City of Stillwater Lake Management Plans

Lily Lake
McKusick Lake

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Prepared for:

City of Stillwater
Brown's Creek Watershed District

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Executive Summary

The purpose of the McKusick and Lily Lake Management Plan is to provide a framework for the restoration and protection of Lily, Long and McKusick Lakes and to implement the City of Stillwater's Alternative Urban Areawide Review (AUAR; see section 1.2.1). The management plan is intended to assess the current conditions of the lakes and identify opportunities for improving the lakes' ecological, aesthetic, and recreational opportunities.

McKusick and Lily Lakes are located within the City of Stillwater in the northeastern suburban Twin Cities metropolitan area. McKusick Lake receives drainage from approximately 6,600 acres including approximately 1,500 acres of impervious cover and discharges to the St. Croix River. Long and Lily Lakes discharge into McKusick Lake which then discharges to the St. Croix River and ultimately the Mississippi River.

LILY LAKE

Lily Lake has a surface area of 35.9 acres, average depth of 18 feet, and an ordinary high water level of 844.8 feet. Lily Lake is a deep lake with a maximum depth of 50 feet and is 55% littoral (less than 15 feet in depth) where the majority of the aquatic plants grow.

Lily Lake is currently demonstrating some signs of eutrophication with exceedances occurring for both total phosphorus and chlorophyll-a. However, water clarity is relatively good, with most years at or better than the State standard for deep lakes in the North Central Hardwood Forest ecoregion. Data for recent years is relatively sparse with only four samples collected in each year over the past four years. However, lake conditions appear to have remained the same over the past ten years. Lily Lake has a dominant panfish population which can exhibit heavy predation pressure on zooplankton. The DNR has been stocking top predators which should help control panfish populations. Overall, the most likely driver for eutrophication in Lily Lake is increased phosphorus loading from the watershed.

MCKUSICK LAKE

McKusick Lake has a surface area of 45 acres, average depth of 3 feet, and an ordinary high water level of 851.7 feet. McKusick Lake is a shallow lake with a maximum depth of 10 feet and is 100% littoral.

McKusick Lake receives stormwater runoff from a 2,200 acre, partially developed urban watershed. The McKusick Lake watershed is approximately 63% single family residential, 16% multi-family residential, 12% open water, and 9% agriculture, wetlands, and undeveloped area.

The contributing area west of the Brown's Creek Diversion Structure is comprised of 35% agriculture, 24% single family residential, 23% undeveloped, 7% golf course, and 10% institutional, commercial, wetlands, open water, and multifamily residential. Drainage from Long Lake and Lily Lake comprise approximately 4,400 acres of additional contributing area. The total contributing area is 6,600 acres and is primarily west and south of McKusick Lake.

In general, McKusick Lake has fairly good water clarity for an urban shallow lake. However, there is some evidence of eutrophication. Both total phosphorus and chlorophyll-a have exceeded the state standards over the past ten years and the lake is demonstrating nuisance filamentous algae blooms. Water clarity is likely maintained by the presence of a relatively healthy aquatic vegetation and zooplankton community. The documented occurrence of fish kills actually helps increase water clarity by reducing planktivorous fish, in turn reducing the predation pressure on zooplankton. Consequently, the absence of rough fish and the occurrence of fish kills to control planktivorous fish populations are maintaining the current clear water conditions in McKusick Lake.

MANAGEMENT GOALS

Given the issues raised in this diagnostic study, the following goals are proposed to guide the management of McKusick and Lily Lake and their respective watersheds. These goals fall into three categories – recreation, environmental preservation, and lake management education.

Recreational Use

1. Reduce nuisance algal blooms and improve water clarity
2. Protect public health from fecal contamination, swimmer's itch, toxic chemicals, or other toxic agents.
3. Reduce the potential for aquatic vegetation to impede swimming and fishing in designated areas
4. Promote healthy and diverse fish communities

Environmental Preservation

5. Prevent the introduction of exotic plants and eliminate current exotic populations
6. Preserve aquatic wildlife habitat including fish spawning areas
7. Achieve a healthy and diverse community of native plants and animals
8. Provide a natural land/water interface that reduces runoff and enhances pollutant filtration while providing access for recreational use of the lakes.
9. Manage watershed runoff to reduce sediment and pollutant transport to the lakes

Lake Management Education

10. Assure that decision makers have an understanding of lake ecology basics so they can make informed decisions about lake management
11. Identify target audiences
12. Raise awareness of boundaries of McKusick and Lily Lake watershed
13. Raise awareness of nonpoint source pollution and its effects on lake water quality
14. Provide general and targeted information in various formats
15. Provide opportunities for active reinforcement of behavioral change

MANAGEMENT ACTIONS

Management Actions include both capital projects and ongoing management activities for Lily and McKusick Lakes. The initial management emphasis should be on controlling external loading, which is the highest priority. However, at some point enough external load reduction will have occurred that it will become feasible to turn to controlling the internal loads. An important part of that strategy is restoring and maintaining biological integrity and associated impacts to water quality through management of the aquatic plant community, fishery, zooplankton assemblages. Those activities can be ongoing as time and resources permit. However, biological manipulation cannot provide all the internal load reduction that would be required. More detailed study is required to evaluate whether chemical treatment with alum or other means of reducing internal loading are feasible.

In general it is recommended that implementation proceed according to the following sequence of activities:

Short Term

- Conduct diagnostic study for Annex Area phosphorus source
- Investigate internal loading rates for Lily and McKusick Lakes
- Implement specific BMP projects as funding allows including:
  - Excavate dry ponds in Lily Lake 13 and 18 to create wet detention ponds
- Investigate and implement infiltration basins the Lily Lake subwatersheds
- Evaluate loads from Annex/Long Lake drainage with internal loads to select project
- Conduct invasive species education

Long Term

- Implement project (alum or annex infiltration) for load reduction to control filamentous algae
- Consider drawdown in McKusick Lake for aquatic vegetation control
- Shoreline restoration as opportunities arise
- Continue monitoring

- Evaluate progress towards goals (nutrient reductions and filamentous algae blooms)
- Amend Management Plan as necessary based on progress
- Implement BMP retrofits as opportunities arise to continue to reduce external loading
- When sufficient external load controls are in place, prepare feasibility studies for internal load reduction strategies such as chemical treatment
- Implement internal load reduction BMPs

The load reductions identified in this management plan are aggressive and will require significant capital projects and management activities to achieve. Consequently, it is recommended that this Management Plan be implemented using adaptive management principles. Adaptive management is an iterative approach of implementation, evaluation, and course correction. It is appropriate here because it is difficult to predict the lake response to the various activities. Future conditions and technological advances may alter the specific course of actions detailed in this Plan. Continued monitoring and course corrections responding to monitoring results offer the best opportunity for meeting the various management goals set forth in this Plan.

1.0 Introduction

1.1 Purpose

The purpose of the McKusick and Lily Lake Management Plan is to provide a framework for the restoration and protection of Lily, Long and McKusick Lakes and to implement the City of Stillwater's Alternative Urban Areawide Review (AUAR; see section 1.2.1). The management plan is intended to assess the current conditions of the lakes and identify opportunities for improving the lakes' ecological, aesthetic, and recreational opportunities.

1.2 Previous Studies

Numerous studies have been completed that are relevant to this management plan. Following is a brief description of the studies incorporated into this comprehensive lake management plan.

1.2.1 Stillwater Annexation Area Alternative Urban Areawide Review (May 1997)

In May 1997 the City of Stillwater adopted an AUAR and mitigation plan for annexing just over 1,800 acres on the west side of the City. One of the key mitigation efforts identified in the study was the diversion of stormwater flowing from Long Lake and other portions of the annexation area away from Brown's Creek and through McKusick Lake. The purpose of this diversion was to protect the trout fishery in Brown's Creek, a high priority DNR designated trout stream.

1.2.2 Save Lily Lake…Now (December 1998)

A report was prepared by local citizens detailing the history of Lily Lake and identifying several key processes affecting water quality in the lake. The plan proposed improving water quality through several capital projects focused on reducing sediment and phosphorus loading to the lake.

1.2.3 McKusick Lake Analysis and Management Plan (March 1999)

In March 1999 an initial review of McKusick Lake conditions looked at modeled conditions predicted after implementation of the diversion structure. The report identified several options for improving the recreational value of McKusick Lake including some general recommendations for additional wet detention and nonstructural improvements such as street sweeping.

1.2.4 McKusick Lake Water Quality Assessment (July 2005)

In July 2005 the City of Stillwater reviewed current water quality conditions in response to citizen concerns regarding filamentous algae blooms on Lake McKusick. Results of the analysis suggest that no significant degradation of water quality has occurred as a result of the installation of the diversion structure. The report also presents an overview of filamentous algal growth in shallow lakes as well as potential mitigation options.

1.2.5 Long Lake Management Plan (May 2006)

In May 2006 the Brown's Creek Watershed District (BCWD) completed a management plan for Long Lake, which ultimately drains to McKusick Lake. The study developed a P8 model for the watershed to estimate watershed loads to the Lake. The plan identified both watershed load reductions and some in-lake management options.

1.3 Relevant Regulations

Numerous current regulations impact management activities for the protection of water quality in the City of Stillwater's receiving waters. Following is a brief discussion of the relevant regulations for this management plan.

1.3.1 Clean Water Act and Total Maximum Daily Loads

The federal Clean Water Act (CWA) requires states to adopt water-quality standards to protect waters from pollution. These standards define how much of a pollutant can be in the water and still allow it to meet designated uses, such as drinking water, fishing and swimming.

The MPCA first included Lily and Long Lakes on the 303(d) impaired waters list for Minnesota in 2002 (see Table 1) and McKusick in 2006. The lakes are impaired by excess nutrient concentrations, which inhibit aquatic recreation. The MPCA's projected schedule for TMDL completions, as indicated on the 303(d) impaired waters list, 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 waterbody; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

Table 1. Impaired waters listings.

Lake	DNR Lake #	Listing Year	Affected use	Pollutant or Stressor	Target TMDL Start	Target TMDL Completion
Lily	82-23P	2002	Aquatic recreation	Excess nutrients	2010	2014
Long	82-21P	2002	Aquatic recreation	Excess nutrients	2010	2014
McKusick	82-20W	2006	Aquatic recreation	Excess nutrients	2008	2012

Minnesota's standards for nutrients are narrative criteria that limit the quantity of nutrients which may enter waters. Minnesota's standards (Minnesota Rules 7050.0150(3)) state that in all Class 2 waters of the State (i.e., "…waters…which do or may support fish, other aquatic life, bathing, boating, or other recreational purposes…") "…there shall be no material increase in undesirable slime growths or aquatic plants including algae…." In accordance with Minn. Rules 7050.0150(5), to evaluate whether a waterbody is in an impaired condition the MPCA has developed "numeric translators" for the narrative standard for purposes of determining which lakes should be included in the section 303(d) list as being impaired for nutrients. The numeric translators establish numeric thresholds for phosphorus, chlorophyll-a, and clarity as measured by Secchi depth. Table 2 lists the thresholds for listing lakes on the 303(d) list of impaired waters in Minnesota.

Table 2. Trophic status thresholds for determination of use support for lakes.

305(b) Designation	Full Support			Partial Support to Potential Non-Support			
303(d) Designation	**Not Listed**			**Review**	**Listed**		
Ecoregion	**TP (ppb)**	**Chl-a (ppb)**	**Secchi (m)**	**TP Range (ppb)**	**TP (ppb)**	**Chl-a (ppb)**	**Secchi (m)**
Northern Lakes and Forests	< 30	<10	> 1.6	30 – 35	> 35	> 12	< 1.4
(Carlson's TSI)	(< 53)	(< 53)	(< 53)	(53-56)	(> 56)	(> 55)	(> 55)
North Central Hardwood Forests	< 40	< 15	> 1.2	40 - 45	> 45	> 18	< 1.1
(Carlson's TSI)	(<57)	(<57)	(<57)	(57 – 59)	(> 59)	(> 59)	(> 59)
Western Cornbelt Plain and Northern Glaciated Plain	< 70	< 24	> 1.0	70 - 90	> 90	> 32	< 0.7
(Carlson's TSI)	(< 66)	(< 61)	(< 61)	(66 – 69)	(> 69)	(> 65)	(> 65)

A water quality standards rules revision is in progress in Minnesota. Since the State's standards are currently narrative and not numeric, the numeric targets in this TMDL must result in the attainment of the narrative water quality standard set forth in the current rules (Minn. Rules 7050.0150(3) and (5)). The MPCA has designed the proposed numeric standards to meet the current applicable narrative water quality standards and designated uses. The translators in Table 2 above and the proposed numeric standards are based on the known relationship between phosphorus concentrations and levels of algae growth. The numeric standards indicate the point at which the average lake will experience severe nuisance blooms of algae. The proposed rules would also establish different standards for deep and shallow lakes, taking into account nutrient cycling differences between shallow and deep lakes and resulting in more appropriate standards for Minnesota lakes.

1.3.2 MS4 Stormwater Permits

Stormwater discharges associated with municipal separate storm sewer systems (MS4s) are regulated through the use of National Pollutant Discharge Elimination System (NPDES) permits. NPDES permits are legal documents. Through this permit, the owner or operator is required to develop a stormwater pollution prevention program (SWPPP) that incorporates best management practices (BMPs) applicable to their MS4. The City of Stillwater is an MS4.
MS4s are required to develop and implement a stormwater pollution prevention program (SWPPP) to reduce the discharge of pollutants from their storm sewer system to the maximum extent practicable. 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 control; and
- Pollution prevention/good housekeeping.

The MS4 must identify best management practices (BMPs) and measurable goals associated with each minimum control measure. An annual report on the implementation of the SWPPP must be submitted each year. Additionally, if the MS4 discharges to an impaired water, the permit holder must address the TMDL load allocations once the TMDL is in place.

2.0 Watershed and Lake Characterization

2.1 Lake and Watershed Descriptions

McKusick and Lily Lakes are located within the City of Stillwater in the northeastern suburban Twin Cities metropolitan area. McKusick Lake receives drainage from approximately 6,600 acres including approximately 1,500 acres of impervious cover and discharges to the St. Croix River. Long and Lily Lakes discharge into McKusick Lake which then discharges to the St. Croix River and ultimately the Mississippi River.

Protected waters within the McKusick, Long and Lily Lake watersheds are presented in Table 3.

Table 3. DNR protected waters in the McKusick Lake watershed.

Waterbody	DNR Number
McKusick Lake	82-20W
Long Lake	82-21P
Unnamed (Market Place Pond)	82-22W
Lily Lake	82-23P
Unnamed (Jackson Pond)	82-305W
Unnamed	82-306W
Unnamed	82-307W
Brick Pond	82-308W
Unnamed	82-309W

2.2 Lily Lake

Lily Lake has a surface area of 35.9 acres, average depth of 18 feet, and an ordinary high water level of 844.8 feet. Lily Lake is a deep lake with a maximum depth of 50 feet and is 55% littoral (less than 15 feet in depth) where the majority of the aquatic plants grow.

Table 4. Lake characteristics of Lily, Long, and McKusick Lakes.

Parameter	Lily	Long	McKusick
Surface Area (ac)	36	112	45
Average Depth (ft)	18	5	3
Maximum Depth (ft)	50	20	10
Volume (ac-ft)	628	587	144
Littoral Area (ac)	19.5	108.5	45
Littoral Area (%)	55	95	100
Watershed (ac)	590	3,800	6,600

Lily Lake receives stormwater runoff from a 587 acre, fully developed urban watershed. The Lily Lake watershed is approximately 30% single family residential, 30% multi-family residential, 10% commercial, 10% industrial, 10% open water, 7% undeveloped, and 6% institutional, wetlands, and major highway. The contributing area is primarily south and east of Lily Lake and extends south of Highway 36 to 58th Street North; west to Northwestern Avenue South; north to Olive Street West; and east nearly to Osgood Avenue North (Figure 1)

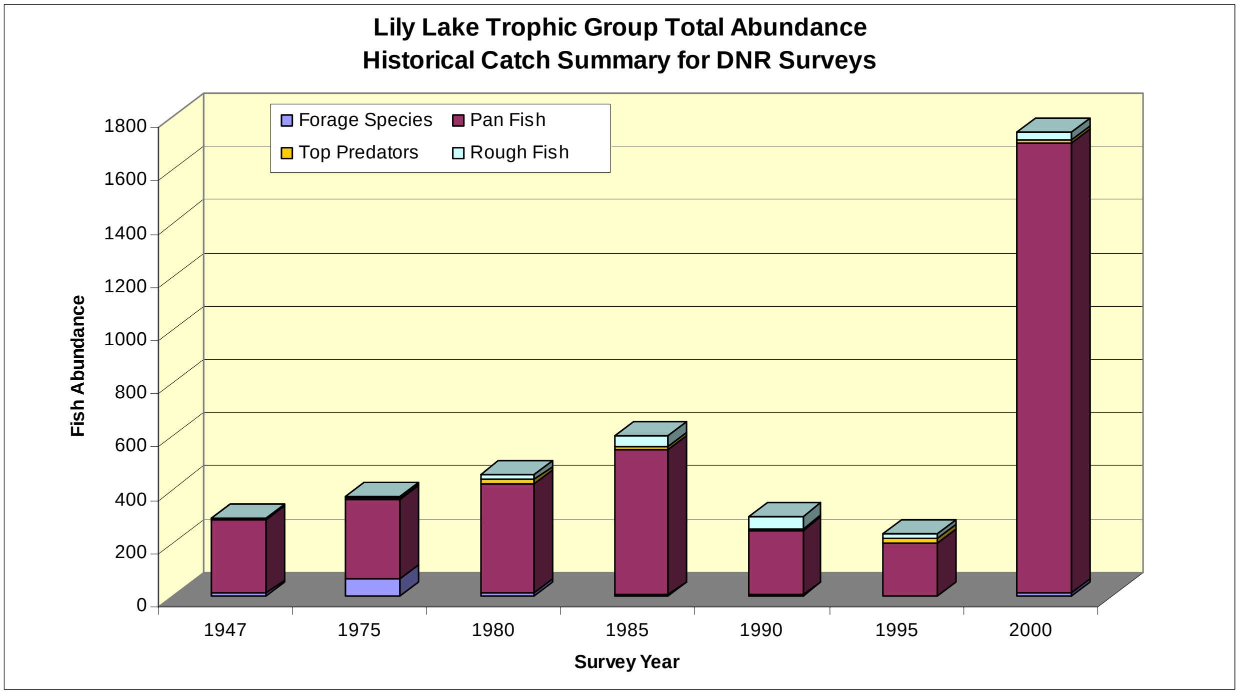
Stormwater is conveyed mostly through a network of storm sewers and ponds. The area was developed prior to implementation of regulations requiring stormwater treatment, so there is minimal pretreatment of runoff. Subwatersheds south and southeast of Lily Lake drain into Brick Pond (82-308W) which drains into Lily Lake. Subwatersheds west, north, and east drain directly to Lily Lake through storm sewers and overland flow. Lily Lake is pumped north to a drainage area that drains north to McKusick Lake.

2.2.1 Recreational Uses

Lily Lake is recreational lake that supports swimming, boating and fishing. The City maintains a beach and public boat ramp on the southern side of the lake and residents along the lake shore have access to the lake.

2.2.2 Fish Populations and Fish Health

Historical fish survey data from DNR collection efforts was reviewed for Lily Lake. There have been a total of seven DNR fish surveys from 1947 through 2000. The fish data was grouped into trophic groups for comparative purposes, which are a better indicator of lake ecological processes than individual species comparisons. The Minnesota DNR fish based lake index of biotic integrity uses trophic metrics such as top carnivore biomass and insectivore abundance to examine fish population health (Drake and Pereira, 2002; Drake and Valley, 2005). Species for Lily Lake were grouped into four trophic groups: forage species, pan fish, top predators, and rough fish. This data is shown in Figure 2. The population of Lily Lake is dominated by panfish across all DNR surveys, comprising 90 percent or more of the total catch. Biomass comparisons revealed that panfish accounted for a large portion of the total biomass but that top predators also account for a significant portion of the fish biomass. Rough fish abundance and biomass has remained fairly consistent across all surveys, and rough fish populations do not appear to be a problem in the lake.



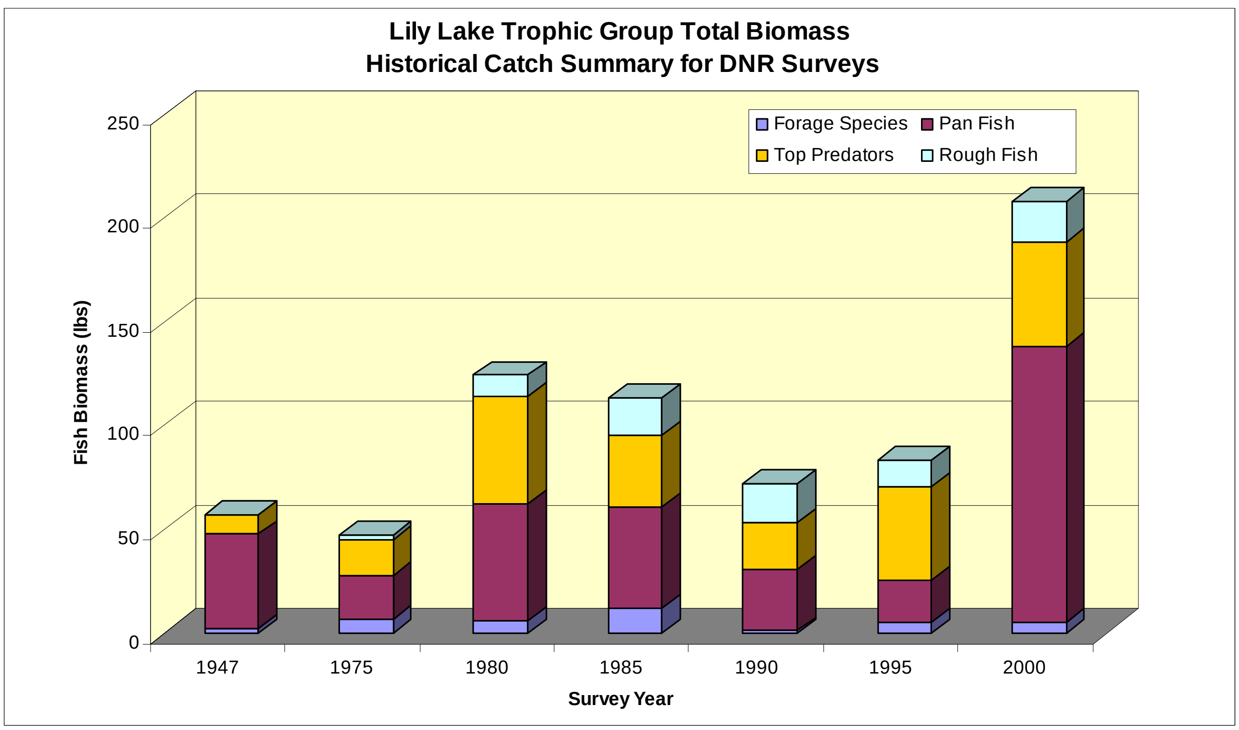


Figure 1. Historic fish survey data.

While fish populations appeared to be stable during the 1975 through the 1995 surveys, panfish abundance and biomass increased dramatically during 2000 survey. Panfish species such as black crappie can become stunted with increasing populations of smaller individuals under lake conditions with increased fertility and excessive submerged macrophyte cover (Schupp, 1992). Top predators, such as largemouth bass and northern pike, can be stocked to help control panfish populations. Review of the DNR Lakefinder data shows that the during the last decade the DNR has been stocking adult northern pike and largemouth bass fry in Lily Lake, which should help to balance the panfish populations. Walleye fingerlings were also stocked in 2001 and a few walleyes were collected in the most recent DNR survey. Walleye spawning habitat is not abundant in Lily Lake but with the amount of available forage in the lake, it is possible for Lily Lake to support a put-grow-take walleye fishery.

2.2.3 Aquatic Vegetation

Aquatic vegetation surveys were conducted on Lily Lake by the DNR in 1975 and 1997, and the results are shown in Figure 3. The lake has experienced an increase in both Robbins and Large Leaf pondweeds as well as filamentous algae. The increase in filamentous algae suggests increased nutrient loads to the lake which are likely enriching lake sediments. However, the plant community is in relatively good shape for an urban lake. Reductions in nutrient loads and shoreline restorations would benefit the aquatic plant community.

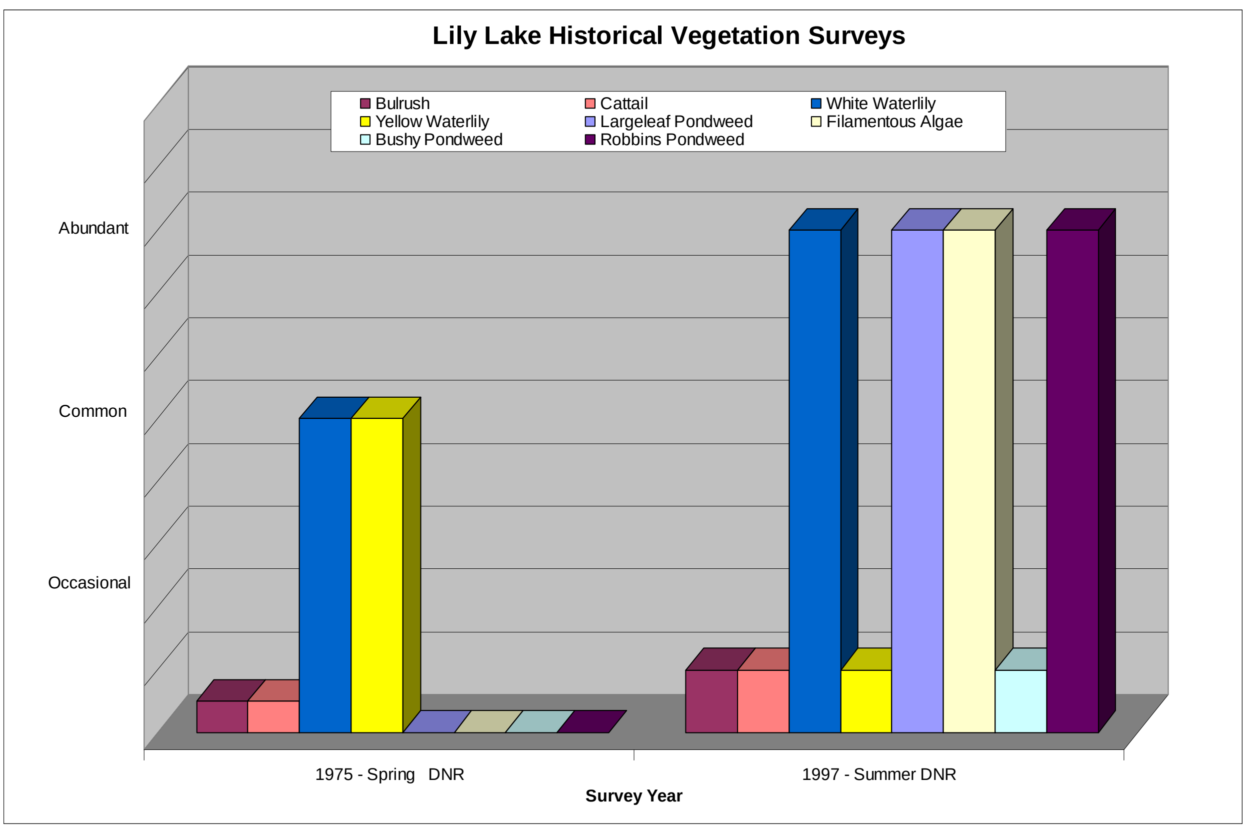


Figure 2. Lily Lake historic aquatic vegetation survey data.

2.2.4 Shoreline Habitat and Conditions

Shoreline conditions on Lily Lake have not been surveyed. Much of the shoreline is developed with a significant portion city parkland. A shoreline survey would be useful for better quantifying shoreline conditions. However, opportunistic shoreline restoration would benefit Lily Lake (Table A).

2.3 McKusick Lake

McKusick Lake has a surface area of 45 acres, average depth of 3 feet, and an ordinary high water level of 851.7 feet. McKusick Lake is a shallow lake with a maximum depth of 10 feet and is 100% littoral.

McKusick Lake receives stormwater runoff from a 2,200 acre, partially developed urban watershed. The McKusick Lake watershed is approximately 63% single family residential, 16% multi-family residential, 12% open water, and 9% agriculture, wetlands, and undeveloped area. The contributing area west of the Brown’s Creek Diversion Structure is comprised of 35% agriculture, 24% single family residential, 23% undeveloped, 7% golf course, and 10% institutional, commercial, wetlands, open water, and multifamily residential. Drainage from Long Lake and Lily Lake comprise approximately 4,400 acres of additional contributing area. The total contributing area is 6,600 acres and is primarily west and south of McKusick Lake. The contributing area (excluding Lily and Long Lake drainage) extends south to Olive Street West; west nearly to Lake Elmo Ave North; north to McKusick Road North; and east to Everett Street North (see Figure 1).

Stormwater is conveyed mostly through a network of storm sewers, channels, and ponds. Development occurred prior to implementation of regulations requiring stormwater treatment, so there is minimal pretreatment of runoff. Subwatersheds southwest of McKusick Lake drain into an unnamed wetland system (82-306W) which drains to separate wetland and into McKusick Lake. Subwatersheds south of McKusick Lake including drainage from Lily Lake bypasses the unnamed wetland system (82-306W) and drains into McKusick Lake. Subwatersheds east and north drain directly into McKusick Lake via storm sewer and stormwater ponds. Subwatersheds downstream of the Brown’s Creek Diversion Structure (BCDS) drain into McKusick Lake via storm sewer and channels. The contributing area upstream of the Brown’s Creek Diversion Structure is comprised of primarily agricultural land west of the diversion structure and Long Lake drainage south of the diversion structure.

2.3.1 Recreational Uses

McKusick Lake does not have a public beach or access, however many residents use the lake for wading. Motors are currently prohibited on McKusick Lake.

2.3.2 Fish Populations and Fish Health

Fish population data was not available from the Minnesota DNR for McKusick Lake. A lake resident on McKusick Lake provided photographs of a recent winter fish kill (Appendix A). Based on these photos the dominant species in McKusick Lake is bluegill. The majority of the small fish in most of the photos appear to be bluegills but green sunfish, pumpkinseed sunfish and hybrid sunfish may also be present. The additional species identified from the photos include yellow perch, black crappie and northern pike. Both yellow perch and black crappie are piscivorous during their adult stages but prefer to feed on minnows and would not be effective predators in controlling the large bluegill population. Northern pike is a top predator that is capable of providing top-down control on a large bluegill population but northern pike do not appear to be abundant in McKusick Lake. However, in shallow lakes such as McKusick, a natural mechanism of top down control on panfish and roughfish populations is winter fish kills.

Figure 3. Evidence of recent fish kill on McKusick Lake.

2.3.3 Aquatic Vegetation

Two plant surveys have been conducted on McKusick Lake. The first was conducted in 1958 by the DNR. The second was completed in 2007 by the Washington Conservation District. The 1958 survey demonstrated a relatively diverse native plant community including such species as sago and narrow leaf pondweeds. However, the most recent survey has demonstrated a shift to a coontail dominated plant community. This type of shift is common in lakes experiencing eutrophication and is indicative of nutrient enrichment in the sediments. Although the lake is currently in a healthy clear water state, the shift in the plant community suggests that the lake is moving closer to a point where it could easily shift into a turbid water state. There is likely a viable native seed bed still in the lake which might be invigorated through a whole lake draw-down.

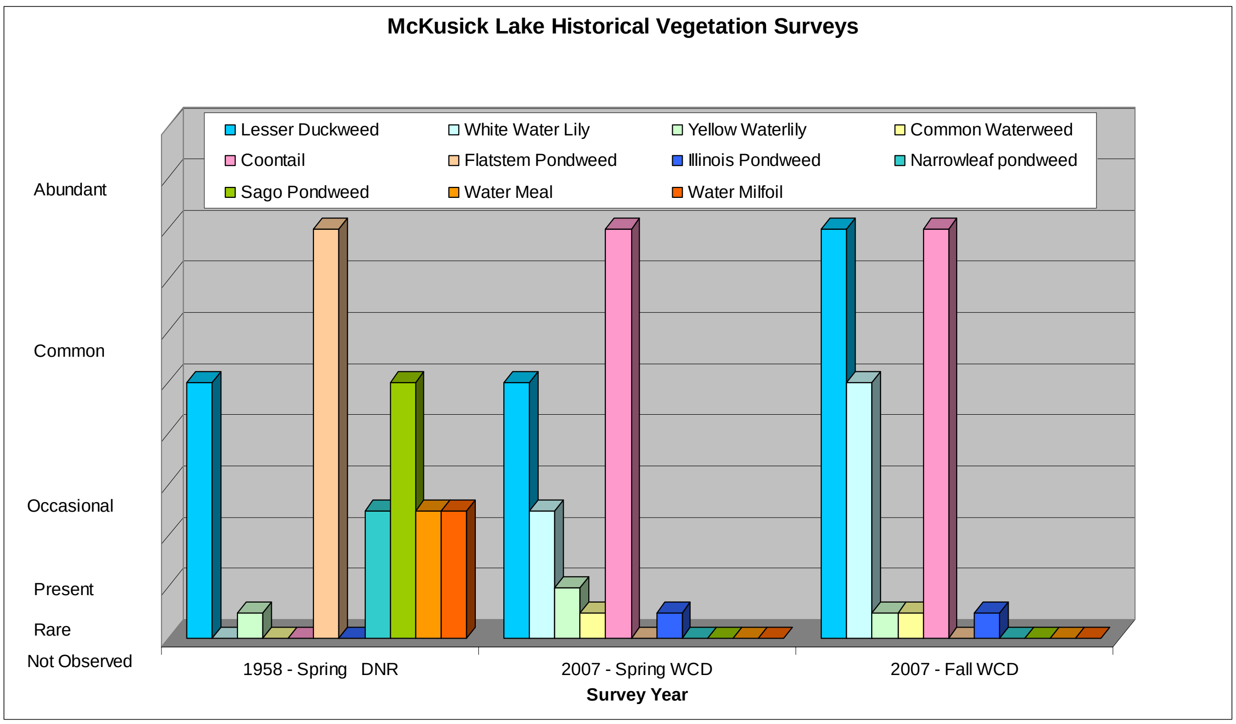


Figure 4. McKusick Lake historic vegetation surveys.

2.3.4 Shoreline Habitat and Conditions

Shoreline conditions on McKusick Lake have not been surveyed. Much of the shoreline is developed with a significant portion in the boulevard on the east side of the lake. A shoreline survey would be useful for better quantifying shoreline conditions. However, opportunistic shoreline restoration would benefit McKusick Lake.

3.0 Nutrient Source Assessment

3.1 Introduction

Understanding the sources of nutrients to the lakes is a key component in identifying appropriate lake management techniques. In this section, we provide a brief description of the potential sources of phosphorus to the lakes.

3.2 Stormwater

Phosphorus transported by stormwater represents one of the largest contributors of phosphorus to lakes in Minnesota. In fact, phosphorus export from urban watersheds rivals that of agricultural watersheds. Impervious surfaces in the watershed improve the efficiency of water moving to streams and lakes resulting in increased transport of phosphorus into local water bodies. Phosphorus in stormwater is a result of transporting organic material such as leaves and grass clippings, fertilizers, and sediments to the water body. Consequently, stormwater is a high priority pollution concern in urban and urbanizing watersheds.

Local storm sewer systems increase the efficiency of urban runoff transport to local water bodies. As a result, other materials are transported to the water bodies including grass clippings, leaves, car wash wastewater, and animal waste. All of these materials contain phosphorus which can impair local water quality. Some of the material may add to increased internal loading through the breakdown of organics and subsequent release from the sediments. Additionally, the addition of organic material increases the sediment oxygen demand further exacerbating the duration and intensity of sediment phosphorus release from lake sediments.

3.3 Fertilizers

Excess fertilizer applied to lawns is readily transported to local streams and lakes during runoff events and is immediately available for algal growth. Consequently, excess fertilizer represents a significant threat to lake water quality in urban watersheds.

3.4 Wetlands

The traditional paradigm for wetlands and water quality is that wetlands act as a sink for nutrients such as nitrogen and phosphorus. However, wetlands, especially in urban areas, can be a source of phosphorus to surface waters in Minnesota. Wetlands in urban areas often receive stormwater runoff that includes significant amounts of nutrients due to the limited treatment and efficient transport through stormwater conveyances. Understanding the nutrient dynamics of wetlands, especially wetlands impacted by urban runoff for a long period, is critical to understanding the nutrient sources to lakes.

3.5 Atmospheric Deposition

Precipitation contains phosphorus that can ultimately end up in the lakes as a result of direct input on the lake surface or as a part of stormwater runoff from impervious surfaces in the watershed. Although, atmospheric inputs must be accounted for in development of a nutrient budget, these inputs are impossible to control.

3.6 Internal Phosphorus Release

Internal phosphorus loading from sources already in lakes has been demonstrated to be an important aspect of the phosphorus budgets of lakes. Measuring or estimating internal loads, however, can be a difficult process which is exacerbated by complex systems such as shallow lakes that may mix many times throughout the year. Internal loads were estimated independently for Lily and McKusick Lakes (Section 5.3.4).

3.7 Lake Exchange

Lakes and bays can exchange nutrients through advection (movement of water carrying nutrients) or diffusion (nutrients moving from high concentration to low concentration). Drainage from Long Lake and Lily Lake is directed via channels and stormwater conveyance to McKusick Lake. The exchange of phosphorus was assumed to be caused by advection and diffusive exchange of nutrients was assumed to be negligible. Furthermore, backwater effects were assumed to have no impact on the exchange process.

4.0 Assessment of Water Quality Data

4.1 Introduction

Lake water quality data is available from the Minnesota Pollution Control Agency (MPCA) in McKusick Lake from 1994 to 2006. Lake water quality measurements in Lily Lake are available as far back as 1947, but regular annual measurements began in 1995.

4.2 Lake Monitoring Parameters

4.2.1 Temperature and Dissolved Oxygen

Understanding lake stratification is important to the development of both the nutrient budget for a lake as well as ecosystem management strategies. Lakes that are dimictic (mix from top to bottom in the spring and fall) can have very different nutrient budgets than lakes that are completely mixed multiple times throughout the year. Temperature difference typically causes stratification in a lake because water density changes with water temperature. Dissolved oxygen, however, can have significant implications as a result of stratification. As cooler, denser water is trapped at the bottom of a lake, it can become devoid of oxygen affecting both aquatic organisms and sediment chemistry. Dissolved oxygen and temperature profiles from 2004 and 2005 were created for McKusick and Lily Lakes.

4.2.2 Phosphorus and Nitrogen

Lake algal production is typically limited by the availability of nutrients, specifically phosphorus and nitrogen. Minnesota lakes are almost exclusively limited by phosphorus but excessive phosphorus concentration can lead to nitrogen-limited conditions. Phosphorus and nitrogen are measured to determine the availability of the nutrients for algal production. Dissolved and ortho-phosphorus are the most biologically available forms of phosphorus and total phosphorus is a measure of all forms of phosphorus including dissolved and particulate. Nitrate is the most biologically available form of nitrogen for algal production and Total Kjeldahl Nitrogen (TKN) is a measure of all forms of nitrogen in the water column.

4.2.3 Chlorophyll-a and Secchi Depth

Algal biomass can be measured directly by developing cell-by-cell counts and volumes. This process, however, is time intensive and often expensive. Chlorophyll-a has been shown to be a good surrogate for algal biomass and is inexpensive and easy to analyze.

Secchi depth is a measure of water clarity and can also be a surrogate for algal production. Secchi depth measurements involve lowering a round disc shaded black and white over the shady side of the boat and recording the depth at which the disc is no longer visible.

4.3 Lily Lake Results

4.3.1 Historical Data

Historic chlorophyll-a, total phosphorus, and Secchi depth for Lily Lake are given in Table 4.1. Total phosphorus concentrations are historically near or above the MPCA standard of 40 µg/L for Lily Lake. Data from 2005 and 2006 do demonstrate higher chlorophyll-a concentrations, however, Secchi disc transparency was fairly typical for the last 10 years. This may be a result of increased filamentous algae blooms that tend to form mats rather than increasing turbidity.

Table 5. Historic data for Lily Lake.

	Chlorophyll-a		Total Phosphorus		Secchi Depth	
Year	**N**	**Growing Season Average [µg/L]**	**N**	**Growing Season Average [µg/L]**	**N**	**Growing Season Average [m]**
1995	--	--	9	47.8	12	2.42
1996	--	--	9	43.3	14	2.08
1997	--	--	10	36.0	15	1.64
1998	--	--	9	48.9	16	1.29
1999	--	--	8	53.8	16	1.37
2000	--	--	9	62.2	9	1.37
2001	4	7.0	9	38.9	9	2.52
2002	8	9.6	8	49.8	8	1.77
2003	4	11.8	4	38.8	4	1.79
2004	4	9.8	4	42.0	4	1.75
2005	4	22.9	4	40.5	4	2.13
2006	4	31.4	4	69.3	4	1.14

4.3.2 Temperature and Dissolved Oxygen

Dissolved oxygen and temperature profiles for 2004 in Lily Lake are shown in Figure 5 and Figure 6. Lily Lake demonstrates stratification with the thermocline typically between 6 and 8 meters (12 and 18 feet respectively). However, dissolved oxygen profiles demonstrate anoxia (<2 mg/L DO) as shallow as 2 meters in depth. This shallow anoxic zone can result in large release rates of phosphorus from the sediments by activating sediment release from a larger area. The shallow anoxic area can also stress fish by providing few refugia with reasonable dissolved oxygen concentrations (>5 mg/L). The shallow anoxic area in Lily Lake is not uncommon in urban lakes that have received decades of nutrient additions from anthropogenic sources.

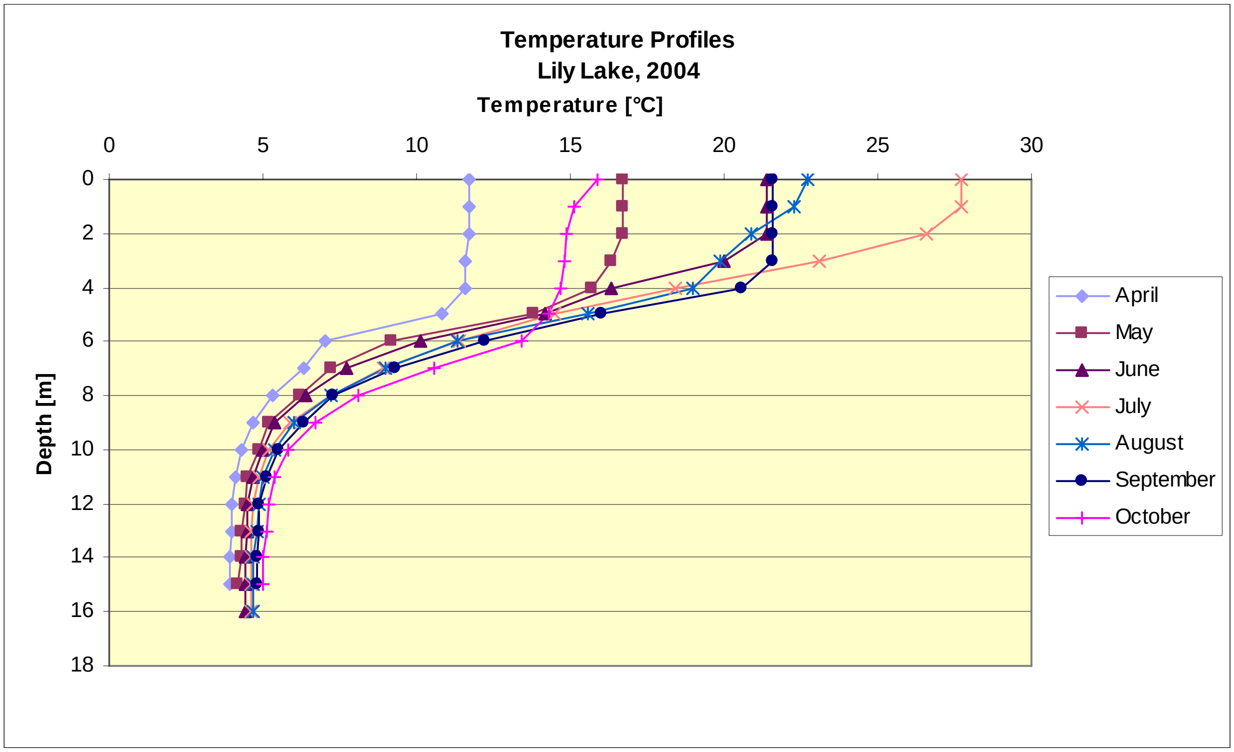


Figure 5. Temperature profile for Lily Lake, 2004.

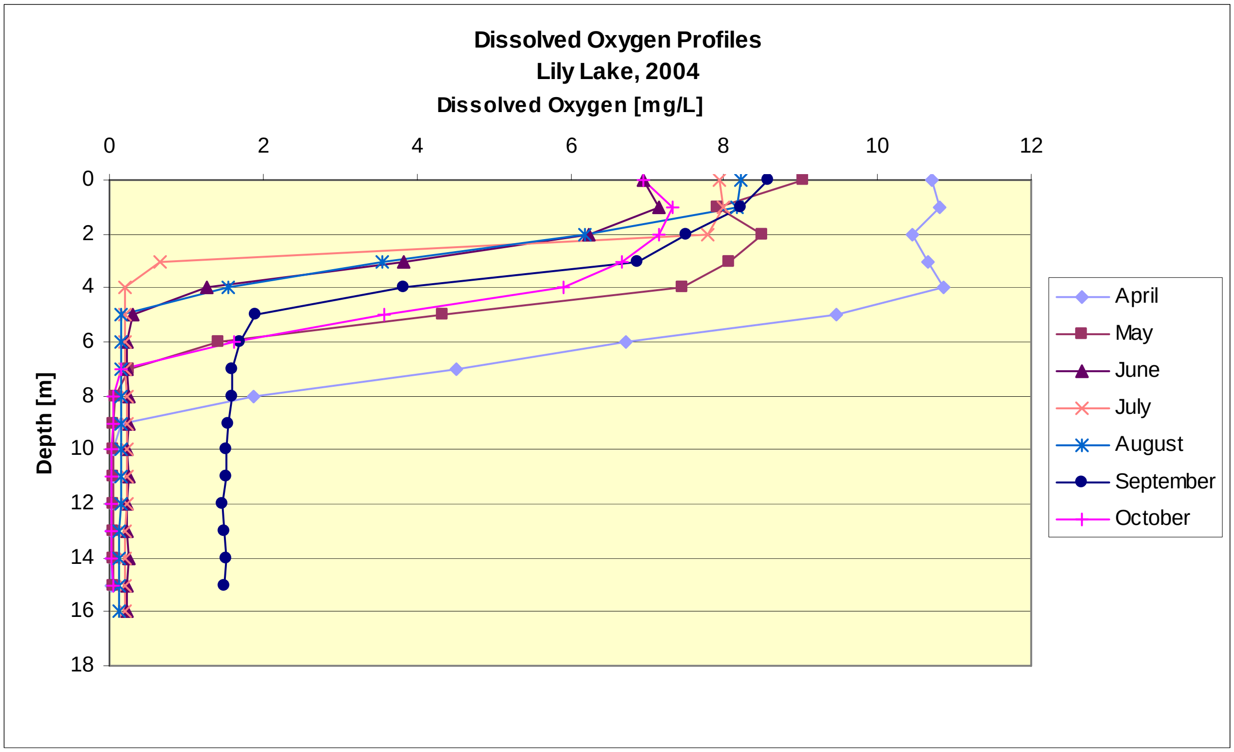


Figure 6. Dissolved Oxygen profile for Lily Lake, 2004.

4.3.3 Phosphorus

Total phosphorus summer average concentrations for Lily Lake are shown in Figure 7. Between 1995 and 2006, total phosphorus concentration ranged from 36 to 69 micrograms per liter. Only 3 out of the 12 years shown were at or below the standard concentration of 40 µg/L. There is no apparent trend in TP concentrations over the past 12 years.

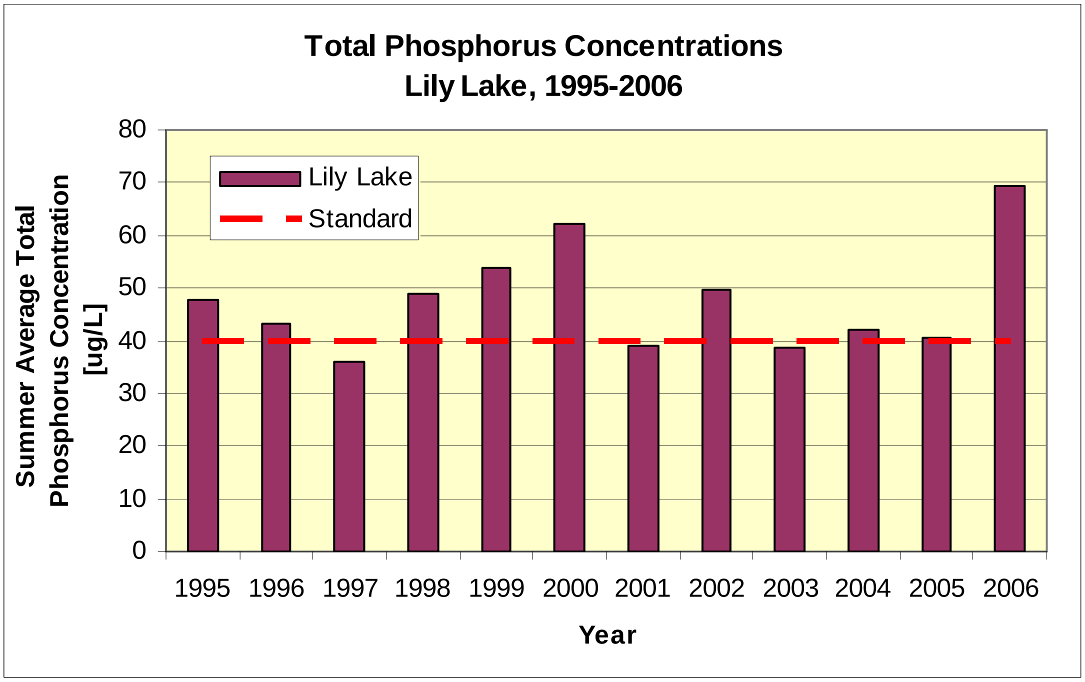


Figure 7. Summer average total phosphorus concentration for Lily Lake, 1995 – 2006.

4.3.4 Chlorophyll-a and Secchi Depth

Although TP concentrations are typically above the State standard of 40 µg/L, Chlorophyll-concentrations have only exceeded the State standard in 2 of the past five years (Figure 8). The difference in the past two years where exceedances of the chlorophyll-a standard have occurred may be a result of changes in the algal community (shift from filamentous to blue-green algae) or a loss of zooplankton grazing with an increase in the panfish population. Either way, the lake is beginning to demonstrate signs of eutrophication that need to be addressed.

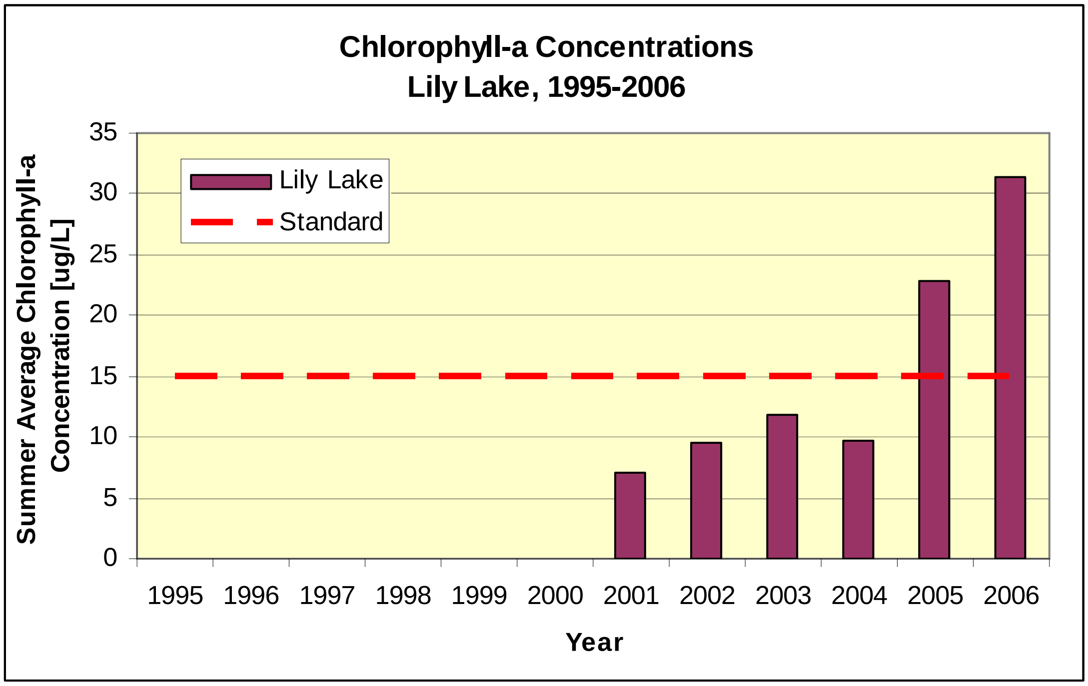


Figure 8. Summer average chlorophyll-a concentration for Lily Lake, 1995 – 2006.

Summer average Secchi depth measurements are shown in Figure 9. Secchi depth is a measure of water clarity and can also be a surrogate for algal production. Eleven out of the twelve years shown were at or above the standard Secchi depth of 1.2 meters.

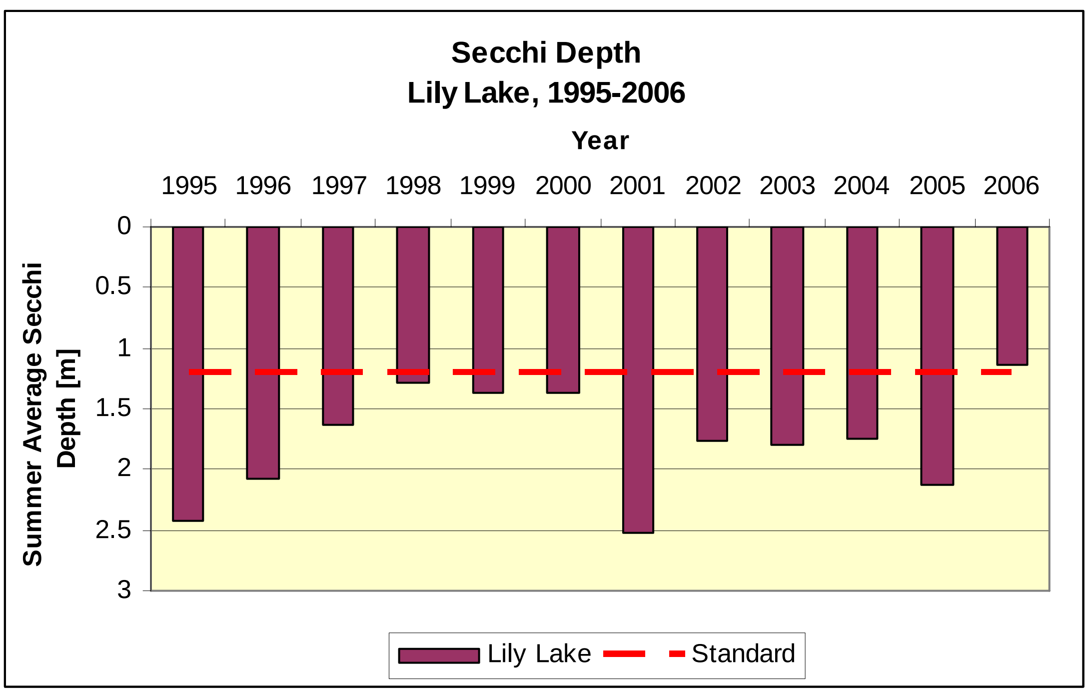


Figure 9. Summer average Secchi depth for Lily Lake, 1995 – 2006.

4.4 McKusick Lake

4.4.1 Historical Data

Historic chlorophyll-a, total phosphorus, and Secchi depth for McKusick Lake are presented in Table 6. Total phosphorus growing season average concentrations are at or below the MPCA standard during three of the six years in which measurements were taken.

Table 6. Historic data for McKusick Lake.

	Chlorophyll-a		Total Phosphorus		Secchi Depth	
Year	**N**	**Growing Season Average [ug/L]**	**N**	**Growing Season Average [ug/L]**	**N**	**Growing Season Average [m]**
1994	--	--	--	--	8	0.85
1995	--	--	--	--	8	1.04
1996	--	--	--	--	9	0.99
1997	--	--	--	--	10	1.24
1998	--	--	--	--	8	0.99
1999	--	--	--	--	8	0.84
2000	--	--	--	--	10	2.51
2001	4	15.8	4	40.0	9	2.20
2002	8	30.9	8	69.3	8	1.09
2003	8	10.3	8	44.3	8	1.81
2004	9	5.1	9	34.1	9	2.59
2005	7	20.6	8	58.5	8	1.85
2006	9	16.8	9	71.6	9	2.07

4.4.2 Temperature and Dissolved Oxygen

Dissolved oxygen and temperature profiles for McKusick Lake in 2004 are shown in Figure 10 and Figure 11. Stratification is less common in shallow lakes because wind shear can cause turbulence in shallow lakes sufficient enough to mix the lake throughout the depth of the water column. However, McKusick Lake does demonstrate dissolved oxygen stratification with anoxia reaching as shallow as 2 meters in depth. During these anoxic periods, phosphorus can be released into the water column. This phosphorus is then readily available for algal production. This type of internal loading is typical in eutrophic shallow lakes. However, these data suggest that internal loading may become problematic for maintaining a clear water state in McKusick Lake.

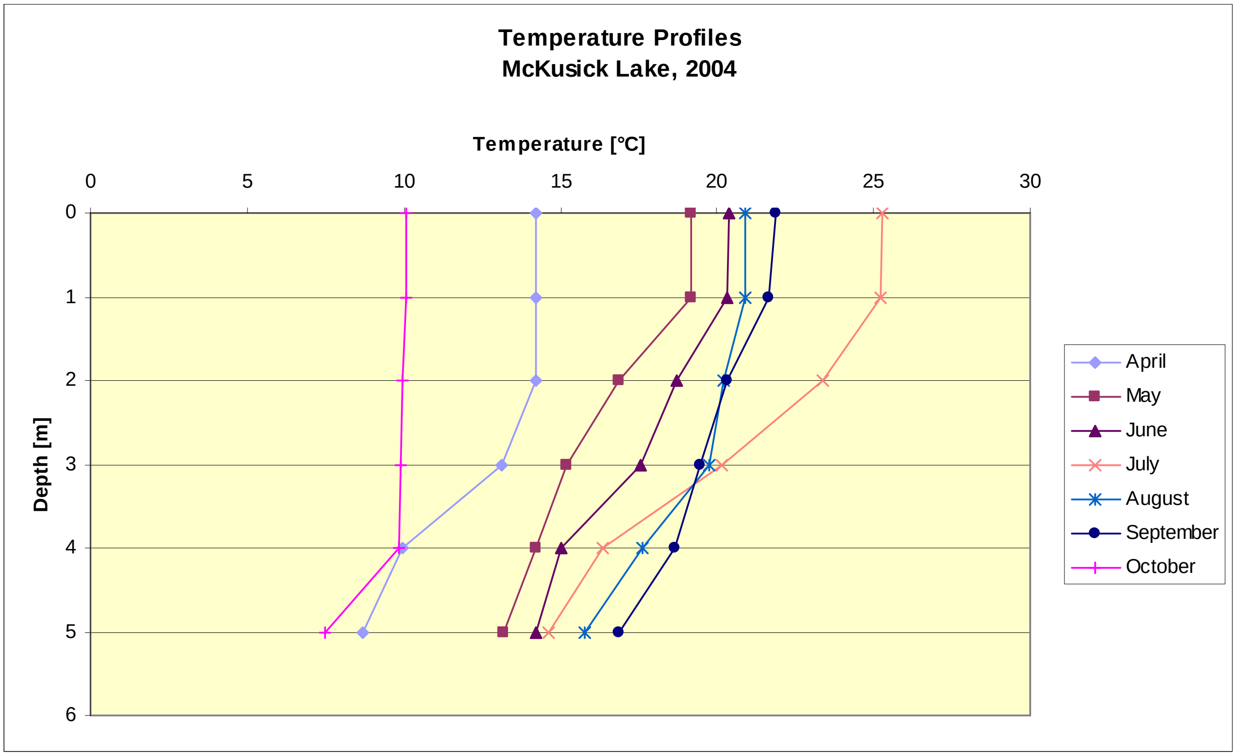


Figure 10. Temperature profile for McKusick Lake, 2004.

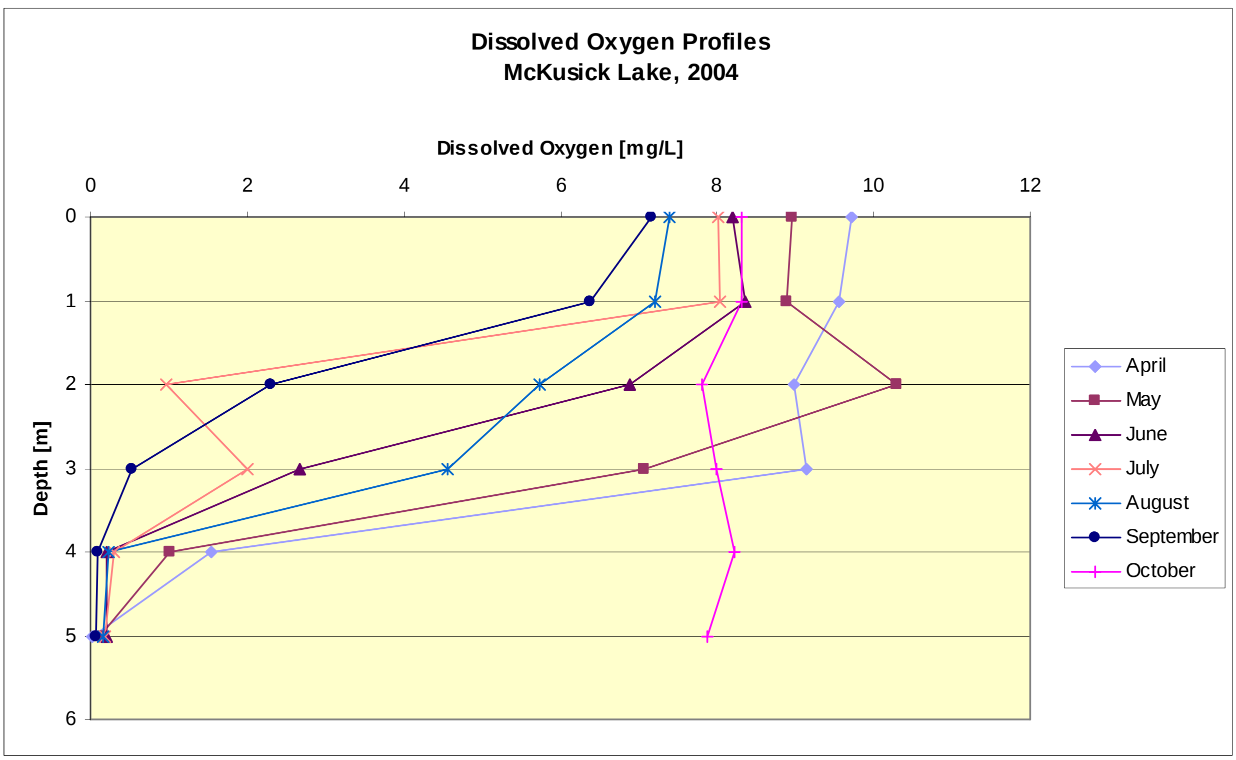


Figure 11. Dissolved Oxygen profile for McKusick Lake, 2004.

4.4.3 Phosphorus

Total phosphorus summer average concentration for McKusick Lakes is shown in Figure 12. Between 1995 and 2006, total phosphorus concentration ranged from 34 to 69 micrograms per liter. Only 2 out of the 6 years shown were above the standard concentration of 60 micrograms per liter.

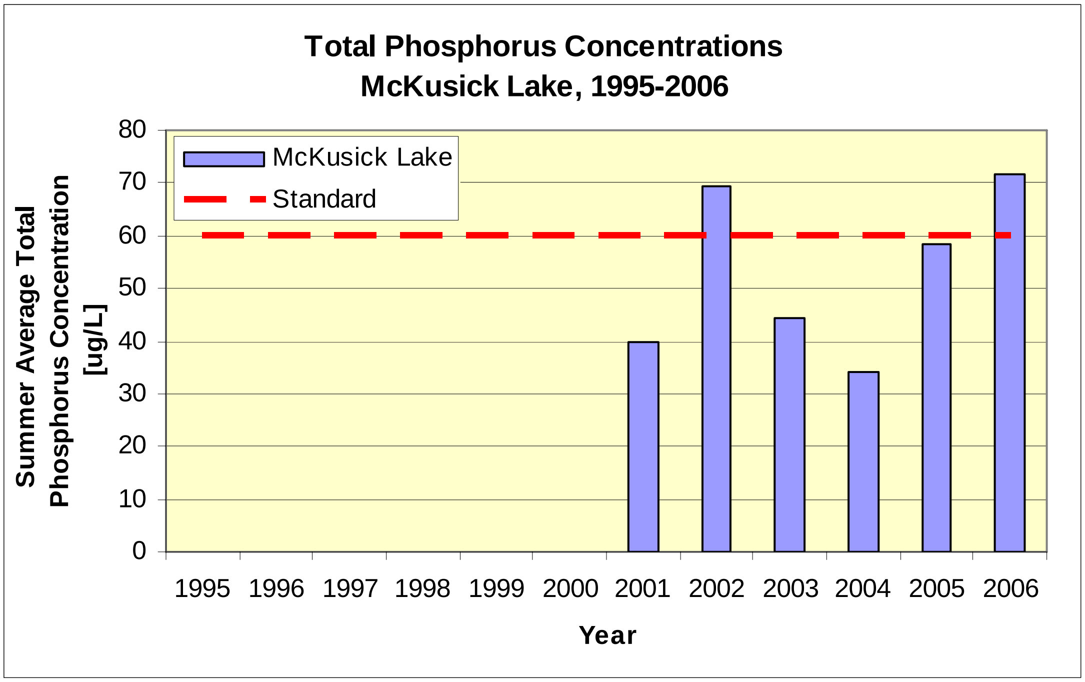


Figure 12. Summer average total phosphorus concentration for McKusick Lake, 1995 – 2006.

4.4.4 Chlorophyll-a and Secchi Depth

Four out of the six years shown were below the standard concentration of 20 micrograms per liter chlorophyll-a (Figure 13) while 7 of the past twelve years met the Secchi disc transparency standard (>1 meter). In fact, McKusick Lake did not meet the State standard in one of the past six years. Secchi depth is a measure of water clarity and can also be a surrogate for algal production.

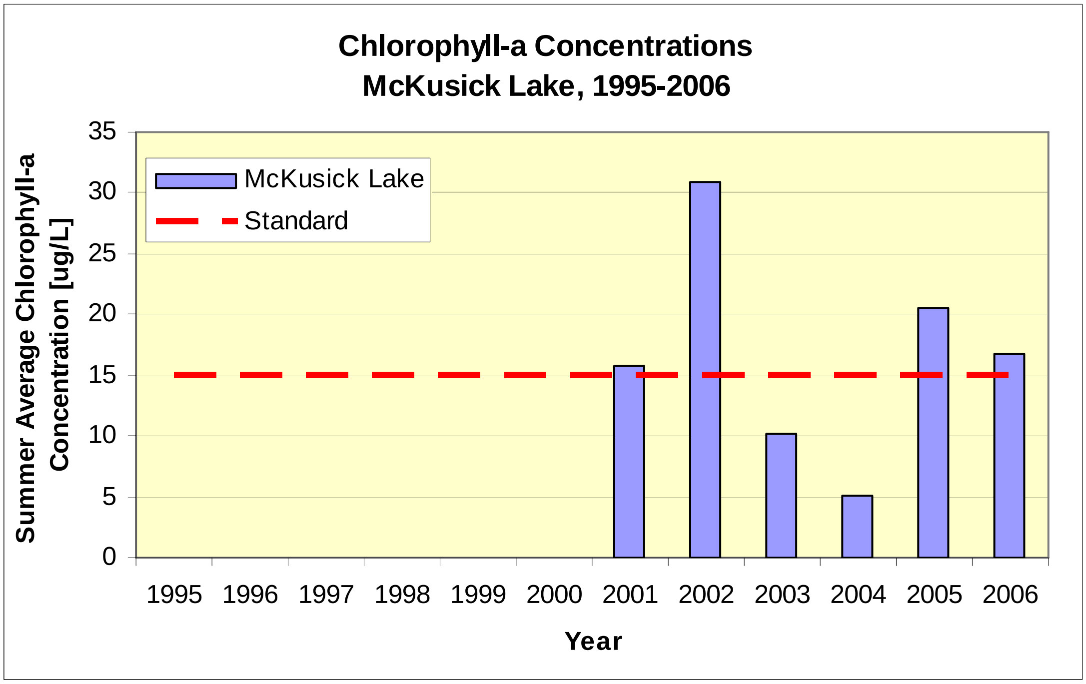


Figure 13. Summer average chlorophyll-a concentration for McKusick Lake, 1995 – 2006.

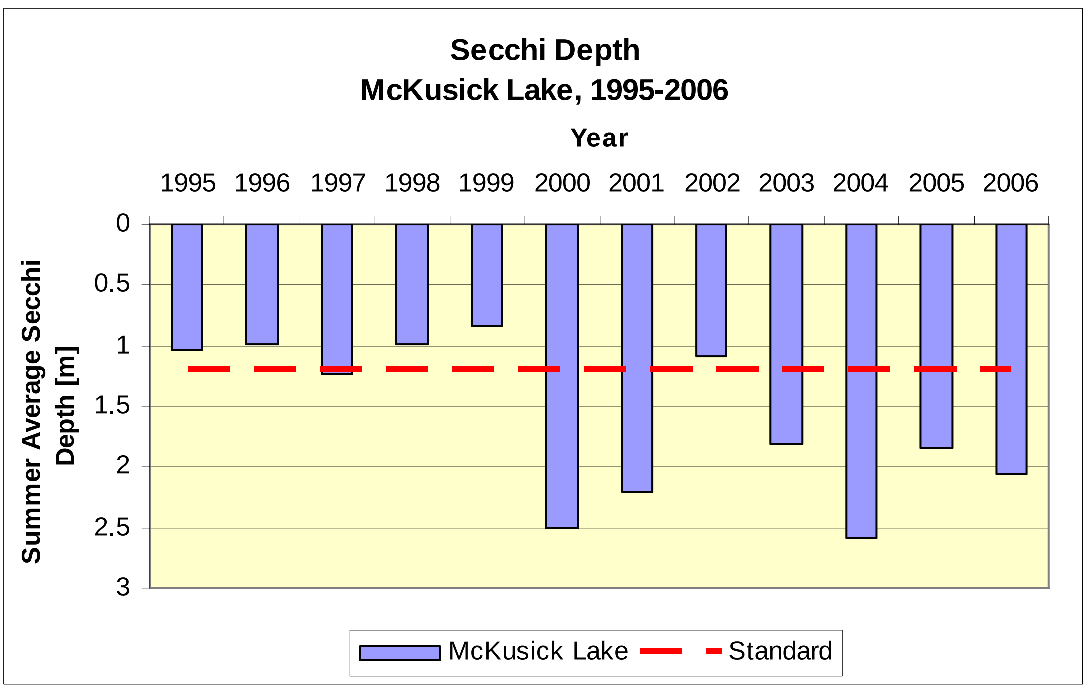


Figure 14. Summer average Secchi depth for McKusick Lake, 1995 – 2006.

4.5 Conclusions

Lily Lake is currently demonstrating some signs of eutrophication with exceedances occurring for both total phosphorus and chlorophyll-a. However, water clarity is relatively good, with most years at or better than the State standard for deep lakes in the North Central Hardwood Forest ecoregion. Data for recent years is relatively sparse with only four samples collected in each year over the past four years. However, lake conditions appear to have remained the same over the past ten years. Lily Lake has a dominant panfish population which can exhibit heavy predation pressure on zooplankton. The DNR has been stocking top predators which should help control panfish populations. Overall, the most likely driver for eutrophication in Lily Lake is increased phosphorus loading from the watershed.

In general, McKusick Lake has fairly good water clarity for an urban shallow lake. However, there is some evidence of eutrophication. Both total phosphorus and chlorophyll-a have exceeded the state standards over the past ten years. Water clarity is likely maintained by the presence of a relatively healthy aquatic vegetation and zooplankton community. The documented occurrence of fish kills actually helps increase water clarity by reducing planktivorous fish, in turn reducing the predation pressure on zooplankton. Consequently, the absence of rough fish and the occurrence of fish kills to control planktivorous fish populations are maintaining the current clear water conditions in McKusick Lake.

5.0 Linking Water Quality Targets and Sources

5.1 Introduction

A detailed nutrient budget for Lily and McKusick Lakes can be a useful tool for identifying management options and their potential effects on water quality. Additionally, models can be developed to understand the response of other variables such as chlorophyll-a and Secchi depth. Through this knowledge, managers can make educated decisions about how to allocate restoration dollars and efforts as well as the resultant effect of such efforts.

5.2 Selection of Model and Tools

Modeling of the McKusick and Lily Lakes system included use of P8 (Walker 2007), Pondnet, and model equations extracted from BATHTUB (Walker 1996). The watershed hydraulics and pollutant loading rates were estimated with P8 models that were calibrated to monitored data, where available. Pondnet was used to estimate the transport and treatment of the outflow from lakes through ponds to downstream lakes where necessary. Output from P8 and Pondnet was used as input into the BATHTUB model equations in spreadsheet format to predict lake response to hydraulic and pollutant loading.

5.3 Current Phosphorus Budget Components

The phosphorus budget for Lily and McKusick Lakes includes watershed loads through stormwater runoff, upstream load (i.e., Long and Lily Lake outflow to McKusick), atmospheric load, and internal load from lake sediments. These components are described in detail in the sections below.

5.4 Watershed Loads

Watershed phosphorus loads were estimated using P8 models calibrated to monitoring data, where available. Separate P8 models were developed for the Lily Lake subwatershed (Lily), McKusick Lake subwatershed (McKusick), and the northwest annexed area subwatershed (NW), respectively. Monitoring data at the Brown's Creek Diversion Structure was used to calibrate the NW P8 model for runoff and pollutant loading. Calibration included modification of the impervious runoff coefficient (from 1.0 to 0.45) to match hydraulic loading and the scale factor for particle loads (from 1.0 to 1.38) to match pollutant loading. The Lily and McKusick Lake subwatershed models were not calibrated because monitoring data was not available. Watershed hydraulic and pollutant loads can be found in Appendix B within the Lake Response Modeling Data.

5.4.1 Upstream Loads

Watershed, atmospheric, and internal loads for Lily Lake were used as input for BATHTUB model equations to predict response in Lily Lake. Pondnet was used to estimate the transport and treatment of Lily Lake outflow from the Lily Lake outlet, through a series of ponds, to McKusick Lake. The output from Pondnet was used as an upstream input load for McKusick Lake.

Long Lake summer average total phosphorus concentration and previously modeled XPSWMM results (provided by the BCWD) were used to estimate the outflow from Long Lake. Pondnet was then used to estimate the transport and treatment of Long Lake outflow from the Long Lake outlet, through a series of ponds, to the Brown's Creek Diversion Structure. The output from Pondnet was used as an upstream input load for McKusick Lake.

5.4.2 Atmospheric Load

Atmospheric loads were estimated using published literature values for aerial loading rates (14.91 kg/km^2-yr for an average precipitation year) in Minnesota (Barr Engineering 2004). Aerial loading rates were multiplied by lake surface area to determine the annual loading rate (kg/yr) due to atmospheric deposition.

5.4.3 Internal Load

Internal phosphorus loading from sources already in lakes has been demonstrated to be an important aspect of the phosphorus budgets of lakes. Measuring or estimating internal loads, however, can be a difficult process, exacerbated by complex systems such as shallow lakes that may mix many times throughout the year. Internal loads were estimated independently for Lily and McKusick Lakes.

5.4.4 Lily Lake Internal Load

Internal loading for Lily Lake was estimated using the anoxic factor (days) and phosphorus release rate (mg/m2-day) (Nürnberg 1988). The anoxic factor was estimated using the depth of anoxia (from dissolved oxygen profiles, see section 4.4.1.2) and the surface area of the anoxic zone. The release rate was estimated from literature values. Calibration of the water quality response in Lily Lake included modification of the phosphorus release rate to predict measured in-lake total phosphorus concentration more accurately (section 5.5).

5.4.5 McKusick Lake Internal Load

Internal loading for McKusick Lake was estimated using the anoxic factor (days) and phosphorus release rate (mg/m2-day) (Nürnberg 1988). The anoxic factor was estimated using a relationship based on surface total phosphorus concentration and lake geometry (Nürnberg 1995). The release rate was estimated from literature values. Calibration of the water quality response in McKusick Lake included modification of the phosphorus release rate to predict measured in-lake total phosphorus concentration more accurately (section 5.5).

5.5 Current Phosphorus Budget

Modeled data from 2003 to 2006 was used to estimate the current sources of phosphorus to Lily and McKusick Lakes. The hydraulic and phosphorus budget for Lily and McKusick Lakes is presented in Table 7 and Table 8, respectively.

The Lily Lake subwatershed contributes 100% of the hydraulic load and 93% of the phosphorus load to Lily Lake while atmospheric deposition and internal load contribute the remaining 7% phosphorus load. Hydraulic loading for McKusick Lake is contributed by Lily Lake (46%), Long Lake (33%), the northwest annexed area (11%), and the contributing subwatershed (10%), respectively. Phosphorus loading for McKusick Lake is contributed by the northwest annexed area (44%), Long Lake (20%), Lily Lake (18%), the contributing subwatershed (18%), and atmospheric deposition (1%), respectively.

Table 7. Current total phosphorus budget for Lily Lake, 2003 - 2006.

	2003	2004	2005	2006
Precipitation [in]				
Calendar Year	28.4	29.2	32.7	31.6
Annual Inflow Volume [ac-ft]				
Drainage Areas	579	661	663	521
Upstream Lakes	N/A	N/A	N/A	N/A
Atmosphere	0	0	0	0
TOTAL =	579	661	663	521
Annual Total Phosphorus Load [lb]				
Drainage Areas	250	303	309	264
Upstream lakes	N/A	N/A	N/A	N/A
Atmosphere	5	5	5	5
Internal (1 mg/m^2-day)	17	17	17	17
TOTAL =	272	324	331	285

Table 8. Current total phosphorus budget for McKusick Lake, 2003 - 2006.

McKusick Lake	**2003**	**2004**	**2005**	**2006**
Precipitation [in]				
Calendar Year	28.4	29.2	32.7	31.6
Growing Season	10.9	12.3	18.9	14.8
Growing Season Inflow Volume [ac-ft]				
Drainage Areas	85	95	143	109
Annexed Area	108	78	152	98
Lily Lake through 4p and 11p	496	594	438	349
Long Lake through diversion	314	353	376	322
Atmosphere	0	0	0	0
TOTAL =	1002	1121	1107	879
Growing Season Total Phosphorus Load [lb]				
Drainage Areas	51	66	97	84
Annexed Area	145	149	248	200
Lily Lake through McK 11p	73	90	71	67
Long Lake through diversion	81	73	96	89
Atmosphere	6	6	6	6
Internal (0 mg/m^2-day)	0	0	0	0
TOTAL =	355	383	518	447

The most significant phosphorus source to Lily and McKusick Lakes is the contributing watersheds. The northwest annexed area is primarily undeveloped or agricultural land with minimal stormwater treatment and contributes 44% of the phosphorus load entering McKusick Lake. In combination with the McKusick Lake subwatershed, 61% of the phosphorus load to McKusick Lake comes from drainage areas. Similarly, 93% of the phosphorus load to Lily Lake is generated and transported through the subwatershed.

5.6 Water Quality Response Modeling

Model equations from BATHTUB were used to estimate the in-lake response to hydraulic and pollutant loads from 2003 to 2006 in Lily and McKusick Lakes. Several models are used within the BATHTUB model. The Canfield-Bachmann model for natural lakes was used to estimate lake response for phosphorus. Diffusive exchange of nutrients is expected to be negligible because the McKusick Lake is connected to Lily and Long Lakes via channels and stormwater pipes.

Model 1 from BATHTUB is used to estimate chlorophyll-a concentration as a function of nitrogen, phosphorus, light, and flushing rate. BATHTUB model 1 was modified and used to estimate Secchi depth as a function of chlorophyll-a and non-algal turbidity. The coefficient for chlorophyll-a concentration was modified from 0.025 to 0.015 (Steve Heiskary, pers. comm.) to represent shallow lake systems more accurately. Detailed model results are presented in Appendix B.

The lake response model for in-lake total phosphorus predicted larger in-lake phosphorus concentrations than was observed in all years (2003 – 2006) for both Lily and McKusick Lakes. To compensate for the difference, the internal loading rate was reduced by adjusting the phosphorus release rate. After reducing the internal load to one, the in-lake phosphorus model approximately predicted measured in-lake total phosphorus concentrations for Lily Lake in 2006 only. Without additional data, it is difficult to identify the role of internal loading in Lily Lake. Hypolimnetic samples or measured sediment release rates would further clarify the role of internal loading. Because Lily is a deep lake, it is appropriate to focus on external loads and monitor the response of the lake.

5.6.1 Model Validation

The results from the in-lake phosphorus response model are compared to measured in-lake phosphorus concentrations as shown in Figure 15 and Figure 16 for Lily and McKusick Lakes, respectively.

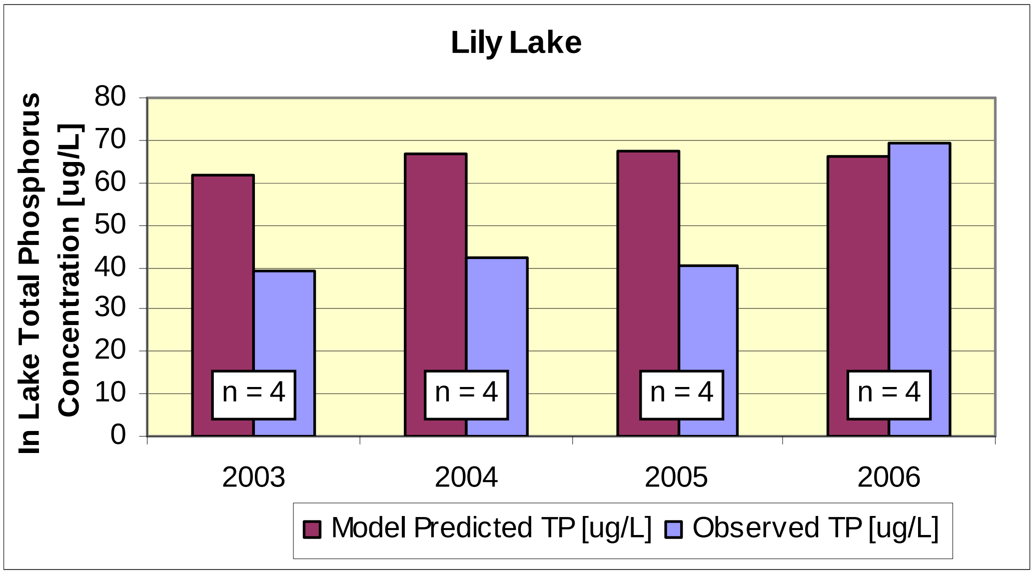


Figure 15. In-lake phosphorus model comparison to measured in-lake total phosphorus for Lily Lake, 2003 – 2006.

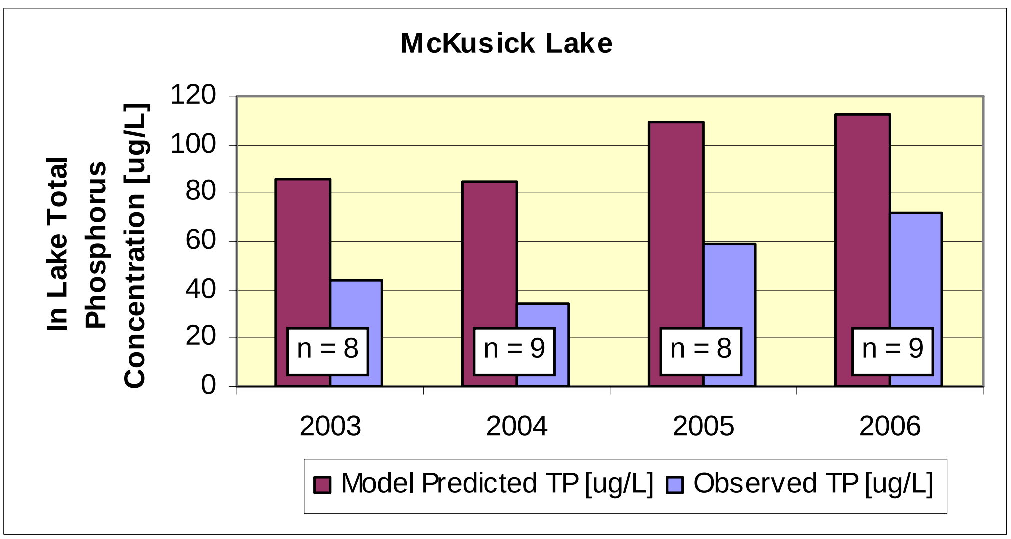


Figure 16. In-lake phosphorus model comparison to measured in-lake total phosphorus for McKusick Lake, 2003 - 2006.

Annual hydraulic and phosphorus loads were used to estimate the in-lake total phosphorus response in Lily Lake, which is a deep lake. For shallow lakes, however, In-lake total phosphorus concentration is strongly influenced by the biological and physical processes that occur the growing season. Therefore, growing season hydraulic and phosphorus loads were used to estimate the in-lake phosphorus response in McKusick Lake because the lake is a shallow lake system.

The in-lake phosphorus response model predicts a larger phosphorus concentration than measured values. There are two possible explanations for this difference. McKusick Lake exhibits a large filamentous algae bloom that is typically not sampled as a part of routine water quality monitoring. Much of the TP load to the lake is tied up in the filamentous algal mass and therefore not accounted for in the monitoring data. The second possible explanation is that shallow lakes typically demonstrate higher sedimentation rates due to high levels of zooplankton grazing. This effect is not accounted for in the Canfield-Bachmann equation, and would therefore over-predict in lake concentrations.

For Lily Lake, the poor calibration is likely due to the relatively small data set available for Lily Lake. Only four samples were collected in each of the past four growing seasons. Better data may lead to better calibration.

5.7 Conclusions

Although the models over-predicted phosphorus concentrations in the lakes, they still provide a relative target for nutrient reductions. By maintaining the over predicted concentrations, reduction targets are conservative and ultimately over protective of water quality. However, this management plan is intended to be implemented adaptively, allowing for monitoring of the success of implemented practices. Ultimately, this plan is an aggressive approach to restoring water quality in the lakes while providing a monitoring plan to prevent unnecessary expenditures.

6.0 Management Targets

6.1 Issues

This diagnostic study identifies several issues and concerns affecting water quality in Lily and McKusick Lakes. These issues fall into five categories:

Swimmability – nuisance algal blooms, the threat of fecal contamination and swimmers itch occurrences, and invasive aquatic plants impeding swimming.

Fishability – healthy and diverse fish communities, assure fish are safe to eat, and assure that aquatic vegetation does not impede fishing access.

Aesthetics – displeasing odors, water clarity, nuisance algal blooms, and shoreline environments.

Diversity of plants and wildlife – need to remove exotic plant and animals and prevent occurrences, increase numbers and species of native plants and animals, improve wildlife habitat, and assure toxic agents are not inhibiting wildlife diversity.

Shoreline environment – need to manage shorelines to enhance filtration of runoff, provide natural water/land transitions, and prevent the formation of deltas.

6.2 Goals

Given the issues raised in this diagnostic study, the following goals are proposed to guide the management of McKusick and Lily Lake and their respective watersheds. These goals fall into three categories – recreation, environmental preservation, and lake management education.

<u>Recreational Use</u>

16. Reduce nuisance algal blooms and improve water clarity
17. Protect public health from fecal contamination, swimmer's itch, toxic chemicals, or other toxic agents.
18. Reduce the potential for aquatic vegetation to impede swimming and fishing in designated areas
19. Promote healthy and diverse fish communities

Environmental Preservation

20. Prevent the introduction of exotic plants and eliminate current exotic populations
21. Preserve aquatic wildlife habitat including fish spawning areas
22. Achieve a healthy and diverse community of native plants and animals
23. Provide a natural land/water interface that reduces runoff and enhances pollutant filtration while providing access for recreational use of the lakes.
24. Manage watershed runoff to reduce sediment and pollutant transport to the lakes

Lake Management Education

25. Assure that decision makers have an understanding of lake ecology basics so they can make informed decisions about lake management
26. Identify target audiences
27. Raise awareness of boundaries of McKusick and Lily Lake watershed
28. Raise awareness of nonpoint source pollution and its effects on lake water quality
29. Provide general and targeted information in various formats
30. Provide opportunities for active reinforcement of behavioral change

6.3 Management Targets

Goal 1. Reduce nuisance algal blooms and improve water clarity

Minnesota's standards include narrative criteria for nutrients which limits the quantity of nutrients which may enter the waters. These standards state that all Class 2 waters of the State shall be free from any material increase in undesirable slime growths or aquatic plants including algae. The MPCA has developed "numeric translators" for lakes and uses those translators to determine the impairment status of lakes. The translators are based on the known relationship between phosphorus concentrations and levels of algae growth. The numeric standards indicate the point at which the average lake will experience severe nuisance blooms of algae.

A water quality standards rules revision is in progress in Minnesota. The proposed rules would establish different standards for deep and shallow lakes, taking into account nutrient cycling differences between shallow and deep lakes and resulting in more appropriate standards for Minnesota lakes. The State proposed numeric standards shown in Table 9 are appropriate for both Lily (deep) and McKusick (shallow) Lakes. Meeting the State standards would result in a healthy lake system with no nuisance algal blooms and improved water clarity.

Table 9. Target total phosphorus concentration end points.

	Current TP Standard (µg/L)	Proposed TP Standard (µg/L)
Lily Lake	40	40
Long Lake	40	60
McKusick Lake	40	60

Goal 2. *Protect public health from fecal contamination, swimmer's itch, toxic chemicals, or other toxic agents.*

The presence of pathogenic bacteria, toxic chemicals such as pesticides or PCBs, or hazardous solid waste in lake water or sediments can pose threats to lake users. Swimmer's itch has been associated with waterfowl and snails. A swimmer's itch infection is unpleasant, but not a health threat. The following targets are suggested for meeting goal 2:

1. Fecal coliform levels should meet state standards for beaches.
2. Meet state standards for PCBs, heavy metals, and any other pollutant.
3. Reduce the level of mercury and PCBs in fish to levels where fish are safe to eat.

Goal 3. *Reduce the potential for aquatic vegetation to impede swimming and fishing in designated areas.*

Although aquatic plants are a part of any healthy lake system, overabundant native and exotic aquatic plants can become a nuisance. The following targets are suggested for meeting goal 3:

1. Develop a lake aquatic plant management plan
2. Meet goals set forth in aquatic management plan

Goal 4. *Promote healthy and diverse fish communities*

Fish kills occur when oxygen is depleted from the water column as a result of excess biological respiration. Although historical information is spotty, there have been reported fish kills in McKusick Lake. The following targets are suggested for meeting goal 4:

1. Maintain spring through fall dissolved oxygen concentrations above 5 ppm
2. As long as rough fish are absent, allow for winter fish kills to provide top-down control of panfish populations and to prevent stunted fish communities

6.4 Environmental Preservation Targets

Goal 5. *Prevent the introduction of exotic plants and eliminate current populations.*

Aquatic invasive vegetation can have adverse effects on a lake ecosystem including loss of critical habitat, eutrophication, and loss of native species. The recommended target for invasive species:

1. Prevent the introduction of invasive aquatic vegetation from the lake

Goal 6. Preserve aquatic wildlife habitat including fish spawning areas.

Habitat preservation is key to maintaining a healthy aquatic ecosystem, particularly a healthy fishery. Over the years, the lake has been impacted by the elimination of native habitats. The following targets are suggested for meeting goal 6:

1. Cultivate native vegetation around 50% to 75% of the shoreline
2. Provide habitat for native aquatic plants in at least 75% of the littoral areas.

Goal 7. Achieve a healthy and diverse community of native plants and animals.

In urban and suburban environments, ecosystems have been disturbed. Some of the features that make Stillwater desirable are its natural areas and lakes. Protection of these natural features is essential to maintaining quality of life. The following targets are suggested for meeting goal 7:

1. See goals 1, 4, 5, 6, and 9.

Goal 8. Provide a natural land/water interface that reduces runoff and enhances pollutant filtration while providing access for recreational use of the lakes.

A natural transition from the water to land areas provide key habitat, filters runoff, and protects shorelines from erosion. The following targets are suggested for meeting goal 8:

1. Conduct shoreline restorations in degraded shoreline areas
2. See goal number 6.

Goal 9. Manage watershed runoff to reduce sediment and pollutant transport to the lakes

Vegetated buffers and natural shorelines can decrease and filter runoff. Additionally, water quality ponds, infiltration, Low Impact Development practices, and other activities in the watershed can have large impacts on water quality. The following targets are suggested for meeting goal 9:

1. Identify areas where buffers, water quality ponds, and wetlands can enhance water quality
2. Implement capital improvements where opportunities exist to protect and improve water quality.

6.5 Lake Management Education Targets

Educational success is often a function of quality and quantity. Therefore, setting quantitative educational goals does not necessarily reflect the success of educational programs. Additionally, measuring the success of education is difficult since the ultimate goal is not only to raise awareness but also to change people's behaviors. At this time, no quantitative goals are set for the educational goals of this plan. Rather, the educational goals are set to provide guidance on those topics that need to be addressed for improving lake water quality. Many of the concepts presented in this management plan are the same as those outlined in the State of Minnesota's environmental education plan (www.moea.state.mn.us/ee/greenprint.cfm).

7.0 Recommended Management Activities

7.1 Introduction

Successful lake management requires an understanding of not only nutrient cycling in the lake and its watershed, but also an understanding of in-lake processes that may be affecting water quality and lake value. To successfully restore and protect lake quality, managers must address both the phosphorus loads to the lake as well as degraded biological conditions including an imbalanced fishery, lack of appropriate aquatic vegetation, and degraded habitats and shorelines.

The management activities set forth here are an integrated set of capital projects and ongoing management and operations activities that would help achieve the management goals in Section 6. Some of these activities could be completed by the City of Stillwater, while others may best be implemented by the watershed, state agencies, or even private property owners. The activities have been roughly prioritized taking into account actions that are already in process, but it is expected that implementation will proceed as opportunities, partnerships, and resources arise. Lake management is an ongoing and iterative effort, and ongoing monitoring is an important component of this Management Plan. This Plan assumes that periodic evaluation of progress towards the goals established in Section 6 will lead to periodic adjustment to the Management Plan, a process known as "adaptive management."

This section outlines projects and costs necessary to address water quality in Lily and McKusick Lakes. Additionally, several recommendations are provided for Long Lake to supplement the current management plan developed by the Brown's Creek Watershed District. Project costs were estimated for each project individually. Projects were selected and preliminarily designed according to drainage and available information. Activities (e.g., excavation, vegetation restoration, etc.) and materials (gallons of alum, hydraulic structures, etc.) for individual projects were listed and given quantities based on project size and scope. Costs were associated with activities and materials for each project and summed to determine the initial construction cost. Operation and maintenance costs were estimated and accrued over a 20 year life cycle including any necessary reapplication or reconstruction to determine the total present cost of operation and maintenance. The total present cost of construction, operation, and maintenance were summed to determine the total present cost for the project.

7.2 Loading Summary

Successful lake management starts with an understanding of the nutrient budget for the lake and the lakes response. The 2006 phosphorus budgets were used to identify targets for load reductions in each of the watersheds draining to McKusick and Lily Lakes. Load reductions were determined by identifying the load if the lake were currently meeting the State water quality standard to the current load (2006). The difference represents the load reduction needed to meet the State standard (Table 10).

Table 10. Loadings by major watershed for 2006. Also included is the load if the lake were meeting the State standard under those hydrologic conditions as well as the required reduction to meet the State standard.

Lake	Watershed	Current TP Load (pounds)	TP Load @ State Standard (pounds)	Required Reduction (pounds)
Lily Lake	Entire Watershed	285	140	145
McKusick	Direct Drainage Areas	84	22	62
	Annexed Areas	200	52	148
	Lily Lake through 4p and 11p	67	57	10[1]
	Long Lake	89	74	15[1]

[1]These loads would be achieved by bringing Lily and Long Lakes into compliance with State Standards

7.3 Lily Lake

A summary of projects identified for Lily Lake and associated costs are presented in Table 11 (Figure it should be insert it here Map 2).. Projects were selected and prioritized based on these targeted reductions. Priority of management activities are based on sequencing, relative cost or effort, available resources, and potential benefit. Additionally, in-lake management activities have been identified that are important in protecting water quality in these lakes.

Table 11. Prioritized capital projects for the Lily Lake subwatershed. Reduction goal = 145 pounds.

Priority	Management Strategy	Location	Total Present Cost[1] [$]	Annual Phosphorus Load Reduction [lb]	Cost per pound reduction [$/lb]	Required Footprint [ac]
1	Hospital Ponds	Lily 08	$ -	7	$ -	0.4
2	Parking Lot Improvements and rain garden installation	Lily 04	$ 30,500	3	$ 8,971	0.1
4	Wet Pond Excavation	Lily 13	$ 130,000	20	$ 6,500	N/A
5	Wet Pond Excavation	Lily 18	$ 265,000	30	$ 8,833	N/A
6	Infiltration Basin[2]	Lily 03	$ 92,500	20	$ 4,625	1
7	Infiltration Basin[2]	Lily 02	$ 83,500	15	$ 5,567	0.8
8	Infiltration Basin[2]	Lily 15	$ 84,500	15	$ 5,633	0.8
9	Infiltration Basin[2]	Lily 01	$ 77,500	10	$ 7,750	0.85
		Totals	***$ 763,500***	***120***	***$ 6,840***	***7***

[1]Total present cost includes construction, operation, maintenance, and overhaul costs, where applicable.
[2]Infiltration can also be implemented across the watershed using techniques such as rain gardens

7.3.1 Watershed Projects

Construct wet detention ponds in subwatershed Lily 08
The City of Stillwater has indicated that water quality ponds were constructed near Lakeview Hospital. These ponds, as modeled, capture seven pounds of phosphorus annually.

Estimated Associated Cost: None (already constructed).

Parking lot improvements and rain garden installation (Lily 04).
Improving parking lot surfaces and drainage patterns reduces the amount of pollutants that run off the impervious surface and ensures that runoff is directed to the appropriate destination. A rain garden is proposed by the City of Stillwater to be installed downstream from the improved parking lot to infiltrate stormwater runoff. Rain gardens reduce the volume of runoff that is delivered to downstream waterbodies by infiltrating stormwater and improve water quality by allowing pollutants to settle out or be used by the vegetation.

Estimated Associated Cost: $30,500.

Wet pond excavation (Lily 13 and Lily 18).
Drainage from subwatersheds Lily 13 and Lily 18 is delivered to a narrow vegetated swale/dry pond within their respective watersheds. Swales and dry ponds provide treatment of particulate pollutants and uptake of dissolved pollutants by vegetation but are susceptible to resuspension and erosion during intense storm events. Wet detention provides additional removal of pollutants from stormwater and is less susceptible to erosion and re-suspension. Feasibility of excavation for the dry pond in Lily 13 should be evaluated.

The subwatersheds draining to the dry pond should be identified and characterized for land use and impervious cover. Wet detention storage should be calculated based on the drainage area to provide greater than or equal to 50% total phosphorus removal. The necessary excavation should be compared to the feasibility of excavation performed in Action 1. The result of this action should include design and extent of the proposed excavation.

Wet detention ponds require maintenance and removal of accumulated sediments at regular intervals. The interval length is dependent on the specific subwatershed and basin characteristics, but usually varies between 10 and 15 years.

Estimated Associated Cost: $395,000.

Infiltration Basin (Lily 01, Lily 02, Lily 03, Lily 15).
Drainage from subwatersheds 01, 02, 03 and 15 is delivered to Lily Lake via stormwater conveyance without treatment. Infiltration opportunities should be investigated in these subwatersheds. Infiltration basins reduce the volume of runoff that is delivered to downstream water bodies and improve water quality through infiltration. Infiltration can be accomplished through regional infiltration basins or on an accumulated basis throughout the watershed using rain gardens.

Infiltration basins require maintenance and removal of accumulated sediments at regular intervals. The interval length is dependent on the specific subwatershed and basin characteristics, but usually varies between 5 and 10 years.

Estimated Associated Cost: $338,000.

7.3.2 In-Lake Management

Table 12. Prioritized management activities for the Lily Lake subwatershed.

Priority	Management Strategy	Location	Total Present Cost[1] [$]
1	Fisheries Management	Lily Lake	DNR funded
2	Measure Internal Phosphorus Release	Lily Lake	$3,000
3	Monitor Water Quality in Lily Lake	Lily Lake	$5,000
4	Monitor Brick Pond Water Quality	Brick Pond	$3,000
5	Invasive Vegetation Education	Lily Lake	$2,000
	Shoreline Restoration	Lily Lake	$ 50,000
	In-Lake Alum Treatment	Lily Lake	$ 56,000
		Totals	***$119,000***

<u>In-lake alum treatment (Lily Lake).</u>

One consideration for Lily Lake is an in-lake alum treatment. In-lake alum treatment reduces the release of phosphorus from lake sediments and reduces the amount of existing phosphorus in the water column. However, internal loading was not directly measured. Consequently, internal loading rates should be estimated prior to completing an alum treatment.

Estimated Associated Cost: $56,000 per application as needed.

<u>Shoreline restoration</u>

Maintenance of natural shorelines is an important aspect of lake management. Natural shorelines provide filtration of direct runoff, provide fish refugia and habitat, and provide protection from erosion associated with wind and wave action. Natural shorelines can be maintained while still providing recreation access to the lake for shoreline owners. It was assumed that half of the shoreline would need to be restored and that volunteers would be used for much of the planting.

Estimated Associated Cost: $50,000 for half of the shoreline using volunteers.

Invasive species control

In the 1997 survey conducted by the DNR, no invasive species were present in Lily Lake. However, prevention of the introduction of species such as curly-leaf pondweed and Eurasian water milfoil should be a priority to protect the lake. To accomplish this goal, education and signs should be used to prevent introduction of invasive species. Materials and information are available from the DNR.

Estimated Associated Cost: $2,000 for education materials and signs.

Fisheries management

Because Lily Lake is a panfish-dominated lake, there is the potential for the lake to develop a stunted panfish population which would result in poorer water quality. However, the DNR has been stocking top predators such as large mouth bass and northern pike to Lily Lake. Continuing this stocking should help maintain a healthy, top predator dominated fish population.

Estimated Associated Cost: None. DNR is the project sponsor.

7.3.3 Monitoring

Measure internal phosphorus release

One of the primary data gaps for Lily Lake was data used to estimate internal loading. Several monitoring options are available, however, the most const effective monitoring approach includes collecting 6-8 paired surface and bottom samples for ortho-phosphorus throughout the growing season. These data provide evidence for the both the presence and rate of internal loading and is necessary to determine if an alum treatment is warranted (see section 7.3.2).

Estimated Associated Cost: $3,000.

Monitor Brick Pond Water Quality and Fisheries

Brick Pond collects a significant amount of water prior to discharging to Lily Lake. Consequently, Brick Pond has the potential to control water quality from this drainage. Water quality samples from Brick Pond will help clarify current conditions in the pond. If water quality conditions are poor (i.e. high phosphorus), diagnosing the cause is critical. For example, the presence of rough fish in stormwater ponds can have a large deleterious effect on the treatment effectiveness of that pond. Monitoring should begin with water quality (total phosphorus). If concentrations are high, then the fishery should be evaluated.

Estimated Associated Cost: $ 3,000.

Monitor Water Quality in Lily Lake

Recent data for Lily Lake only include four surface samples. Targeting 6-8 surface samples provides better resolution for developing summer average concentrations.

Estimated Associated Cost: $ 5,000.

7.4 McKusick Lake

The Northwest Annexed Area appears to contribute 44% of the phosphorus load to McKusick Lake. However, the actual source of the phosphorus is unclear. Monitoring data at the diversion structure demonstrates high phosphorus concentrations. Based on monitoring data, Long Lake is not the source of these concentrations. The source is either from the area below the Long Lake outlet or the northwest drainage area. The actual source needs to be identified prior to implementation.

Providing targeted treatment for this drainage area can have a significant impact on the phosphorus budget for McKusick Lake. Potential management activities should include wet detention, infiltration, watershed education, and source reduction. The projects proposed in this study are on a regional basis, however the practices can be implemented cumulatively on a smaller scale.

Table 13. Prioritized capital projects for McKusick Lake. Load reduction goal – 235 pounds.

Priority	Management Strategy	Location	Total Present Cost[1] [$]	Annual Phosphorus Load Reduction [lb]	Cost per pound reduction [$/lb]	Required Footprint [ac]
1	Infiltration Basin[2]	BWW 03	$ 1,050,000	97	$ 10,825	2.5
2	Infiltration Basin[2]	Div. Struc.	$ 1,550,000	140	$ 11,071	4
1	Infiltration Basin[2]	McK 26	$ 73,500	7	$ 10,500	0.6
2	Infiltration Basin[2]	McK 18 (NE)	$ 99,000	5	$ 19,800	0.1
3	Infiltration Basin[2]	McK 18 (SE)	$ 74,000	5	$ 14,800	0.1
6	Lily Lake @ 40 ug/L	Lily Lake	$ -	10	N/A	N/A
7	Long Lake @ 60 ug/L	Long Lake	$ -	15	N/A	N/A
		Totals	$2,846,500	279	$17,479	7.3

[1]Total present cost includes construction, operation, maintenance, and overhaul costs, where applicable.
[2]Infiltration can also be implemented across the watershed using techniques such as rain gardens

7.4.1 Watershed Projects

<u>Infiltration Basin (McKusick 26).</u>
Drainage from Lily 26 and upstream watersheds is delivered to McKusick Lake via stormwater conveyance without treatment. Feasibility of an infiltration basin to reduce runoff and pollutant load to McKusick Lake should be evaluated. If an infiltration basin is feasible, a suitable location within McKusick 26 should be determined and an infiltration basin should be designed accordingly.

An infiltration basin should be installed at the location determined in Action 1. Infiltration basins reduce the volume of runoff that is delivered to downstream waterbodies and improve water quality through infiltration.

Infiltration basins require maintenance and removal of accumulated sediments at regular intervals. The interval length is dependent on the specific subwatershed and basin characteristics, but usually varies between 5 and 10 years.

Estimated Associated Cost: $73,500.

Infiltration Basin (BWW 03).
Drainage from BWW 03 and upstream watersheds is delivered to McKusick Lake via stormwater conveyance without treatment. Feasibility of an infiltration basin to reduce runoff and pollutant load to McKusick Lake should be evaluated. If an infiltration basin is feasible, a suitable location within BWW 03 should be determined and an infiltration basin should be designed accordingly. Infiltration basins reduce the volume of runoff that is delivered to downstream water bodies and improve water quality through infiltration. Infiltration can be accomplished through regional infiltration basins or on an accumulated basis throughout the watershed using smaller basins or rain gardens.

Infiltration basins require maintenance and removal of accumulated sediments at regular intervals. The interval length is dependent on the specific subwatershed and basin characteristics, but usually varies between 5 and 10 years.

Estimated Associated Cost: $1,050,000.

Infiltration Basin (Diversion Structure).
Drainage from the Northwest Annexed Area and Long Lake is delivered to the Brown's Creek Diversion structure with minimal treatment. The large phosphorus concentration evident from the available monitoring data indicates that a significant reduction in phosphorus load to McKusick Lake can be achieved with an infiltration basin upstream of the Diversion structure. Feasibility of an infiltration basin in this location should have been completed by management activity 7.3 (see above). If an infiltration basin is feasible, a suitable location near the diversion structure should be determined and an infiltration basin should be designed accordingly. Infiltration can be accomplished through regional infiltration basins or on an accumulated basis throughout the watershed using smaller basins or rain gardens.

Infiltration basins require maintenance and removal of accumulated sediments at regular intervals. The interval length is dependent on the specific subwatershed and basin characteristics, but usually varies between 5 and 10 years.

Estimated Associated Cost: $1,550,000.

Infiltration Basin (McKusick 18, Northeast).
Drainage from the Northeast portion of the McKusick 18 subwatershed is delivered directly to McKusick Lake. Infiltration opportunities should be investigated in this subwatershed. Infiltration basins reduce the volume of runoff that is delivered to downstream water bodies and improve water quality through infiltration. Infiltration can be accomplished through regional infiltration basins or on an accumulated basis throughout the watershed using rain gardens.

Estimated Associated Cost: $99,000.

Infiltration Basin (McKusick 18, Southeast).

Drainage from the Southeast portion of the McKusick 18 subwatershed is delivered directly to McKusick Lake. Infiltration opportunities should be investigated in this subwatershed. Infiltration basins reduce the volume of runoff that is delivered to downstream water bodies and improve water quality through infiltration. Infiltration can be accomplished through regional infiltration basins or on an accumulated basis throughout the watershed using rain gardens.

Estimated Associated Cost: $74,000.

Ensure that Lily Lake meets water quality goal of 40 µg/L for in-lake total phosphorus concentration.

Gather measured in-lake total phosphorus concentration from several years. Determine the summer average concentration and compare to the water quality goal of 40 micrograms per liter (µg/L).

If the summer average total phosphorus concentration in Lily Lake is at or below 40 ug/L for several continuous years, then additional management strategies for Lily Lake may not be necessary. If Lily Lake is not at or below the goal, additional management strategies should be investigated for potential implementation.

Estimated Associated Cost: Up to $900,000.

Ensure that Long Lake meets water quality goal of 60 µg/L for in-lake total phosphorus concentration.

Gather measured in-lake total phosphorus concentration from several years. Determine the summer average concentration and compare to the water quality goal of 60 micrograms per liter (µg/L).

Estimated Associated Cost: Up to 2.3 Million.

7.4.2 In-Lake Management

Table 14. Prioritized management activities and monitoring for McKusick Lake.

Priority	Management Strategy	Location	Total Present Cost[1] [$]
1	Diagnostic Study for Annexed Area Phosphorus Source	Diversion Structure	$40,000
2	Measure Internal Phosphorus Release	McKusick Lake	$3,000
3	Invasive Vegetation Education	McKusick Lake	$2,000
4	Monitor Water Quality in McKusick Lake	McKusick Lake	$5,000
5	Filamentous Algae – Mechanical Removal (10 years)	McKusick Lake	$75,000
6	Nuisance Aquatic Vegetation/Fish (draw down)	McKusick Lake	$100,000
	Shoreline Restoration	McKusick Lake	$ 204,000
	In-Lake Alum Treatment	McKusick Lake	$ 67,000
9	Manage Winter Fish Kills	McKusick Lake	$50,000
		Totals	***$546,000***

<u>In-lake alum treatment (McKusick Lake).</u>
In-lake alum treatment reduces the release of phosphorus from lake sediments and reduces the amount of existing phosphorus in the water column. However, the role of internal loading is unclear. Measuring internal loading would provide a better understanding of the effectiveness of an alum treatment.

Estimated Associated Cost: $67,000.

<u>Aquatic vegetation</u>
Aquatic vegetation in McKusick Lake is dominated by coon tail, suggesting that the lake is nutrient enriched in both the water column and the sediments. Although coon tail dominates the vegetation community, it is not necessary from an ecological perspective to control. However, it can be seen as a nuisance. Control options include herbicides, mechanical control, and drawdown. Both mechanical removal and herbicides are not selective and would present too much damage to other native species. Consequently, the best option is likely a winter drawdown, however this is not needed at this time.

Estimated Associated Cost: $100,000.

<u>Filamentous algae management</u>
The best way to control both the nuisance levels of filamentous algae is to control nutrient inputs. There are two possible sources of nutrients for the filamentous algae: the water column and internal loading. Because filamentous algae begin their life cycle as a benthic organism, it can often be associated with lakes that have a high internal loading rate. However, the lake response models over-predicted in-lake nutrient concentrations suggesting that the nutrients were tied up in the filamentous algae mat that is not sampled as a part of routine monitoring.

Consequently, measuring internal loading rates would help identify the source of load causing the filamentous algae problem.

Mechanical removal of filamentous algae is a reasonable short term solution; however it becomes an expensive option because it is a perpetual action. Nutrient controls through an alum application may be the most effective control for the filamentous algae.

Estimated Associated Cost: Mechanical Removal $75,000 for 10 years.

Shoreline Restoration

Maintenance of natural shorelines is an important aspect of lake management. Natural shorelines provide filtration of direct runoff, provide fish refugia and habitat, and provide protection from erosion associated with wind and wave action. Natural shorelines can be maintained while still providing recreation access to the lake for shoreline owners. It was assumed that half of the shoreline would need to be restored and that volunteers would be used for much of the planting.

Estimated Associated Cost: $50,000 for half of the shoreline using volunteers.

Invasive Species Control

In the 2007 survey conducted by the Washington Conservation District, no invasive species were present in McKusick Lake. However, prevention of the introduction of species such as Curly Leaf Pondweed and Eurasian Water Milfoil should be a priority to protect the lake. To accomplish this goal, education and signs should be used to prevent introduction of invasive species. Materials and information are available from the DNR.

Estimated Associated Cost: $2,000 for education materials and signs.

7.4.3 Monitoring

Diagnostic study for annex area phosphorus source

Monitoring data at the diversion structure indicates high phosphorus concentrations. These concentrations are a result of two potential source areas: the annexed area or the outlet drainage from Long Lake. Based on lake monitoring, the source is unlikely from Long Lake itself, however, there may be a source area as the water moves through a wetland complex. The other possible source is the water from the annexed area. Monitoring is needed to verify the source area.

Estimated Associated Cost: $40,000 for diagnostic study and monitoring.

Measure internal phosphorus release

One of the primary data gaps for McKusick Lake was data used to estimate internal loading. Because McKusick Lake is a shallow lake, the best approach would be to measure sediment phosphorus release rates in a laboratory. Additionally, DO profiles should be monitored for a season. This monitoring is necessary to determine whether an alum treatment is warranted.

Estimated Associated Cost: $3,000 for release rate experiment.

Monitor Water Quality in McKusick Lake
Continued monitoring in McKusick Lake is critical to develop an understanding of the long term trend in water quality.

Estimated Associated Cost: $5,000 annually for water quality monitoring.

7.4.4 Long Lake

A management plan has been completed by the Brown's Creek Watershed District for Long Lake (BCWD 2006). The plan identified phosphorus reduction strategies for the watershed as well as some in lake projects. The identified watershed projects would help reduce phosphorus loading to the lake.

It is our view that although the watershed projects are beneficial, the focus for management and restoration of Long Lake should be on in-lake management and education. The major drivers for poor water quality in long lake are the presence of rough fish (koi) and an impacted aquatic vegetation community. The Long Lake Management Plan does identify a whole lake draw-down as an appropriate action for management. This action should be evaluated and implemented now as there are remnants of a healthy aquatic vegetation community in the lake.

Sustainable Use Education
One of the key factors in Long Lake is the issue of sustainable use. There is evidence in the scientific literature that boating can impact aquatic vegetation, especially in shallow lakes. Education of local stakeholders regarding the sustainable uses of a shallow lake can help set the scientific basis for the recommended management actions.

Estimated Associated Cost: $3,000.

Aquatic vegetation management and winter lake drawdown
One of the primary techniques for restoring impaired shallow lakes is management of the fishery and drawdown. A winter drawdown associated with a rotenone treatment to eliminate the fishery would act as a key reverse switch to bring the lake back to a clear water state. Additionally, the drawdown will reconsolidate the sediments and bring back the native aquatic vegetation in the lake. Additionally, a vegetation management plan should be developed for Long Lake.

Estimated Associated Cost: $200,000 (from the Long Lake Plan).

Fisheries management
Management of the Long Lake fishery will be critical in maintaining water quality in Long Lake. Because Long Lake is such a shallow lake, it would be difficult to maintain a top predator dominated fishery required for maintaining water clarity. Rather, since the lake is prone to winterkill, the fishery should be a sunfish and crappie dominated system with periodic winter kills acting as the top down control (predator influence). Because the lake is so shallow, installation and maintenance of an aerator for top predators is unlikely to maintain water clarity.

Without the top predator habitat, significant stocking efforts would have to be maintained which can be costly.

The best management option for Long Lake is to manage for a fishless or a healthy panfish system with periodic top-down controls (winterkills). This approach requires periodic monitoring of the dish populations and potential lake draw downs to promote winter fish kills. However, it is important to not that as long as rough fish are present, winter kills will have limited effects on water quality.

Estimated Associated Cost: $50,000.

<u>Shoreline restoration</u>
Maintenance of natural shorelines is an important aspect of lake management. Natural shorelines provide filtration of direct runoff, provide fish refugia and habitat, and provide protection from erosion associated with wind and wave action. Natural shorelines can be maintained while still providing recreation access to the lake for shoreline owners. This activity was identified in the Long Lake Management Plan.

Estimated Associated Cost: $46,000 as proposed in Long Lake Management Plan.

7.5 Management Action Summary

Management Actions include both capital projects and ongoing management activities for Lily and McKusick Lakes. The initial management emphasis should be on controlling external loading, which is the highest priority. However, at some point enough external load reduction will have occurred that it will become feasible to turn to controlling the internal loads. An important part of that strategy is restoring and maintaining biological integrity and associated impacts to water quality through management of the aquatic plant community, fishery, and macroinvertebrate and zooplankton assemblages. Those activities can be ongoing as time and resources permit. However, biological manipulation cannot provide all the internal load reduction that would be required. More detailed study is required to evaluate whether chemical treatment with alum or other means of reducing internal loading are feasible.

7.5.1 Sequencing

Some of the management activities may be undertaken immediately, while others should be implemented as opportunities arise. In general it is recommended that implementation proceed according to the following sequence of activities:

<u>Short Term</u>

- Conduct diagnostic study for Annex Area phosphorus source
- Investigate internal loading rates for Lily and McKusick Lakes
- Implement specific BMP projects as funding including:
    - Excavate dry ponds in Lily Lake 13 and 18 to create wet detention ponds

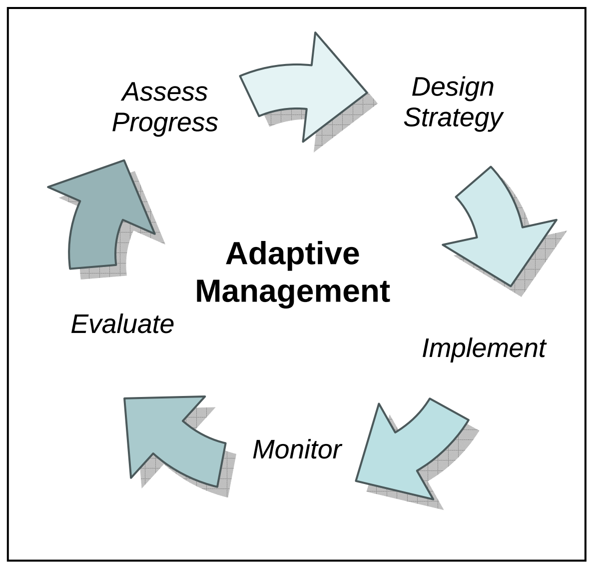
- Investigate and implement infiltration basins the Lily Lake subwatersheds
- Evaluate loads from Annex/Long Lake drainage with internal loads to select project
- Conduct invasive species education

Long Term

- Implement project (alum or annex infiltration) for load reduction to control filamentous algae
- Consider drawdown in McKusick Lake for aquatic vegetation control
- Shoreline restoration as opportunities arise
- Continue monitoring
- Evaluate progress towards goals (nutrient reductions and filamentous algae blooms)
- Amend Management Plan as necessary based on progress
- Implement BMP retrofits as opportunities arise to continue to reduce external loading
- When sufficient external load controls are in place, prepare feasibility studies for internal load reduction strategies such as chemical treatment
- Implement internal load reduction BMPs

7.6 Adaptive Management

The load reductions identified in this management plan are aggressive and will require significant capital projects and management activities to achieve. Consequently, it is recommended that this Management Plan be implemented using adaptive management principles. Adaptive management is an iterative approach of implementation, evaluation, and course correction. It is appropriate here because it is difficult to predict the lake response to the various activities. Future conditions and technological advances may alter the specific course of actions detailed in this Plan. Continued monitoring and course corrections responding to monitoring results offer the best opportunity for meeting the various management goals set forth in this Plan.



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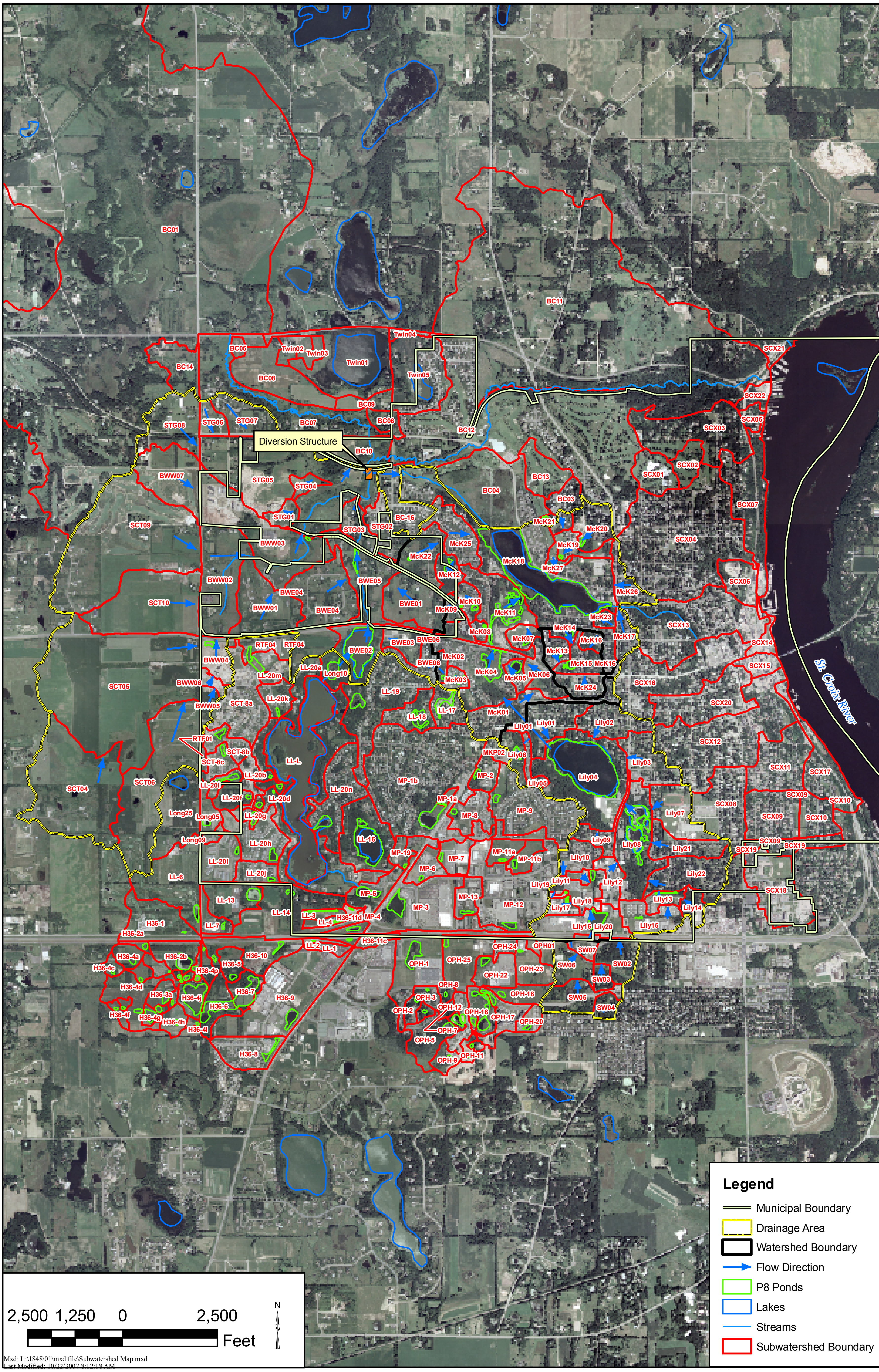
Maps



CITY OF STILLWATER

Subwatershed Map

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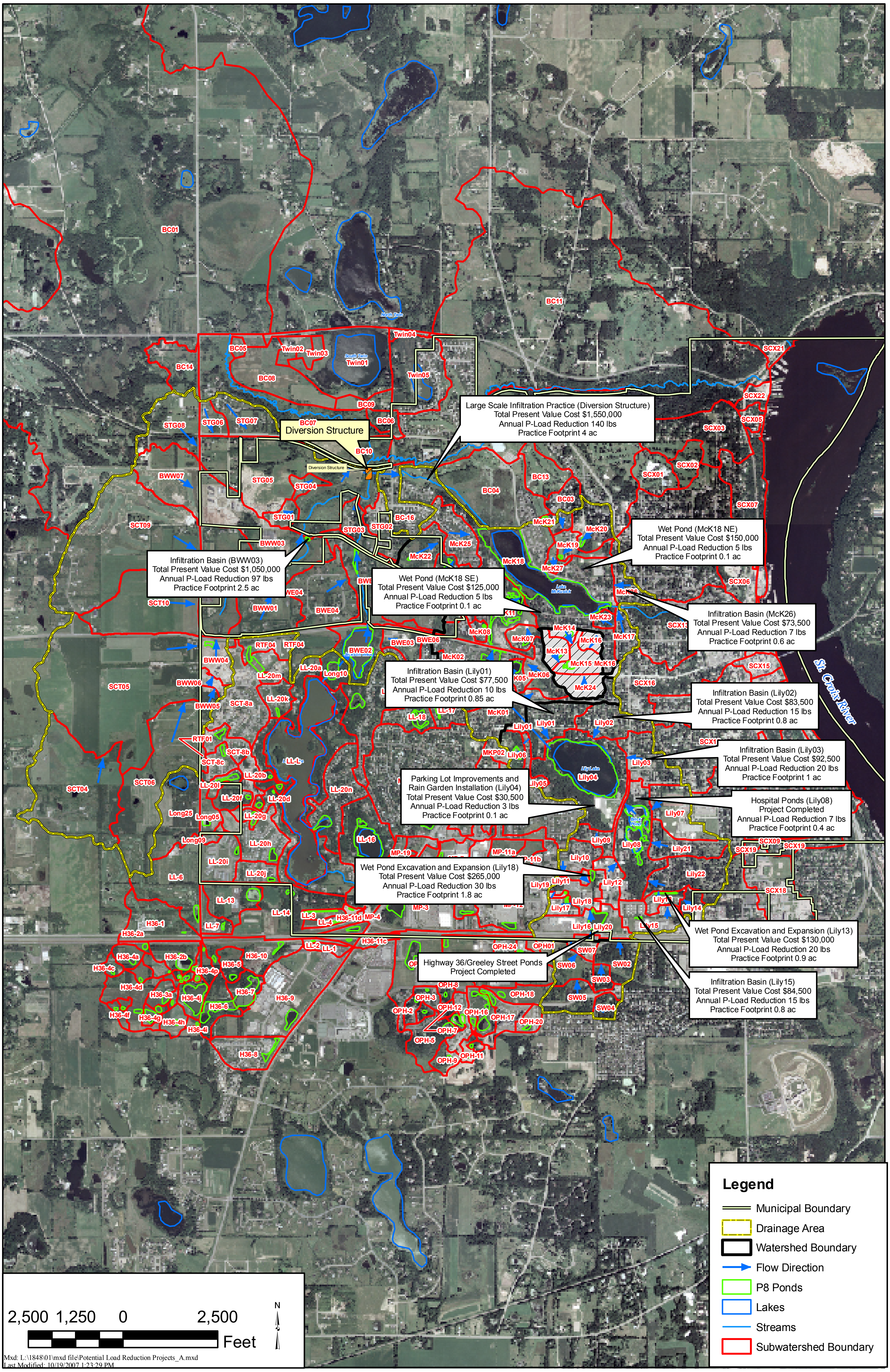
Wenck

Wenck Associates, Inc.
Environmental Engineers

1800 Pioneer Creek Center
Maple Plain, MN 55359-0429

OCT 2007

Figure 1



CITY OF STILLWATER

Potential Load Reduction Projects

Wenck

Wenck Associates, Inc. 1800 Pioneer Creek Center
Environmental Engineers Maple Plain, MN 55359-0429

OCT 2007

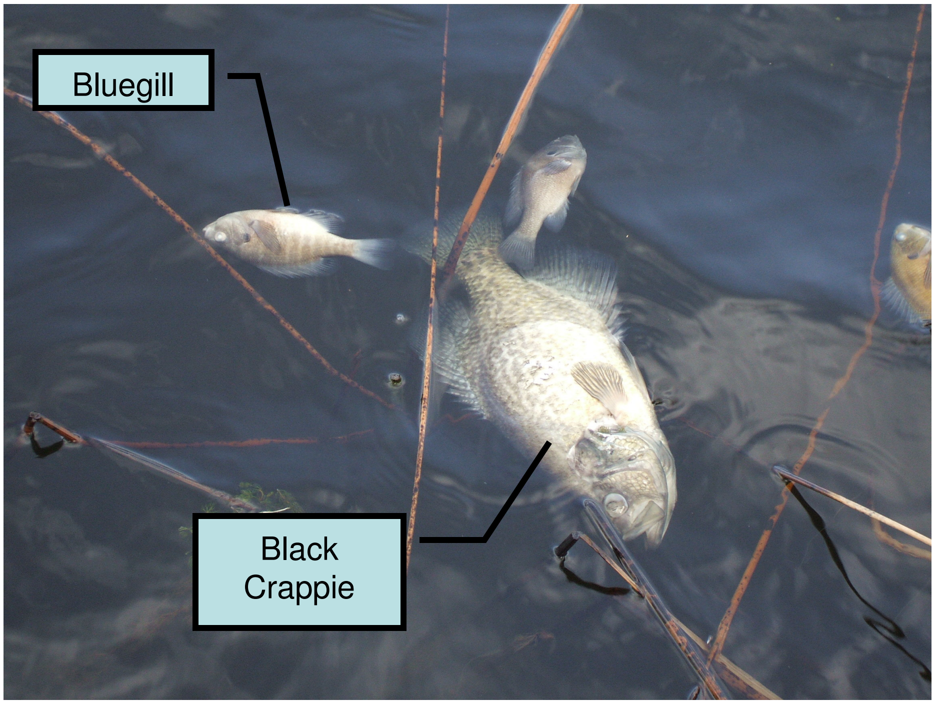
Figure 2

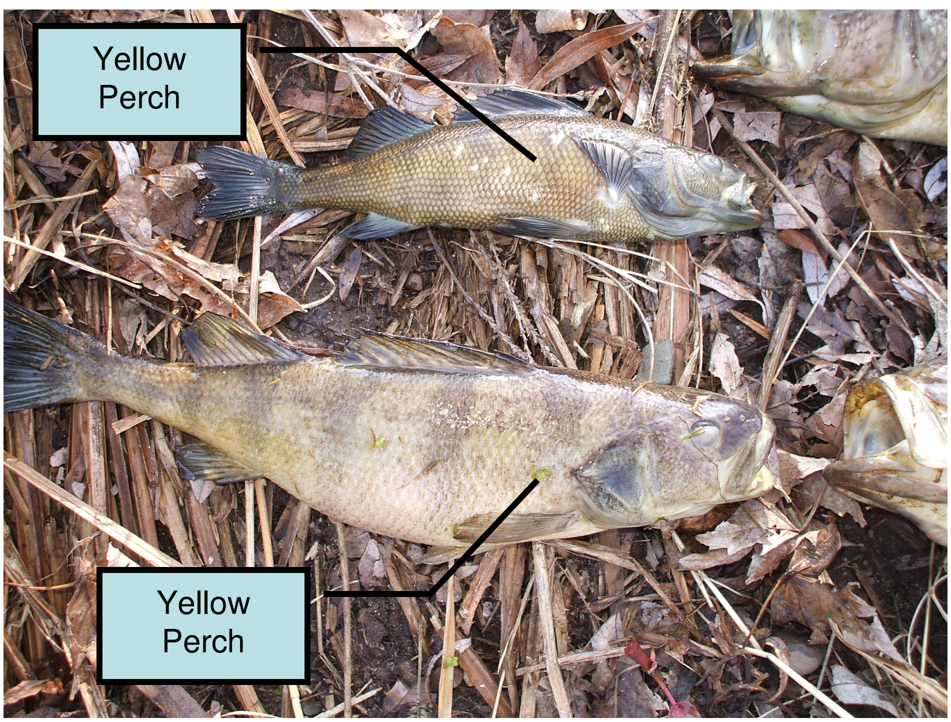
Appendix A

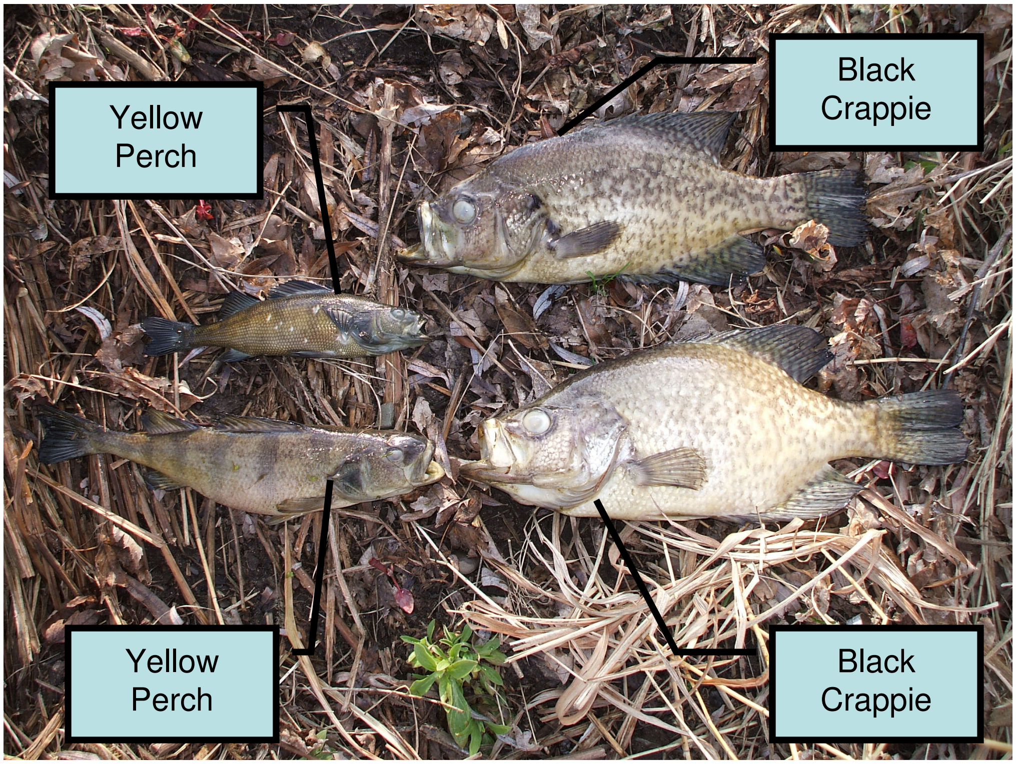
Photographs of Fish Kill

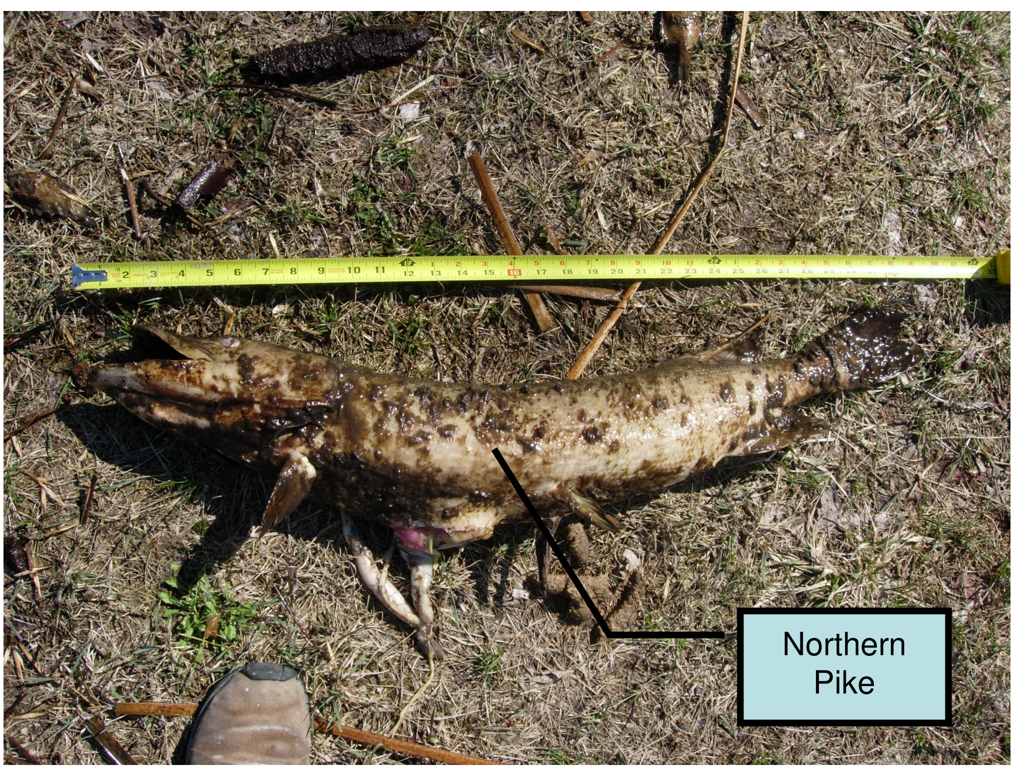
Majority of the fish in the above picture are bluegills; some may be pumpkinseed sunfish, green sunfish or hybrid sunfish.

Majority of the fish in the above picture are bluegills; some may be pumpkinseed sunfish or a hybrid.


Bluegill
Black Crappie


Yellow Perch
Yellow Perch


Yellow Perch
Black Crappie
Yellow Perch
Black Crappie


Northern Pike

Appendix B

Lake Response Modeling Data

1.1.1 2003

2003 Loading Summary for: Lily Lake							
Water Budgets				**Phosphorus Loading**			
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Lily 02	29.8	13.2	32.7	268.9	1.0	23.9
2	Lily 03	33.6	14.9	41.7	271.6	1.0	30.8
3	Lily 04	61.0	8.4	42.5	262.4	1.0	30.4
4	507	56.4	8.0	37.5	221.3	1.0	22.6
5	Lily 09	15.0	12.0	14.9	269.2	1.0	10.9
6	Brick Pond Basin B	347.0	14.2	409.6	117.9	1.0	131.3
7						1.0	
8						1.0	
9						1.0	
10						1.0	
11						1.0	
12						1.0	
13						1.0	
	Summation	*543*	*12.8*	*579*	*235.2*		*250.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	36	27.32	27.32	0.00	14.91	1.0	4.7
				Dry-year total P deposition =	12.18		
				Average-year total P deposition =	14.91		
				Wet-year total P deposition =	17.68		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	36	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[acre]	[days]			[mg/m²-day]	[--]	[lb/yr]
	36	53.0			1.00	1.0	17
				Net Discharge [ac-ft/yr] = **579**		**Net Load [lb/yr] =**	**272**

NOTES
[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2003 Lake Response Modeling for: Lily 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 =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	272 [lb/yr]
		Q (lake outflow) =	579 [ac-ft/yr]
		V (modeled lake volume) =	628 [ac-ft]
		T = V/Q =	1.08 [yr]
		P_i = W/Q =	172 [ug/l]
Model Predicted In-Lake [TP]			**61.8 [ug/l]**
Observed In-Lake [TP]			**38.8 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**17.3 [ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	62 [ug/l]
		N (Total Nitrogen) =	2000 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	50.6 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	57.4 [ug/l]
		G (Kinematic factor) =	0.57 [--]
		F_s (Flushing Rate) =	0.92 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	13.12 [ft]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.40 [m^{-1}]
		S (Secchi Depth) =	4.33 [ft]
		Maximum lake depth =	50.00 [ft]
Model Predicted In-Lake [Chl-a]			**23.8 [ug/l]**
Observed In-Lake [Chl-a]			**11.8 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\text{a} + 0.015 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.40 [m^{-1}]
Model Predicted In-Lake SD			**1.32 [m]**
Observed In-Lake SD			**1.79 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**174** [lb/yr]
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**97 [lb/yr]**

2003 Loading Summary for: McKusick Lake

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 McK 23p	5.4	6.0	2.7	104.2	1.0	0.8
2 McK 27p	51.0	4.0	17.0	123.9	1.0	5.7
3 McK 18p	142.0	2.9	34.5	266.3	1.0	25.0
4 503	32.3	6.0	16.1	271.3	1.0	11.9
5 502	71.8	2.4	14.2	185.8	1.0	7.2
6 701/702/703	1349.7	1.0	107.9	493.0	1.0	144.7
7					1.0	
8					1.0	
9					1.0	
10					1.0	
11					1.0	
12					1.0	
13					1.0	
Summation	*1652*	*1.4*	*192*	*240.8*		*195.2*

Inflow from Upstream Lakes

Name	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1 Lily Lake through McK 11p	496.3	54.0	1.0	73
2 Long Lake through BWE 2 and BWE 5 to Diversior	313.6	95.0	1.0	81
3		-	1.0	
Summation	*810*	*74.5*		*154*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
45	27.32	27.32	0.00	14.91	1.0	6.0
			Dry-year total P deposition =	12.18		
			Average-year total P deposition =	14.91		
			Wet-year total P deposition =	17.68		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
45	0.0	0.00	0	1.0	0

Internal

Lake Area [acre]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
45	41.5	0.00	1.0	0

Net Discharge [ac-ft/yr] =	**1,002**	**Net Load [lb/yr] =**	**355**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2003 Lake Response Modeling for: McKusick 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 =	1.00	[--]
C_{CB} =	0.162	[--]
b =	0.458	[--]
W (total P load = inflow + atm.) =	355	[lb/yr]
Q (lake outflow) =	1,002	[ac-ft/yr]
V (modeled lake volume) =	144	[ac-ft]
T = V/Q =	0.14	[yr]
P_i = W/Q =	130	[ug/l]
Model Predicted In-Lake [TP]	**85.3**	**[ug/l]**
Observed In-Lake [TP]	**44.3**	**[ug/l]**

CHLOROPHYLL-A CONCENTRATION

$$[\text{Chl}a] = CB \times 0.28 \times [TP]$$

as f(TP), Walker 1999, Model 4

CB (Calibration factor) =	1.00	[--]
Model Predicted In-Lake [Chl-a]	**23.9**	**[ug/l]**

$$[\text{Chl}a] = \frac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$$

$$B_x = \frac{X_{pn}^{1.33}}{4.31}$$

$$X_{pn} = \left[P^{-2} + \left(\frac{N - 150}{12}\right)^{-2}\right]^{-0.5}$$

$$G = Z_{mix}(0.14 + 0.0039 F_s)$$

$$F_s = \frac{Q}{V}$$

$$a = \frac{1}{SD} - 0.015 \times [\text{Chl}a]$$

as f(TP, N, Flushing), Walker 1999, Model 1

CB (Calibration factor) =	1.00	
P (Total Phosphorus) =	85	[ug/l]
N (Total Nitrogen) =	2000	[ug/l]
B_x (Nutrient-Potential Chl-a conc.) =	71.9	[ug/l]
X_{pn} (Composite nutrient conc.)=	74.6	[ug/l]
G (Kinematic factor) =	0.16	[--]
F_s (Flushing Rate) =	6.94	[year^{-1}]
Z_{mix} (Mixing Depth) =	3.18	[ft]
a (Non algal turbidity) =	0.40	[m^{-1}]
S (Secchi Depth) =	2.77	[ft]
Maximum lake depth =	10.00	[ft]
Model Predicted In-Lake [Chl-a]	**52.3**	**[ug/l]**
Observed In-Lake [Chl-a]	**10.3**	**[ug/l]**

SECCHI DEPTH

$$SD = \frac{CS}{(\text{a} + 0.015 \times [\text{Chl}a])}$$

as f(Chla), Walker (1999)

CS (Calibration factor) =	1.00	[--]
a (Non algal turbidity) =	0.40	[m^{-1}]
Model Predicted In-Lake SD	**0.84**	**[m]**
Observed In-Lake SD	**1.81**	**[m]**

PHOSPHORUS SEDIMENTATION RATE

$$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$$

P_{sed} (phosphorus sedimentation) = **123** [lb/yr]

PHOSPHORUS OUTFLOW LOAD

W-P_{sed} = **232 [lb/yr]**

1.1.2 2004

2004 Loading Summary for: Lily Lake

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Lily 02	29.8	15.1	37.4	303.1	1.0	30.8
2 Lily 03	33.6	17.0	47.7	306.4	1.0	39.7
3 Lily 04	61.0	9.7	49.1	293.7	1.0	39.2
4 507	56.4	9.2	43.1	245.8	1.0	28.8
5 Lily 09	15.0	13.7	17.1	302.7	1.0	14.1
6 Brick Pond Basin B	347.0	16.1	466.1	118.3	1.0	149.9
7					1.0	
8					1.0	
9					1.0	
10					1.0	
11					1.0	
12					1.0	
13					1.0	
Summation	*543*	*14.6*	*661*	*261.7*		*302.6*

Inflow from Upstream Lakes

Name	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1		-	1.0	
2		-	1.0	
3		-	1.0	
Summation	*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
36	31.30	31.30	0.00	14.91	1.0	4.7
			Dry-year total P deposition =	12.18		
			Average-year total P deposition =	14.91		
			Wet-year total P deposition =	17.68		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
36	0.0	0.00	0	1.0	0

Internal

Lake Area [acre]	Anoxic Factor [days]	Release Rate [mg/m²-day]	Calibration Factor [--]	Load [lb/yr]
36	53.0	1.00	1.0	17

Net Discharge [ac-ft/yr] =	**661**	**Net Load [lb/yr] =**	**324**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2004 Lake Response Modeling for: Lily 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 =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	324 [lb/yr]
		Q (lake outflow) =	661 [ac-ft/yr]
		V (modeled lake volume) =	628 [ac-ft]
		T = V/Q =	0.95 [yr]
		P_i = W/Q =	180 [ug/l]
Model Predicted In-Lake [TP]			**66.8 [ug/l]**
Observed In-Lake [TP]			**42.0 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**18.7 [ug/l]**
	$[\text{Chl}a] = \frac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \frac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	67 [ug/l]
		N (Total Nitrogen) =	2000 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	55.3 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	61.3 [ug/l]
		G (Kinematic factor) =	0.58 [--]
		F_s (Flushing Rate) =	1.05 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	13.12 [ft]
	$F_s = \frac{Q}{V}$; $a = \frac{1}{SD} - 0.015 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.42 [m^{-1}]
		S (Secchi Depth) =	4.13 [ft]
		Maximum lake depth =	50.00 [ft]
Model Predicted In-Lake [Chl-a]			**24.7 [ug/l]**
Observed In-Lake [Chl-a]			**9.8 [ug/l]**
SECCHI DEPTH			
	$SD = \frac{CS}{(\text{a} + 0.015 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.42 [m^{-1}]
Model Predicted In-Lake SD			**1.26 [m]**
Observed In-Lake SD			**1.75 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**204 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**120 [lb/yr]**

2004 Loading Summary for: McKusick Lake

Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 McK 23p	5.4	6.7	3.0	103.9	1.0	0.8
2 McK 27p	51.0	4.5	19.2	125.6	1.0	6.6
3 McK 18p	142.0	3.3	38.8	317.2	1.0	33.5
4 503	32.3	6.7	18.0	324.6	1.0	15.9
5 502	71.8	2.7	16.2	209.9	1.0	9.2
6 701/702/703	1349.7	0.7	78.4	698.9	1.0	149.1
7					1.0	
8					1.0	
9					1.0	
10					1.0	
11					1.0	
12					1.0	
13					1.0	
Summation	*1652*	*1.3*	*174*	*296.7*		*215.2*

Inflow from Upstream Lakes

Name	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1 Lily Lake through McK 11p	594.3	55.4	1.0	90
2 Long Lake through BWE 2, BWE 5, and Diversion	352.9	75.6	1.0	73
3		-	1.0	
Summation	*947*	*65.5*		*162*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
45	31.30	31.30	0.00	14.91	1.0	6.0
			Dry-year total P deposition =	12.18		
			Average-year total P deposition =	14.91		
			Wet-year total P deposition =	17.68		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
45	0.0	0.00	0	1.0	0

Internal

Lake Area [acre]	Anoxic Factor [days]	Release Rate [mg/m²-day]	Calibration Factor [--]	Load [lb/yr]
45	41.5	0.00	1.0	0

Net Discharge [ac-ft/yr] =	**1,121**	**Net Load [lb/yr] =**	**383**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2004 Lake Response Modeling for: McKusick 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 =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	383 [lb/yr]
		Q (lake outflow) =	1,121 [ac-ft/yr]
		V (modeled lake volume) =	144 [ac-ft]
		T = V/Q =	0.13 [yr]
		P_i = W/Q =	126 [ug/l]
Model Predicted In-Lake [TP]			**84.5 [ug/l]**
Observed In-Lake [TP]			**34.1 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**23.7 [ug/l]**
	$[\mathrm{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \mathrm{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	84 [ug/l]
		N (Total Nitrogen) =	2000 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	71.2 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	74.1 [ug/l]
		G (Kinematic factor) =	0.17 [--]
		F_s (Flushing Rate) =	7.76 [$year^{-1}$]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	3.18 [ft]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	0.40 [m^{-1}]
		S (Secchi Depth) =	2.79 [ft]
		Maximum lake depth =	10.00 [ft]
Model Predicted In-Lake [Chl-a]			**51.6 [ug/l]**
Observed In-Lake [Chl-a]			**5.1 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\mathrm{a} + 0.015 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.40 [m^{-1}]
Model Predicted In-Lake SD			**0.85 [m]**
Observed In-Lake SD			**2.59 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**126 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**258 [lb/yr]**

1.1.3 2005

2005 Loading Summary for: Lily Lake

Water Budgets					**Phosphorus Loading**		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Lily 02	29.8	15.3	38.0	311.3	0.5	32.2
2	Lily 03	33.6	17.5	49.2	312.4	1.0	41.8
3	Lily 04	61.0	9.3	47.4	311.3	1.0	40.1
4	507	56.4	8.6	40.3	260.7	1.0	28.6
5	Lily 09	15.0	13.9	17.3	312.5	1.0	14.7
6	Brick Pond Basin B	347.0	16.3	470.5	118.5	1.0	151.6
7						1.0	
8						1.0	
9						1.0	
10						1.0	
11						1.0	
12						1.0	
13						1.0	
	Summation	*543*	*14.7*	*663*	*271.1*		*309.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1					-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	36	34.10	34.10	0.00	14.91	1.0	4.7
				Dry-year total P deposition =	12.18		
				Average-year total P deposition =	14.91		
				Wet-year total P deposition =	17.68		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	36	0.0		0.00	0	1.0	0
Internal							
	Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	36	53.0			1.00	1.0	17
				Net Discharge [ac-ft/yr] = 663		**Net Load [lb/yr] =**	**331**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2005 Lake Response Modeling for: Lily 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 =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	331 [lb/yr]
		Q (lake outflow) =	663 [ac-ft/yr]
		V (modeled lake volume) =	628 [ac-ft]
		T = V/Q =	0.95 [yr]
		P_i = W/Q =	183 [ug/l]
Model Predicted In-Lake [TP]			**67.6 [ug/l]**
Observed In-Lake [TP]			**40.5 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**18.9 [ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	68 [ug/l]
		N (Total Nitrogen) =	2000 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	56.1 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	61.9 [ug/l]
		G (Kinematic factor) =	0.58 [--]
		F_s (Flushing Rate) =	1.06 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	13.12 [ft]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.40 [m^{-1}]
		S (Secchi Depth) =	4.22 [ft]
		Maximum lake depth =	50.00 [ft]
Model Predicted In-Lake [Chl-a]			**25.2 [ug/l]**
Observed In-Lake [Chl-a]			**22.9 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\text{a} + 0.015 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.40 [m^{-1}]
Model Predicted In-Lake SD			**1.29 [m]**
Observed In-Lake SD			**2.13 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**209 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**122 [lb/yr]**

2005 Loading Summary for: McKusick Lake

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	McK 23p	5.4	10.3	4.6	104.9	1.0	1.3
2	McK 27p	51.0	6.8	28.8	131.5	1.0	10.3
3	McK 18p	142.0	4.9	58.2	309.5	1.0	49.0
4	503	32.3	10.3	27.7	312.3	1.0	23.5
5	502	71.8	3.9	23.3	210.3	1.0	13.4
6	701/702/703	1349.7	1.3	151.6	601.7	1.0	248.0
7						1.0	
8						1.0	
9						1.0	
10						1.0	
11						1.0	
12						1.0	
13						1.0	
	Summation	*1652*	*2.1*	*294*	*278.4*		*345.4*

Inflow from Upstream Lakes					
		Discharge	Estimated P Concentration	Calibration Factor	Load
	Name	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Lily Lake through McK 11p	437.5	59.3	1.0	71
2	Long Lake through BWE 2, BWE 5, and Diversion	375.8	93.8	1.0	96
3			-	1.0	
	Summation	*813*	*76.5*		*166*

Atmosphere						
Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
45	34.10	34.10	0.00	14.91	1.0	6.0
			Dry-year total P deposition =	12.18		
			Average-year total P deposition =	14.91		
			Wet-year total P deposition =	17.68		
			(Barr Engineering 2004)			

Groundwater					
Lake Area	Groundwater Flux	Net Inflow	Phosphorus Concentration	Calibration Factor	Load
[acre]	[m/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
45	0.0	0.00	0	1.0	0

Internal				
Lake Area	Anoxic Factor	Release Rate	Calibration Factor	Load
[acre]	[days]	[mg/m^2-day]	[--]	[lb/yr]
45	41.5	0.00	1.0	0

Net Discharge [ac-ft/yr] =	**1,107**	**Net Load [lb/yr] =**	**518**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2005 Lake Response Modeling for: McKusick 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 =	1.00	[--]
C_{CB} =	0.162	[--]
b =	0.458	[--]
W (total P load = inflow + atm.) =	518	[lb/yr]
Q (lake outflow) =	1,107	[ac-ft/yr]
V (modeled lake volume) =	144	[ac-ft]
T = V/Q =	0.13	[yr]
P_i = W/Q =	172	[ug/l]

Model Predicted In-Lake [TP] **109.7 [ug/l]**

Observed In-Lake [TP] **58.5 [ug/l]**

CHLOROPHYLL-A CONCENTRATION

$$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$$

as f(TP), Walker 1999, Model 4

CB (Calibration factor) = 1.00 [--]

Model Predicted In-Lake [Chl-a] **30.7 [ug/l]**

$$[\mathrm{Chl}a] = \frac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \mathrm{a})]}$$

$$B_x = \frac{X_{pn}^{1.33}}{4.31}$$

$$X_{pn} = \left[P^{-2} + \left(\frac{N - 150}{12}\right)^{-2}\right]^{-0.5}$$

$$G = Z_{mix}(0.14 + 0.0039 F_s)$$

$$F_s = \frac{Q}{V} \qquad a = \frac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$$

as f(TP, N, Flushing), Walker 1999, Model 1

CB (Calibration factor) =	1.00	
P (Total Phosphorus) =	110	[ug/l]
N (Total Nitrogen) =	2000	[ug/l]
B_x (Nutrient-Potential Chl-a conc.) =	91.3	[ug/l]
X_{pn} (Composite nutrient conc.)=	89.4	[ug/l]
G (Kinematic factor) =	0.16	[--]
F_s (Flushing Rate) =	7.67	[$year^{-1}$]
Z_{mix} (Mixing Depth) =	3.18	[ft]
a (Non algal turbidity) =	0.40	[m^{-1}]
S (Secchi Depth) =	2.46	[ft]
Maximum lake depth =	10.00	[ft]

Model Predicted In-Lake [Chl-a] **62.3 [ug/l]**

Observed In-Lake [Chl-a] **20.6 [ug/l]**

SECCHI DEPTH

$$SD = \frac{CS}{(\mathrm{a} + 0.015 \times [\mathrm{Chl}a])}$$

as f(Chla), Walker (1999)

CS (Calibration factor) = 1.00 [--]

a (Non algal turbidity) = 0.40 [m^{-1}]

Model Predicted In-Lake SD **0.75 [m]**

Observed In-Lake SD **1.85 [m]**

PHOSPHORUS SEDIMENTATION RATE

$$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$$

P_{sed} (phosphorus sedimentation) = **187 [lb/yr]**

PHOSPHORUS OUTFLOW LOAD

W-P_{sed} = **330 [lb/yr]**

1.1.4 2006

2006 Loading Summary for: Lily Lake						
Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Lily 02	29.8	12.1	30.1	352.6	1.0	28.8
2 Lily 03	33.6	13.9	39.0	353.0	1.0	37.5
3 Lily 04	61.0	7.4	37.6	351.9	1.0	36.0
4 507	56.4	6.7	31.3	295.4	1.0	25.2
5 Lily 09	15.0	11.1	13.8	352.8	1.0	13.2
6 Brick Pond Basin B	347.0	12.8	368.7	122.6	1.0	122.9
7					1.0	
8					1.0	
9					1.0	
10					1.0	
11					1.0	
12					1.0	
13					1.0	
Summation	*543*	*11.5*	*521*	*304.7*		*263.6*
Inflow from Upstream Lakes						
Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1				-	1.0	
2				-	1.0	
3				-	1.0	
Summation			*0*	-		*0*
Atmosphere						
Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
36	27.01	27.01	0.00	14.91	1.0	4.7
			Dry-year total P deposition =	12.18		
			Average-year total P deposition =	14.91		
			Wet-year total P deposition =	17.68		
			(Barr Engineering 2004)			
Groundwater						
Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
36	0.0		0.00	0	1.0	0
Internal						
Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m²-day]	Calibration Factor [--]	Load [lb/yr]
36	53.0			1.00	1.0	17
			Net Discharge [ac-ft/yr] = 521		**Net Load [lb/yr] =**	**285**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2006 Lake Response Modeling for: Lily Lake

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	285 [lb/yr]
		Q (lake outflow) =	521 [ac-ft/yr]
		V (modeled lake volume) =	628 [ac-ft]
		T = V/Q =	1.21 [yr]
		P_i = W/Q =	201 [ug/l]
Model Predicted In-Lake [TP]			**66.3 [ug/l]**
Observed In-Lake [TP]			**69.3 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**18.6 [ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	66 [ug/l]
		N (Total Nitrogen) =	2000 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	54.9 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	60.9 [ug/l]
		G (Kinematic factor) =	0.57 [--]
		F_s (Flushing Rate) =	0.83 [$year^{-1}$]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	13.12 [ft]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.40 [m^{-1}]
		S (Secchi Depth) =	4.22 [ft]
		Maximum lake depth =	50.00 [ft]
Model Predicted In-Lake [Chl-a]			**25.0 [ug/l]**
Observed In-Lake [Chl-a]			**31.4 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\text{a} + 0.015 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.40 [m^{-1}]
Model Predicted In-Lake SD			**1.29 [m]**
Observed In-Lake SD			**1.14 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**191 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**94 [lb/yr]**

2006 Loading Summary for: McKusick Lake

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	McK 23p	5.4	8.0	3.6	105.0	1.0	1.0
2	McK 27p	51.0	5.2	22.2	133.5	1.0	8.0
3	McK 18p	142.0	3.8	44.4	357.2	1.0	43.1
4	503	32.3	8.0	21.4	357.1	1.0	20.8
5	502	71.8	2.9	17.5	237.5	1.0	11.3
6	701/702/703	1349.7	0.9	98.3	748.8	1.0	200.2
7						1.0	
8						1.0	
9						1.0	
10						1.0	
11						1.0	
12						1.0	
13						1.0	
	Summation	*1652*	*1.5*	*207*	*323.2*		*284.5*

Inflow from Upstream Lakes					
	Name	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Lily Lake through McK 11p	349.1	71.0	1.0	67
2	Long Lake through BWE 2, BWE 5, and Diversion	322.2	101.7	1.0	89
3			-	1.0	
	Summation	*671*	*86.3*		*156*

Atmosphere						
Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
45	27.01	27.01	0.00	14.91	1.0	6.0
			Dry-year total P deposition =	12.18		
			Average-year total P deposition =	14.91		
			Wet-year total P deposition =	17.68		
			(Barr Engineering 2004)			

Groundwater					
Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
45	0.0	0.00	0	1.0	0

Internal				
Lake Area [acre]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
45	41.5	0.00	1.0	0

Net Discharge [ac-ft/yr] =	**879**	**Net Load [lb/yr] =**	**447**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2006 Lake Response Modeling for: McKusick 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 =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	447 [lb/yr]
		Q (lake outflow) =	879 [ac-ft/yr]
		V (modeled lake volume) =	144 [ac-ft]
		T = V/Q =	0.16 [yr]
		P_i = W/Q =	187 [ug/l]
Model Predicted In-Lake [TP]			**112.1 [ug/l]**
Observed In-Lake [TP]			**71.6 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**31.4 [ug/l]**
	$[\mathrm{Chl}a] = \frac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times a)]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \frac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	112 [ug/l]
		N (Total Nitrogen) =	2000 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	93.1 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	90.7 [ug/l]
		G (Kinematic factor) =	0.16 [--]
		F_s (Flushing Rate) =	6.08 [$year^{-1}$]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	3.18 [ft]
	$F_s = \frac{Q}{V}$; $a = \frac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	0.40 [m^{-1}]
		S (Secchi Depth) =	2.41 [ft]
		Maximum lake depth =	10.00 [ft]
Model Predicted In-Lake [Chl-a]			**63.9 [ug/l]**
Observed In-Lake [Chl-a]			**16.8 [ug/l]**
SECCHI DEPTH			
	$SD = \frac{CS}{(a + 0.015 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.40 [m^{-1}]
Model Predicted In-Lake SD			**0.74 [m]**
Observed In-Lake SD			**2.07 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**179 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**268 [lb/yr]**

Appendix C

Cost Estimate Sheets

Alternative:	Parking Lot Improvements and rain garden installation	Lily 04		
Item	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Investment Cost Estimate				
Excavation, disposal	300	cu. yd.	$ 15	$ 4,500
Hydraulic Structures	0	Lump Sum	$ 50,000	$ -
Restoration	1	acre	$ 5,500	$ 2,750
Engineered Soils	150	cu. yd.	$ 8	$ 1,200
Mobilization/Demobilization	1	Lump Sum	$ 10,000	$ 10,000
Contingencies	1	ea.	20%	$ 3,690
Subtotal, Construction	--	--	--	$ 22,140
Engineering, Legal, Admin.	1	ea.	35%	$ 7,749
Land, Easements	0	acre	$ -	$ -
Total Investment Cost				$ 29,889
Annual Operating Cost				
				$ -
				$ -
				$ -
Annual operation costs				$ -
Overhaul Cost at 20 years				
Maintenance excavation, disposal, replacement	45	cu. yd.	$ 23.00	$ 1,035
				$ -
				$ -
Total replacement costs				$ 1,035
Project Present Value				
Investment Cost				$ 29,889
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ -
Present Value of Maintenance & Replacement				$ 390
Total Present Value				$ 30,500
Project Annual Cost				
Annual cost (annuity)				$ 2,400

Alternative: **In-Lake Alum Treatment Lily Lake**

Item	Quantity	Unit	Unit Cost	Cost
Investment Cost Estimate				
Supply and apply alum	24,592	gallon	$ 1.00	$ 24,592
			$ -	$ -
			$ -	$ -
			$ -	$ -
			$ -	$ -
			$ -	$ -
			$ -	$ -
Mobilization, Demobilization	1	ea.	$ 10,000.00	$ 10,000
Contingencies	1	ea.	20%	$ 6,918
Subtotal, Construction	--	--	--	$ 41,510
Engineering, Legal, Admin.	1	ea.	35%	$ 14,528
Land, Easements	--	--	$ -	$ -
Total Investment Cost				$ 56,038
Reapplication Costs				
Reapplication interval	20	yr.	$ -	$ -
Reapplication Costs	-	ea.	$ 56,038.39	$ -
Nominal Interest Rate	165.33%	per 20 yr		
Present Value of Reapplication Costs				$ -
Overhaul Cost at 20 years				
			$ -	$ -
			$ -	$ -
			$ -	$ -
Total replacement costs				$ -
Project Present Value				
Investment Cost				$ 56,038
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Reapplication Costs				$ -
Present Value of Maintenance & Replacement				$ -
Total Present Value				$ 56,000
Project Annual Cost				
Annual cost (annuity)				$ 4,500

Alternative:	Wet Pond excavation and expansion		Lily 13	
Item	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Investment Cost Estimate				
Excavation, disposal	4,546	cu. yd.	$ 15	$ 68,195
Hydraulic Structures	0	Lump Sum	$ 50,000	$ -
Site Restoration	1	acre	$ 5,500	$ 4,950
Aquatic vegetation	1	acre	$ 7,000	$ 6,300
Dewatering	0	ea.	$ 20,000	$ -
Mobilization/Demobilization	1	Lump Sum	$ 10,000	$ 10,000
Contingencies	1	ea.	20%	$ 17,889
Subtotal, Construction		--	--	$ 107,334
Engineering, Legal, Admin.	0	ea.	35%	$ -
Land, Easements	0	acre	$ -	$ -
Total Investment Cost				$ 107,334
Annual Operating Cost				
				$ -
				$ -
				$ -
Annual operation costs				$ -
Overhaul Cost at 20 years				
Maintenance excavation, disposal	6,000	cu. yd.	$ 10	$ 60,000
Pump and motor replacement		ea.	$ -	$ -
Other		ea.	$ -	$ -
Total replacement costs				$ 60,000
Project Present Value				
Investment Cost				$ 107,334
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ -
Present Value of Maintenance & Replacement				$ 22,613
Total Present Value				$ 130,000
Project Annual Cost				
Annual cost (annuity)				$ 10,000

Alternative:	Wet Pond Excavation and Expansion	Lily 18		
Item	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Investment Cost Estimate				
Excavation, disposal	11,296	cu. yd.	$ 15	$ 169,441
Hydraulic Structures	0	Lump Sum	$ 50,000	$ -
Site Restoration	2	acre	$ 5,500	$ 9,900
Aquatic vegetation	2	acre	$ 7,000	$ 12,600
Dewatering	0	ea.	$ 20,000	$ -
Mobilization/Demobilization	1	Lump Sum	$ 10,000	$ 10,000
Contingencies	1	ea.	20%	$ 40,388
Subtotal, Construction	--	--	--	$ 242,329
Engineering, Legal, Admin.	0	ea.	35%	$ -
Land, Easements	0	acre	$ -	$ -
Total Investment Cost				$ 242,329
Annual Operating Cost				
				$ -
				$ -
				$ -
Annual operation costs				$ -
Overhaul Cost at 20 years				
Maintenance excavation, disposal	6,000	cu. yd.	$ 10	$ 60,000
Pump and motor replacement		ea.	$ -	$ -
Other		ea.	$ -	$ -
Total replacement costs				$ 60,000
Project Present Value				
Investment Cost				$ 242,329
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ -
Present Value of Maintenance & Replacement				$ 22,613
Total Present Value				$ 265,000
Project Annual Cost				
Annual cost (annuity)				$ 21,000

Alternative:	Infiltration Basin	Lily 03		
Item	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Investment Cost Estimate				
Excavation, disposal	1675	cu. yd.	$ 15	$ 25,125
Hydraulic Structures	1	Lump Sum	$ 10,000	$ 10,000
Restoration	0	acre	$ 5,500	$ 1,055
Mobilization/Demobilization	1	Lump Sum	$ 20,000	$ 20,000
Contingencies	1	ea.	20%	$ 11,236
Subtotal, Construction	--	--	--	$ 67,416
Engineering, Legal, Admin.	1	ea.	35%	$ 23,596
Land, Easements	0	acre	$ -	$ -
Total Investment Cost				$ 91,012
Annual Operating Cost				
				$ -
				$ -
				$ -
Annual operation costs				$ -
Overhaul Cost at 20 years				
Maintenance excavation, disposal, replacement	251	cu. yd.	$ 15.00	$ 3,769
				$ -
				$ -
Total replacement costs				$ 3,769
Project Present Value				
Investment Cost				$ 91,012
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ -
Present Value of Maintenance & Replacement				$ 1,420
Total Present Value				$ 92,500
Project Annual Cost				
Annual cost (annuity)				$ 7,400

Alternative: **Infiltration Basin** **Lily 02**

Item	Quantity	Unit	Unit Cost	Cost
Investment Cost Estimate				
Excavation, disposal	1,127	cu. yd.	$ 15	$ 16,901
Hydraulic Structures	1	Lump Sum	$ 10,000	$ 10,000
Restoration	0.8	acre	$ 5,500	$ 4,400
Mobilization/Demobilization	1	Lump Sum	$ 20,000	$ 20,000
Contingencies	1	ea.	20%	$ 10,260
Subtotal, Construction	--	--	--	$ 61,561
Engineering, Legal, Admin.	1	ea.	35%	$ 21,546
Land, Easements	0	acre	$ -	$ -
Total Investment Cost				$ 83,107
Annual Operating Cost				
				$ -
				$ -
				$ -
Annual operation costs				$ -
Overhaul Cost at 20 years				
Maintenance excavation, disposal, replacement	169	cu. yd.	$ 10	$ 1,690
				$ -
				$ -
Total replacement costs				$ 1,690
Project Present Value				
Investment Cost				$ 83,107
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ -
Present Value of Maintenance & Replacement				$ 637
Total Present Value				$ 83,500
Project Annual Cost				
Annual cost (annuity)				$ 6,700

Alternative: **Infiltration Basin** **Lily 15**

Item	Quantity	Unit	Unit Cost	Cost
Investment Cost Estimate				
Excavation, disposal	1,154	cu. yd.	$ 15	$ 17,313
Hydraulic Structures	1	Lump Sum	$ 10,000	$ 10,000
Restoration	0.8	acre	$ 5,500	$ 4,400
Engineered Soils		cu. yd.	$ -	$ -
Mobilization/Demobilization	1	Lump Sum	$ 20,000	$ 20,000
Contingencies	1	ea.	20%	$ 10,343
Subtotal, Construction	--	--	--	$ 62,056
Engineering, Legal, Admin.	1	ea.	35%	$ 21,720
Land, Easements	0	acre	$ -	$ -
Total Investment Cost				$ 83,776
Annual Operating Cost				
				$ -
				$ -
				$ -
Annual operation costs				$ -
Overhaul Cost at 20 years				
Maintenance excavation, disposal, replacement	173	cu. yd.	$ 10	$ 1,731
				$ -
				$ -
Total replacement costs				$ 1,731
Project Present Value				
Investment Cost				$ 83,776
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ -
Present Value of Maintenance & Replacement				$ 653
Total Present Value				$ 84,500
Project Annual Cost				
Annual cost (annuity)				$ 6,800

Alternative: **Infiltration Basin** **Lily 01**

Item	Quantity	Unit	Unit Cost	Cost
Investment Cost Estimate				
Excavation, disposal	865	cu. yd.	$ 15	$ 12,977
Hydraulic Structures	1	Lump Sum	$ 10,000	$ 10,000
Restoration	1	acre	$ 5,500	$ 4,675
Engineered Soils	-	cu. yd.	$ -	$ -
Mobilization/Demobilization	1	Lump Sum	$ 20,000	$ 20,000
Contingencies	1	ea.	20%	$ 9,530
Subtotal, Construction	--	--	--	$ 57,182
Engineering, Legal, Admin.	1	ea.	35%	$ 20,014
Land, Easements	0	acre	$ -	$ -
Total Investment Cost				$ 77,196
Annual Operating Cost				
				$ - $ - $ -
Annual operation costs				$ -
Overhaul Cost at 20 years				
Maintenance excavation, disposal, replacement	130	cu. yd.	$ 10.00	$ 1,298 $ - $ -
Total replacement costs				$ 1,298
Project Present Value				
Investment Cost				$ 77,196
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ -
Present Value of Maintenance & Replacement				$ 489
Total Present Value				$ 77,500
Project Annual Cost				
Annual cost (annuity)				$ 6,200

Alternative: **Infiltration Basin** **BWW 03**

Item	Quantity	Unit	Unit Cost	Cost
Investment Cost Estimate				
Excavation, disposal	36,770	cu. yd.	$ 15	$ 551,553
Hydraulic Structures	1	Lump Sum	$ 50,000	$ 50,000
Restoration	3	acre	$ 5,500	$ 13,750
Engineered Soils	-	cu. yd.	$ 8	$ -
Mobilization/Demobilization	1	Lump Sum	$ 20,000	$ 20,000
Contingencies	1	ea.	20%	$ 127,061
Subtotal, Construction	--	--	--	$ 762,363
Engineering, Legal, Admin.	1	ea.	35%	$ 266,827
Land, Easements	0	acre	$ -	$ -
Total Investment Cost				$ 1,029,190
Annual Operating Cost				
				$ -
				$ -
				$ -
Annual operation costs				$ -
Overhaul Cost at 10 years				
Maintenance excavation, disposal, replacement	5,516	cu. yd.	$ 10.00	$ 55,155
				$ -
				$ -
Total replacement costs				$ 55,155
Project Present Value				
Investment Cost				$ 1,029,190
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ -
Present Value of Maintenance & Replacement				$ 20,787
Total Present Value				$ 1,050,000
Project Annual Cost				
Annual cost (annuity)				$ 84,000

Alternative: **Large Scale Infiltration Practice** **Div. Struc.**

Item	Quantity	Unit	Unit Cost	Cost
Investment Cost Estimate				
Excavation, disposal	56,338	cu. yd.	$ 15	$ 845,077
Hydraulic Structures	1	Lump Sum	$ 50,000	$ 50,000
Restoration	4	acre	$ 5,500	$ 22,000
Engineered Soils	-	cu. yd.	$ -	$ -
Mobilization/Demobilization	1	Lump Sum	$ 20,000	$ 20,000
Contingencies	1	ea.	20%	$ 187,415
Subtotal, Construction	--	--	--	$ 1,124,492
Engineering, Legal, Admin.	1	ea.	35%	$ 393,572
Land, Easements	0	acre	$ -	$ -
Total Investment Cost				$ 1,518,064
Annual Operating Cost				
				$ -
				$ -
				$ -
Annual operation costs				$ -
Overhaul Cost at 10 years				
Maintenance excavation, disposal, replacement	8,451	cu. yd.	$ 10	$ 84,508
				$ -
				$ -
Total replacement costs				$ 84,508
Project Present Value				
Investment Cost				$ 1,518,064
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ -
Present Value of Maintenance & Replacement				$ 31,850
Total Present Value				$ 1,550,000
Project Annual Cost				
Annual cost (annuity)				$ 120,000

Alternative: **Infiltration Basin** **McK 26**

Item	Quantity	Unit	Unit Cost	Cost
Investment Cost Estimate				
Excavation, disposal	755.54	cu. yd.	$ 15	$ 11,333
Hydraulic Structures	1	Lump Sum	$ 10,000	$ 10,000
Restoration	1	acre	$ 5,500	$ 3,300
Engineered Soils	-	cu. yd.	$ 8	$ -
Mobilization/Demobilization	1	Lump Sum	$ 20,000	$ 20,000
Contingencies	1	ea.	20%	$ 8,927
Subtotal, Construction	--	--	--	$ 53,560
Engineering, Legal, Admin.	1	ea.	35%	$ 18,746
Land, Easements	0	acre	$ -	$ -
Total Investment Cost				$ 72,306
Annual Operating Cost				
				$ -
				$ -
				$ -
Annual operation costs				$ -
Overhaul Cost at 20 years				
Maintenance excavation, disposal, replacement	113	cu. yd.	$ 23.00	$ 2,607
				$ -
				$ -
Total replacement costs				$ 2,607
Project Present Value				
Investment Cost				$ 72,306
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ -
Present Value of Maintenance & Replacement				$ 982
Total Present Value				$ 73,500
Project Annual Cost				
Annual cost (annuity)				$ 5,900

Alternative: **Wet Pond** **McK 18 (NE)**

Item	Quantity	Unit	Unit Cost	Cost
Investment Cost Estimate				
Excavation, disposal	2,033	cu. yd.	$ 15	$ 30,492
Hydraulic Structures	1	Lump Sum	$ 50,000	$ 50,000
Site Restoration	0	acre	$ 5,500	$ 550
Aquatic vegetation	0	acre	$ 7,000	$ 700
Dewatering	0	ea.	$ 20,000	$ -
Mobilization/Demobilization	1	Lump Sum	$ 10,000	$ 10,000
Contingencies	1	ea.	20%	$ 18,348
Subtotal, Construction	--	--	--	$ 110,090
Engineering, Legal, Admin.	1	ea.	35%	$ 38,532
Land, Easements	0	acre	$ -	$ -
Total Investment Cost				$ 148,622
Annual Operating Cost				
				$ -
				$ -
				$ -
Annual operation costs				$ -
Overhaul Cost at 20 years				
Maintenance excavation, disposal	305	cu. yd.	$ 10	$ 3,049
				$ -
				$ -
Total replacement costs				$ 3,049
Project Present Value				
Investment Cost				$ 148,622
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ -
Present Value of Maintenance & Replacement				$ 1,149
Total Present Value				$ 150,000
Project Annual Cost				
Annual cost (annuity)				$ 12,000

Alternative: Wet Pond		McK 18 (SE)		
Item	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Investment Cost Estimate				
Excavation, disposal	1,027	cu. yd.	$ 15	$ 15,409
Hydraulic Structures	1	Lump Sum	$ 50,000	$ 50,000
Site Restoration	0	acre	$ 5,500	$ 550
Aquatic vegetation	0	acre	$ 7,000	$ 700
Dewatering	0	ea.	$ 20,000	$ -
Mobilization/Demobilization	1	Lump Sum	$ 10,000	$ 10,000
Contingencies	1	ea.	20%	$ 15,332
Subtotal, Construction	--	--	--	$ 91,991
Engineering, Legal, Admin.	1	ea.	35%	$ 32,197
Land, Easements	0	acre	$ -	$ -
Total Investment Cost				$ 124,188
Annual Operating Cost				
				$ -
				$ -
				$ -
Annual operation costs				$ -
Overhaul Cost at 20 years				
Maintenance excavation, disposal	154	cu. yd.	$ 10	$ 1,541
				$ -
				$ -
Total replacement costs				$ 1,541
Project Present Value				
Investment Cost				$ 124,188
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ -
Present Value of Maintenance & Replacement				$ 581
Total Present Value				$ 125,000
Project Annual Cost				
Annual cost (annuity)				$ 10,000

Alternative: **In-Lake Alum Treatment**

Item	Quantity	Unit	Unit Cost	Cost
Investment Cost Estimate				
Supply and apply alum	31,291	gallon	$ 1.00	$ 31,291
			$ -	$ -
			$ -	$ -
			$ -	$ -
			$ -	$ -
			$ -	$ -
			$ -	$ -
Mobilization, Demobilization	1	ea.	$ 10,000	$ 10,000
Contingencies	1	ea.	20%	$ 8,258
Subtotal, Construction	--	--	--	$ 49,550
Engineering, Legal, Admin.	1	ea.	35%	$ 17,342
Land, Easements	--	--	$ -	$ -
Total Investment Cost				$ 66,892
Reapplication Costs				
Reapplication interval	20	yr.	$ -	$ -
Reapplication Costs	-	ea.	$ 66,892	$ -
Nominal Interest Rate	165.33%	per 20 yr		
Present Value of Reapplication Costs				$ -
Overhaul Cost at 20 years				
				$ -
				$ -
				$ -
Total replacement costs				$ -
Project Present Value				
Investment Cost				$ 66,892
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Reapplication Costs				$ -
Present Value of Maintenance & Replacement				$ -
Total Present Value				$ 67,000
Project Annual Cost				
Annual cost (annuity)				$ 5,400

Alternative: **Rough Fish Management**

Item	Quantity	Unit	Unit Cost	Cost
Investment Cost Estimate				
Initial Fish Catch and Removal	4	crew-day	$ 500	$ 2,000
Fish Screen for Upper Watershed	1	ea.	$ 8,000	$ 8,000
Intial Fish Catch and Removal at Hiawatha	1	crew-day	$ 500	$ 500
			$ -	$ -
			$ -	$ -
			$ -	$ -
			$ -	$ -
Mobilization, Demobilization	1	ea.	$ 3,000	$ 3,000
Contingencies	1	ea.	20%	$ 2,700
Subtotal, Construction	--	--	--	$ 16,200
Engineering, Legal, Admin.	1	ea.	35%	$ 5,670
Land, Easements	--	--	$ -	$ -
Total Investment Cost				$ 21,870
Reapplication Costs				
Reapplication interval	2	yr.	$ -	$ -
Reapplication Costs	9	ea.	$ 13,870	$ 124,830
Nominal Interest Rate	10.25%	per 2 yr		
Present Value of Reapplication Costs				$ 79,090
Overhaul Cost at 20 years				
				$ -
				$ -
				$ -
				$ -
Project Present Value				
Investment Cost				$ 21,870
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Reapplication Costs				$ 79,090
Present Value of Maintenance & Replacement				$ -
Total Present Value				$ 100,000
Project Annual Cost				
Annual cost (annuity)				$ 8,000