	CU YD	1,000	$6	$6,000
CLEARING AND GRUBBING	ACRE	0.2	$5,000	$1,000
CONSTRUCT FILTERBENCH	SQ FT	300	$2	$600
INSTALL PERFORATED HDPE DRAINTILE	LIN FT	30	$8	$240
INSTALL COARSE FILTER AGREGATE	CU YD	11	$45	$495
INSTALL CLEAN SAND	CY	16	$35	$560
INSTALL IRON FILINGS	TON	2.0	$800	$1,600
Construction Cost Estimate				$32,495
Contingency (20 %Construction Cost)				$6,499
Total Construction Cost				$38,994
Construction Management Services (5%)				$1,950
Design Fee (15 %)				$4,874
Preliminary Cost Estimate				**$45,818**

Table 30. LP-28 present value unit costs for rain garden installations.

LP-28 RAIN GARDEN COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
MOBILIZATION	LUMP SUM	1	$10,000	$10,000
TRAFFIC CONTROL	LUMP SUM	1	$5,000	$5,000
EROSION CONTROL	LUMP SUM	1	$5,000	$5,000
SITE RESTORATION	LUMP SUM	1	$5,000	$5,000
COMMON EXCAVATION OFF SITE	CU YD	24	$20	$480
CONSTRUCT RAIN GARDEN	SQ FT	4,557	$2	$9,114
CONSTRUCT CURB CUT	EACH	7	$200	$1,400
Construction Cost Estimate				$35,994
Contingency (20 %Construction Cost)				$3,599
Total Construction Cost				$39,593
Construction Management Services (5%)				$1,980
Design Fee (15 %)				$5,399
Preliminary Cost Estimate				**$46,972**

Table 31. LP-28 present value unit costs for tree box installations.

LP-28 TREE BOX COST ESTIMATE				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
INSTALL TREE BOX	EACH	11	$500	$5,500
INSTALL 4X6 FILTERRA BOX	EACH	1	$12,700	$12,700
INSTALL 4X8 FILTERRA BOX	EACH	8	$13,650	$109,200
INSTALL 6X6 FILTERRA BOX	EACH	1	$14,500	$14,500
INSTALL 6X8 FILTERRA BOX	EACH	1	$16,600	$16,600
Construction Cost Estimate				$158,500
Contingency (20 %Construction Cost)				$15,850
Total Construction Cost				$174,350
Construction Management Services (5%)				$8,718
Design Fee (15 %)				$23,775
Preliminary Cost Estimate				**$206,843**

Table 32. Items/actions considered as operation and maintenance costs for each project for the 30-year life cycle analysis.

Project	Item/action	Frequency	Associated Present Value Cost
Rain Gardens	GeneralO&M/SiteVisits	Annually	$50
	Replace media and plants	Once every 10 years	$2,180
	Replace media and plants	Once every 20 years	$0
	Replace media and plants	Once every 30 years	$0
DP-3 Filter Bench	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$15,761
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
DP-3 Expansion	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$3,750
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
DP-3 Filter Bench and Expansio	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$16,511
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
DP-4.2	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$9,812
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
DP-2.3	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$3,959
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
DP-4A_2 Basin	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$4,499
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0

Table 32 (Continued). Items/actions considered as operation and maintenance costs for each project for the 30-year life cycle analysis.

Project	Item/action	Frequency	Associated Present Value Cost
DP-4A_2 Pervious Pavement	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs	Once every 10 years	$12,772
	SiteRestoration/SmallRepairs	Once every 20 years	$96,500
	SiteRestoration/LargerRepairs/Replacements	Once every 30 years	$0
DP-4A, 4B, 26	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$41,258
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
DP-2 Gravity	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$44,940
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$134,723
DP-2 Clarifier	GeneralO&M/SiteVisits	Annually	$50,000
	SiteRestoration/SmallRepairsto system and Infrastructure	Once every 10 years	$68,250
	Replacement of internals and chemical system	Once every 20 years	$192,000
	SiteRestoration/LargerRepairstoSystemand Infrastructure	Once every 30 years	$112,875
JP-20.1	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairsToIrrigationSystem	Once every 10 years	$10,725
	SiteRestoration/SmallRepairsToIrrigationSystem	Once every 20 years	$0
	SiteRestoration/LargerRepairsToIrrigationSystem	Once every 30 years	$0
JP-20.5	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$3,672
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
JP Residential Street Sweep	Street Sweep	Annually	$3,300
		Once every 10 years	
		Once every 20 years	
		Once every 30 years	

Table 32 (Continued). Items/actions considered as operation and maintenance costs for each project for the 30-year life cycle analysis.

Project	Item/action	Frequency	Associated Present Value Cost
GP-5	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$26,171
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
GP-1.2 Basin Expansion	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs	Once every 10 years	$6,263
	SiteRestoration/SmallRepairs	Once every 20 years	$0
	SiteRestoration/LargerRepairs/PartialDredge	Once every 30 years	$0
GP-1.2 Basin Expansion and Filt	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$22,364
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/Replacements/PartialDredge	Once every 30 years	$0
GP-1.2 Filter Bench Only	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$10,782
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
EP-2.4_2	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$5,424
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
EP-2.91	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs	Once every 10 years	$1,125
	SiteRestoration/SmallRepairs	Once every 20 years	$0
	SiteRestoration/LargerRepairs	Once every 30 years	$0
EP-2.92	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs	Once every 10 years	$1,125
	SiteRestoration/SmallRepairs	Once every 20 years	$0
	SiteRestoration/LargerRepairs	Once every 30 years	$0

Table 32 (Continued). Items/actions considered as operation and maintenance costs for each project for the 30-year life cycle analysis.

Project	Item/action	Frequency	Associated Present Value Cost
LP-42 Street Sweep	Street Sweep	Annually	$9,600
		Once every 10 years	
		Once every 20 years	
		Once every 30 years	
LP-42 Under Ground Filter	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$12,364
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
LP-43 Street Sweep	Street Sweep	Annually	$3,750
		Once every 10 years	
		Once every 20 years	
		Once every 30 years	
LP-44 Street Sweep	Street Sweep	Annually	$3,450
		Once every 10 years	
		Once every 20 years	
		Once every 30 years	
LP-53	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$35,175
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
LP-53 Underground	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$49,519
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
LP-70	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$8,540
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0

Table 32 (Continued). Items/actions considered as operation and maintenance costs for each project for the 30-year life cycle analysis.

Project	Item/action	Frequency	Associated Present Value Cost
AP-42	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$8,240
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
AP-44	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$4,062
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
AP-42 Commercial	GeneralO&M/SiteVisits	Annually	$500
	Replace media and plants	Once every 10 years	$5,085
	Replace media and plants	Once every 20 years	$0
	Replace media and plants	Once every 30 years	$0
LP-26.3	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$14,318
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
LP-26.4	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$2,606
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
LP-26.5	GeneralO&M/SiteVisits	Annually	$1,000
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 10 years	$2,684
	SiteRestoration/SmallRepairs/AugmentationofSandandIronMedia	Once every 20 years	$0
	SiteRestoration/LargerRepairs/ReplacefiltrationsystemandMedia	Once every 30 years	$0
LP-28 Rain gardens	GeneralO&M/SiteVisits	Annually	$500
	Replace media and plants	Once every 10 years	$2,117
	Replace media and plants	Once every 20 years	$0
	Replace media and plants	Once every 30 years	$0

Table 32 (Continued). Items/actions considered as operation and maintenance costs for each project for the 30-year life cycle analysis.

Project	Item/action	Frequency	Associated Present Value Cost
LP-28 Tree boxes	GeneralO&M/SiteVisits	Annually	$500
	Replace media and plants	Once every 10 years	$0
	Replace media and plants	Once every 20 years	$0
	Replace media and plants	Once every 30 years	$0

Wenck

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