City of Eagan

Final Report

Fish Lake Nutrient Impairment TMDL and Schwanz Lake Nutrient Management Plan

Prepared for City of Eagan and MPCA

September 2010

Project Number 000049-08143-0

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TMDL Summary Table

U.S. EPA/MPCA Required Elements	Summary			TMDL Page #
Location	Fish and Schwanz lakes are located in the Gun Club Lake Watershed, Lower Minnesota River Basin, Dakota County, and the City of Eagan, Minnesota, which is in the southern part of the Minneapolis and St. Paul Metropolitan area.			6
303(d) Listing Information	**Lake Name (ID Number):** Fish Lake (19-0057-00) and Schwanz Lake (19-0063-00) **Impaired Beneficial Use:** Aquatic Recreation (Minnesota Rules Ch. 7050.0222) **Impairment/Pollutant:** Excess Nutrients (Total Phosphorus) **Proposed TMDL Start/Completion Date:** 2007/2011 **Original Listing Year:** 2006			6
Applicable Water Quality Standards/ Numeric Targets	The North Central Hardwood Forest (NCHF) Ecoregion water quality standards for shallow lakes are: Total Phosphorus $\leq$ 60 μg/L, Secchi Depth $\geq$ 1.0 m, and Chlorophyll-*a* $\leq$ 20 μg/L (Minnesota Rules Ch. 7050).			6
Loading Capacity (expressed as daily load)	The loading capacity (i.e., TMDL) for Fish Lake is 1.11 lb/day, as discussed in Section 6. Fish Lake's (Waste Load and Load) Allocation for Total Phosphorus is 0.96 lb/day, as indicated in Table 6.1. Critical conditions are addressed in the Fish Lake TMDL because the load allocations were developed for the summer growing season when lake water quality is worst and most sensitive to loads. Consequently, the TMDL will be protective of all seasons. Because Schwanz Lake is already meeting the NCHF Ecoregion water quality standards and can be removed from the 303(d) list, no TMDL is necessary.			37
Waste Load Allocation (WLA)	*Source*	*Permit #*	*Individual WLA (Total Phosphorus)*	37
	City of Eagan (permitted stormwater)	MS400014	**Fish Lake** = 0.72 lb/day	
	City of Inver Grove Heights (permitted stormwater)	MS400096	**Fish Lake** = 0.003 lb/day	
	Dakota County (permitted stormwater)	MS400132	**Fish Lake** = 0.049 lb/day	
	Minnesota Department of Transportation (permitted stormwater)	MS400170	**Fish Lake** = 0.005 lb/day	
	Reserve Capacity	NA	Future growth is discussed in Section 6.2	
Load Allocation (LA)	*Source*		*LA*	37
	Internal Loading		**Fish Lake** = 0.16 lb/day	
	Direct Atmospheric Loading		**Fish Lake** = 0.021 lb/day	
Margin Of Safety (MOS)			**Fish Lake** = 0.15 lb/day	39
	MOS is discussed in Section 6.1.5. An explicit MOS is used by setting an in-lake recreation season (June-September) goal 10% below the State standard of 60 μg/L. The MOS is reflected in the WLA for the City of Eagan.			

TMDL Summary Table (continued)		
U.S. EPA/MPCA Required Elements	**Summary**	**TMDL Page #**
Seasonal Variation	Seasonal Variation is discussed in Section 6.1.4. Total Phosphorus loadings to Fish and Schwanz lakes were estimated for dry (2008), average (2006), and wet (2002) years.	38
Reasonable Assurance	Reasonable Assurance is covered in Section 8.2. To maximize effectiveness, an Implementation Plan will be developed with an adaptive management strategy to reduce nutrient loading to Fish and Schwanz lakes. In addition, there are two primary mechanisms assuring the implementation of improvements by the City of Eagan: its Local Water Management Plan and its NPDES Phase II MS4 Stormwater Permit.	42
Monitoring	A follow up Monitoring Plan is included in Section 8.3. The City of Eagan's NPDES Phase II MS4 Annual Report will be the mechanism by which the City will evaluate and report on progress toward implementing the BMPs detailed in the TMDL Implementation Plan.	44
Implementation	An Implementation Strategy is provided in Section 8. A separate, more detailed Implementation Plan will be developed within a year from the U.S. EPA approval date of this TMDL Report. Implementation activities will focus on reducing the movement of total phosphorus from the watershed area into both Fish and Schwanz lakes as well as working within the lakes to reduce internal total phosphorus recycling, decrease algal production as defined by chlorophyll-*a*, and improve water clarity as measured by Secchi depth to achieve the shallow lakes NCHF Ecoregion criteria (as adopted by the MPCA) for Fish Lake and continue meeting the criteria for Schwanz Lake.	41
Public Participation	Public Participation is discussed in Section 7. Between June 2008 and February 2010, three meetings were held with stakeholders and a technical advisory committee. The following were invited to the TMDL stakeholder process: At-large citizens, Fish Lake watershed residents, Schwanz Lake watershed residents, City of Eagan, City of Inver Grove Heights, Dakota County Soil and Water Conservation District, Gun Club Lake Watershed Management Organization, Metropolitan Council, Minnesota Board of Water and Soil Resources, Minnesota Department of Natural Resources, Minnesota Department of Transportation, and Minnesota Pollution Control Agency. The public comment period for this TMDL was from May 24, 2010 to June 23, 2010. One comment was received on the draft TMDL report, and a small change to the stakeholder list was made.	40

Executive Summary

In 2006, the Minnesota Pollution Control Agency (MPCA) listed both Fish and Schwanz lakes, located in the City of Eagan, as impaired for aquatic recreation under Section 303(d) of the Clean Water Act. The main cause for these impairments is excessive nutrients in the lakes. According to the 2006 303(d) list, the proposed start date for a Total Maximum Daily Load (TMDL) study for each lake was 2017, with completion of a TMDL plan proposed for 2020. The City requested the scheduled start and completion dates to be moved to 2007 and 2011, respectively however, because it was ready to pursue TMDL efforts at the heels of completing a comprehensive water management plan in 2007 (City of Eagan, 2007b and 2007c). MPCA made this schedule change to the 2008 303(d) list.

This TMDL document combines assessments of the nutrient load reductions needed for Fish and Schwanz lakes to meet Minnesota water quality standards. The specific sources of nutrients, target reductions from each source, strategies to achieve the reductions, and the approaches to meeting applicable water quality standards for each lake are discussed.

Fish (MDNR ID# 19-0057-00) and Schwanz (MDNR ID# 19-0063-00) lakes are 29 acres and 12 acres in surface area, respectively. Both lakes and their watersheds are within the Gun Club Lake Watershed in the southern part of the Minneapolis and St. Paul Metropolitan area. These are shallow lakes used primarily by local and regional residents for fishing, non-motorized boating, aesthetic enjoyment, and some swimming and wading. Fish Lake has public access via Fish Lake Park, located on the east and north side of the lake, including a boat ramp adjacent to a parking lot off Denmark Avenue. Schwanz Lake has public access via Trapp Farm Park, located along the southwest shoreline of the lake, including a canoe launch adjacent to a parking lot off Wilderness Run Road. Both parks have a fishing pier. The City of Eagan classifies Fish Lake as a Class L1 lake, the highest management goal for which is swimming, and Schwanz Lake as a Class L2 lake, the highest management goal for which is fishing and canoeing.

Fish Lake has a watershed of approximately 3,334 acres (watershed to lake area ratio of 116:1) that includes approximately 150 natural lakes, wetlands, and constructed storm basins. The land use in the watershed is predominantly urbanized and comprised mainly of low- and medium-density residential development, with some commercial and institutional uses. A very small part of the drainage (about 30 acres or 0.1%) lies within the City of Inver Grove Heights, and the rights-of-way of Dakota County Highway Department (about 80 acres) and Minnesota Department of Transportation (Mn/DOT) (about 13 acres) together comprise about 2.8% of the watershed. Fish Lake discharges through a 24-inch diameter concrete pipe to a small wetland, which drains to Blackhawk Lake, a City-designated Class L2 lake.

Schwanz Lake has a watershed of approximately 763 acres (watershed to lake area ratio of 66:1), 84% of which lies within the City of Eagan and 16% of which lies within the City of Inver Grove Heights. The watershed includes over 50 natural lakes, wetlands, and constructed storm basins. The land use is primarily low- and medium-density residential development. Dakota County Highway and MnDOT rights-of-way comprise approximately 4.4% of the watershed area. Discharge from Schwanz Lake is controlled by a 5-cubic foot per second (cfs) capacity stormwater lift station.

In 2006, the MPCA added the two lakes to the Minnesota 303(d) impaired waters list for aquatic recreation as a result of mean summer total phosphorus (TP) values that exceeded the standard for Class 2B recreational waters. Both lakes were listed when the state TP concentration standard for all lakes in the North Central Hardwood Forest (NCHF) Ecoregion was ≤ 40 µg/L.

In May, 2008, the U.S. EPA approved the State of Minnesota's revised eutrophication standards, which differentiate between deep and shallow lakes based on extensive technical analysis and documentation by MPCA staff. The shallow lake eutrophication criteria for NCHF Ecoregion lakes were changed to include a TP concentration of ≤ 60 µg/L, with secondary supporting standards for Secchi depth (i.e., water clarity) of ≥ 1.0 m and for chlorophyll-*a* of ≤ 20 µg/L (measured as June-September means). This TMDL is based on the shallow lakes standard.

MPCA guidance indicates that in order to provide adequate basis for delisting or removing a lake from the 303(d) list, one of the two following conditions relative to the eutrophication standards must be met for data in the most recent 10 years:

1. The monitored in-lake TP concentration and at least one of the other two parameters, chlorophyll-*a* or Secchi depth, must be equal to or better than the applicable standards.
2. The monitored values for both chlorophyll-*a* and Secchi depth must be equal to or better than the standard, even if the in-lake TP concentration does not meet the standard.

To address the issues affecting water quality in Fish and Schwanz lakes, the City of Eagan invited a group of stakeholders including watershed residents as well as representatives from the City of Inver Grove Heights, Dakota County Soil and Water Conservation District, Gun Club Lake Watershed Management Organization, Metropolitan Council, Minnesota Board of Water and Soil Resources, Minnesota Department of Natural Resources (MDNR), Mn/DOT, and MPCA. The general process was to evaluate the current water quality in each lake, estimate actual loadings and the load allocation necessary for each lake to meet state standards for NCHF Ecoregion shallow lakes, and develop a strategy to improve/protect water quality and biological habitat within the lakes consistent with those state standards.

A detailed spreadsheet model called PONDNET (Walker, 1989) was calibrated using monitored inflow volume and water quality data to estimate watershed-driven water and TP budgets for each lake. Watershed loadings were then used as inputs to a Canfield-Bachmann lake response model (Canfield and Bachmann, 1981) that was calibrated to monitored in-lake TP concentrations. Along with supporting analyses to estimate the magnitude of internal loading, overall nutrient and water volume budgets were developed for each lake. A narrative description of the outcome of the TMDL analysis for each lake is presented below.

FISH LAKE

For Fish Lake, the TP load for a normal precipitation year was found to be 436 lb/yr, with approximately 369 lb/yr (85% of the total) delivered to the lake from its surface watershed, 59 lb/yr (13% of the total) from internal loading sources, and the remaining 8 lb/yr (2% of the total) from atmospheric deposition. Over 76% of the TP load is delivered to the lake at a flow-weighted mean concentration less than 150 µg/L through the storm trunk system entering the east end of the lake. This indicates incoming runoff is relatively well treated by the extensive network of wetlands and ponds in the subwatershed. The in-lake TP goal for Fish Lake was set at 54 µg/L, based on the shallow lake eutrophication standard of 60 µg/L and an explicit Margin of Safety (MOS) of 10% (6 µg/L). To achieve the in-lake TP goal, overall loading to the lake should be 352 lb/yr, an 84 lb/yr or 19% reduction from the current estimated total load (23% reduction from current estimated load from permitted sources). Thus, the TMDL was determined to be 407 lb/yr (352 lb/yr + 55 lb/yr for an explicit MOS), according to the following equation:

TMDL	=	WLA	+	LA	+	MOS
407 lb/yr	=	285 lb/yr	+	67 lb/yr	+	55 lb/yr

where WLA = Waste Load Allocation derived from permitted sources, LA = Load Allocation derived from non-permitted sources (internal loading and atmospheric deposition), and MOS = Margin of Safety.

As mentioned previously, the MOS is explicit and reflects the additional load reduction necessary to achieve an in-lake TP concentration (June-September) 10% below the State standard for an average year. The lake response model indicates the TMDL will be sufficient to reach the NCHF Ecoregion standards for TP and Secchi depth, but probably not for chlorophyll-*a*.

The City of Eagan and the stakeholder group determined that the total required reductions in TP loading for Fish Lake would come from decreasing urban stormwater loading by 84 lb/yr. Because the City of Eagan's storm sewer system is regulated by the MPCA and approximately 94% of the stormwater load from all permitted sources to Fish Lake is via Eagan's storm sewer system, the lake's nutrient reduction strategies will be planned for and managed by the City of Eagan and incorporated into its Stormwater Pollution Prevention Program (SWPPP).

SCHWANZ LAKE

Biweekly monitoring of in-lake water quality in Schwanz Lake from 2001 through 2008 by the City of Eagan indicates that June-September mean TP concentrations ranged between 45 and 61 µg/L, with only one year slightly above the 60 µg/L NCHF Ecoregion shallow lakes standard. Secchi depths for the same period ranged from 1.0 to 1.5 m, exceeding the one meter NCHF Ecoregion shallow lakes standard. Thus, mean values for both parameters were equal to or better than the state NCHF Ecoregion standard in seven out of the last eight years. These values meet one of the MPCA guidelines for removing a lake from the 303(d) list, as mentioned above. The estimated maximum TP load to meet the in-lake TP standard (60 µg/L) is 77 lb/yr. From 2001 through 2008, the estimated average annual TP load to the lake was 59 lb/yr, about 23% less than the estimated maximum load. The MPCA determined this was a sufficient basis for it to proceed with removing Schwanz Lake from the 303(d) list. Regardless, the City plans to take additional steps to protect the lake further by decreasing loads from so-called direct drainage areas, nearby subwatersheds that drain directly to the lake without the stormwater runoff first routing through storm basins. Direct drainage areas were identified during the loading assessment process. The City also plans to continue its historical management activities to control watershed loadings, protect the high quality of upstream water bodies that drain to Schwanz Lake, and control internal loading.

1 Introduction

1.1 PURPOSE

The goals of this Total Maximum Daily Load (TMDL) analysis are: 1) to quantify the maximum total phosphorus (TP) loading to Fish and Schwanz lakes that would still allow established water quality standards to be met and 2) to identify TP reduction strategies for source areas in accordance with Section 303(d) of the Clean Water Act.

Fish and Schwanz lakes are identified as priority water resources in the City of Eagan's Water Quality & Wetland Management Plan (City of Eagan, 2007c) and the Gun Club Lake Watershed Management Plan (GCLWMO, 2007). Historical in-lake data, collected by the City through its ongoing lake management efforts, indicate these lakes have been nutrient enriched, with periodic nuisance algae blooms, marginal water clarity, and low oxygen in the deeper portions of the lakes. Since the early 1990s, the City of Eagan has been engaged in intense and sustained management of its lakes and their watersheds in a comprehensive effort to improve water quality by reducing in-lake TP concentrations. These efforts have included joint studies with the Minnesota Pollution Control Agency (MPCA) through the Clean Water Partnership Program in the 1990s. This current effort is to evaluate in-lake water quality and assess the TP loads affecting each system, and then either develop a formal TMDL or proceed with removing the lake from the 303(d) list as justified by the analysis.

1.2 PROBLEM STATEMENT

Fish and Schwanz lakes span 28.7 and 11.5 acres, respectively, and are in the City of Eagan, Minnesota. These lakes and their surrounding drainage areas are in the Gun Club Lake Watershed and largely within the jurisdictional boundaries of the City of Eagan, one of the largest suburbs in the Twin Cities metropolitan area. A very small portion of the watershed of each lake also extends into the City of Inver Grove Heights, located east of Eagan. Fish and Schwanz lakes and their contributing watersheds are both in the North Central Hardwood Forest (NCHF) Ecoregion. Both lakes are located in prominent City parks, which provide good public access to each. They are used primarily for fishing, non-motorized boating, aesthetic enjoyment, and some swimming and wading. Fish Lake has public access via Fish Lake Park, located on the east and north side of the lake, and includes a boat ramp adjacent to a parking lot off Denmark Avenue. Schwanz Lake has public access via Trapp Farm Park, located along the southwest shoreline of the lake. This lake has a canoe launch adjacent to a parking lot off Wilderness Run Road. A fishing pier is present at both parks. The City of Eagan Water Quality & Wetland Management Plan (City of Eagan, 2007c) classifies Fish Lake as a Class L1 lake, which has the highest management goal of direct contact recreation, and Schwanz Lake as a Class L2 lake, which has the highest management goal of fishing and canoeing.

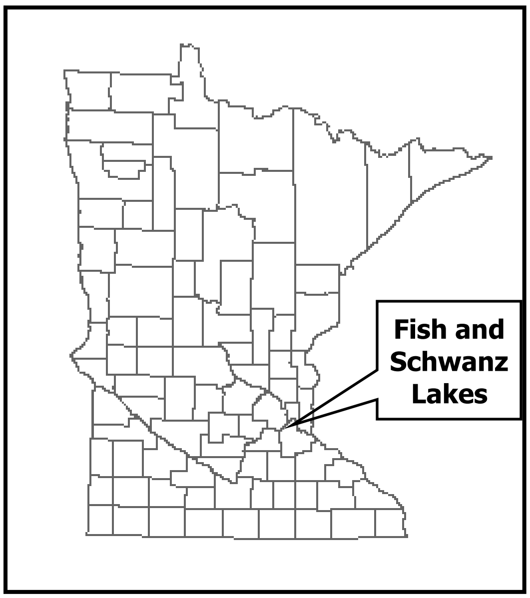
In 2006, both lakes were added to the Minnesota 303(d) impaired waters list for impaired aquatic recreation as a result of mean summer TP values that exceeded the standard for Class 2B recreational waters. Both lakes were listed as impaired at a time when the TP concentration standard was ≤ 40 μg/L for all lakes in the NCHF Ecoregion. In May, 2008, the U.S. EPA approved the State of Minnesota's revised eutrophication standards, which differentiate between deep and shallow lakes based on extensive technical analysis and documentation by MPCA staff. The shallow lake eutrophication criteria for NCHF Ecoregion lakes were changed to a TP concentration ≤ 60 μg/L, with secondary supporting standards of Secchi depth ≥ 1.0 m and chlorophyll-*a* ≤ 20 μg/L (measured as June-September means). Consequently, this TMDL and Waste Load Allocation is based on the shallow lakes standard. According to the 2006 303(d) list, the proposed start date for the TMDL for each lake was 2017 with completion proposed for 2020. The City requested the scheduled start and completion dates be moved to 2007 and 2011, respectively however, to facilitate an earlier TMDL effort.

2 Watershed and Lake Characterization

2.1 HISTORY OF THE LAKES AND THEIR WATERSHEDS

Prior to its conversion to intensive agricultural uses, the land surrounding Fish and Schwanz lakes was predominately forest and wetland. Beginning in the 1960s, urban growth replaced the agricultural land. From a rural township population of 3,382 in 1960, the City of Eagan incorporated in 1972 and grew to a census population of 63,557 in 2000. Little of the former agricultural land now remains. Figure 2.1 shows where the lakes watersheds are in Minnesota.

FIGURE 2.1– LOCATION OF LAKES WATERSHEDS



Prior to urbanization, Fish Lake had a maximum depth of 25 ft and a surface area of approximately 18 acres. In 1971, the first storm sewer discharging to the lake was built to provide drainage for a small residential area adjacent to the lake. In April, 1980, a structural outlet was put in the lake. This outlet and continued development and drainage expansion within the watershed ultimately increased the lake maximum depth to 33.5 ft and its surface area to approximately 29 acres. In 1983, the lake was incorporated into the citywide storm drainage trunk system. As agricultural and forested land in the City was developed into commercial, institutional, and residential suburban neighborhoods, the contributing watershed to Fish Lake grew from an estimated pre-urban development area of 120 acres to a fully developed urban watershed area of approximately 3,300 acres.

The first storm sewer discharging to Schwanz Lake was constructed in 1979. In 1983, the stormwater lift station was installed in the lake. The volume and maximum depth of the lake are apparently unchanged since its incorporation into the City’s storm drainage system, although the lake’s watershed expanded from an estimated 104 acres prior to 1979 to almost 800 acres today.

2.2 SOILS AND GEOLOGY

The soils in the central and southern portions of Eagan are from the Kingsley-Mahtomedi association: loamy and silty textured soils found in gently sloping to very steep topography. These soils are well-drained to excessively well-drained.

The topographic elevations in the Fish Lake watershed vary from a high of approximately 1,000 ft Mean Sea Level (ft MSL) along the southern edge of the watershed near Lexington Avenue to a low of 800 ft MSL in the southeastern portion of the watershed at some pothole ponds. For Schwanz Lake the elevations vary from 1,010 ft MSL on the far east side of the watershed in Inver Grove Heights to 880 ft MSL on the west side of the lake. The terrain in both lake watersheds typically includes hills and pothole depressions that were originally landlocked and have since been interconnected by storm sewer. These many depressions and natural ponds are ideal for long term storage of stormwater runoff.

The surficial geology of Eagan is a moraine topography caused by the most recent geologic processes. The advance and retreat of glacial lobes approximately 10,000 years ago deposited material that characterizes this topography. The specific geomorphic area, the Eastern St. Croix Moraine, consists of relatively steep hills, rolling topography, and some deep depressions that are either filled with small lakes or peat. The Eastern St. Croix Moraine geographic area consists of a mixture of red and grey till and is composed of silt, clay, sand, pebbles, cobbles and boulders. Water tables may be at or near the surface in the depressions, but are 10 ft or deeper in the hills.

2.3 CLIMATOLOGICAL SUMMARY

Annual normal precipitation (1975-2005) in this part of the Twin Cities Metropolitan Area, as measured at the Minneapolis-St. Paul International airport northwest of Eagan, is approximately 30.4 inches, of which approximately two-thirds occurs between May and September. The annual snowfall in Eagan averages approximately 50 inches, with the most severe melt runoff conditions usually occurring in March and early April. Twin Cities mean annual lake evaporation is approximately 30.5 inches per year. On average, lakes in the area have approximately 132 days of ice cover per year, with the average freeze and thaw dates occurring the last week of November and the first week of April, respectively. The average date of the last below-freezing temperature (32°F) in the spring is April 27, and the average date of the first-below freezing temperature in the fall is October 2, yielding an average growing season of 157 days.

2.4 WATERSHED CHARACTERISTICS

The 3,334-acre watershed of Fish Lake generally lies south of Yankee Doodle Road, west of State Highways 149 and 3, north of Highline Trail corridor, and east of Pilot Knob Road. I-35E bisects a portion of the watershed but does not drain to Fish Lake. Instead, its runoff is conveyed to a point downstream of the Fish Lake system. The 763-acre surface watershed for Schwanz Lake extends as far north as Hackmore Drive, east into the Southern Lakes development in Inver Grove Heights, south to Red Pine Lane, and west to residential developments northwest of Trapp Farm Park. Figures 2.2 and 2.3 show the watershed boundaries of and generalized stormwater flow directions toward Fish Lake and Schwanz Lake, respectively. Although the watersheds are adjacent to each other, neither drains to the other, but both lake discharges eventually reach the Minnesota River.

FIGURE 2.2– FISH LAKE WATERSHED
(arrows represent generalized stormwater flow directions)

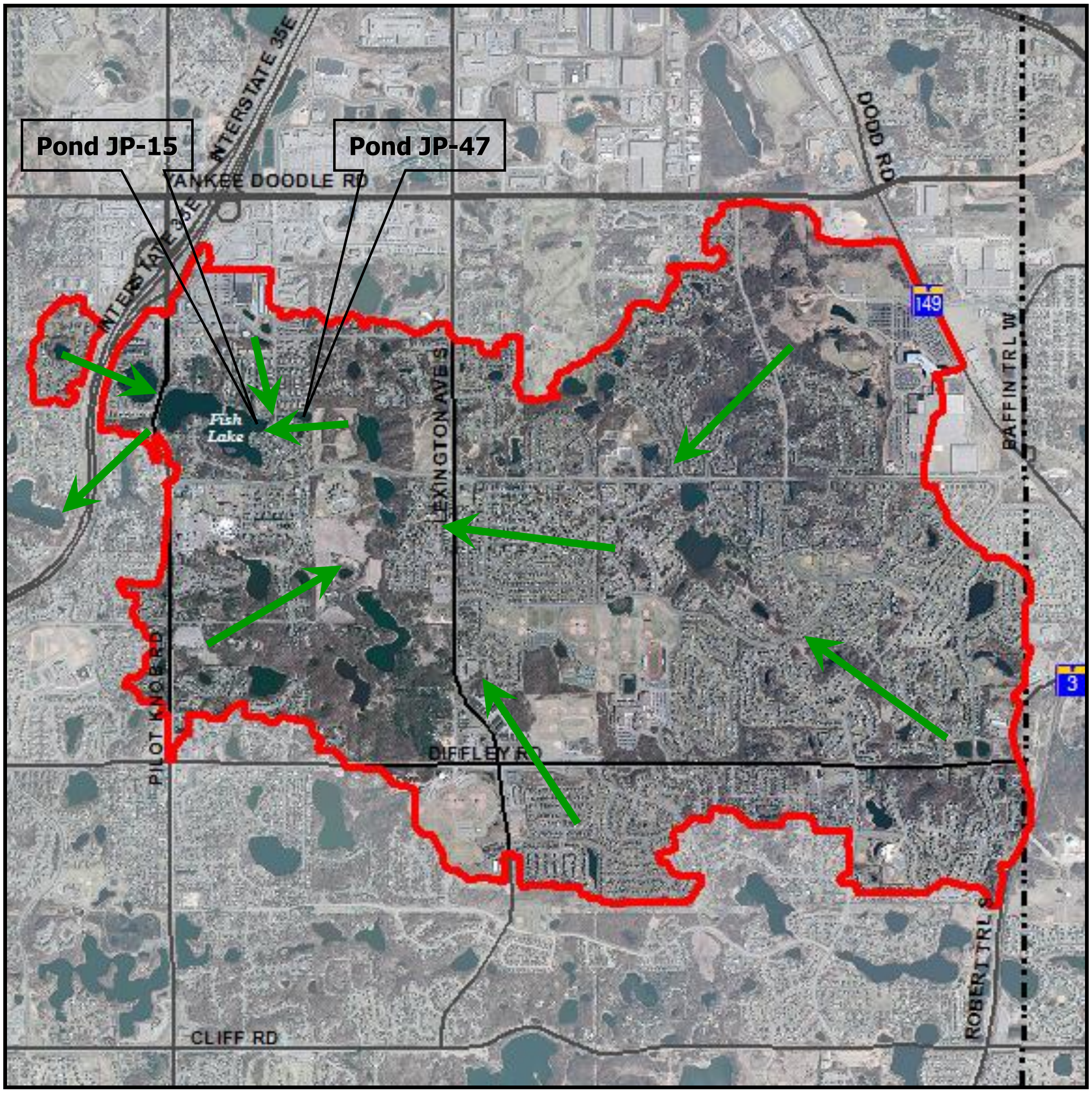
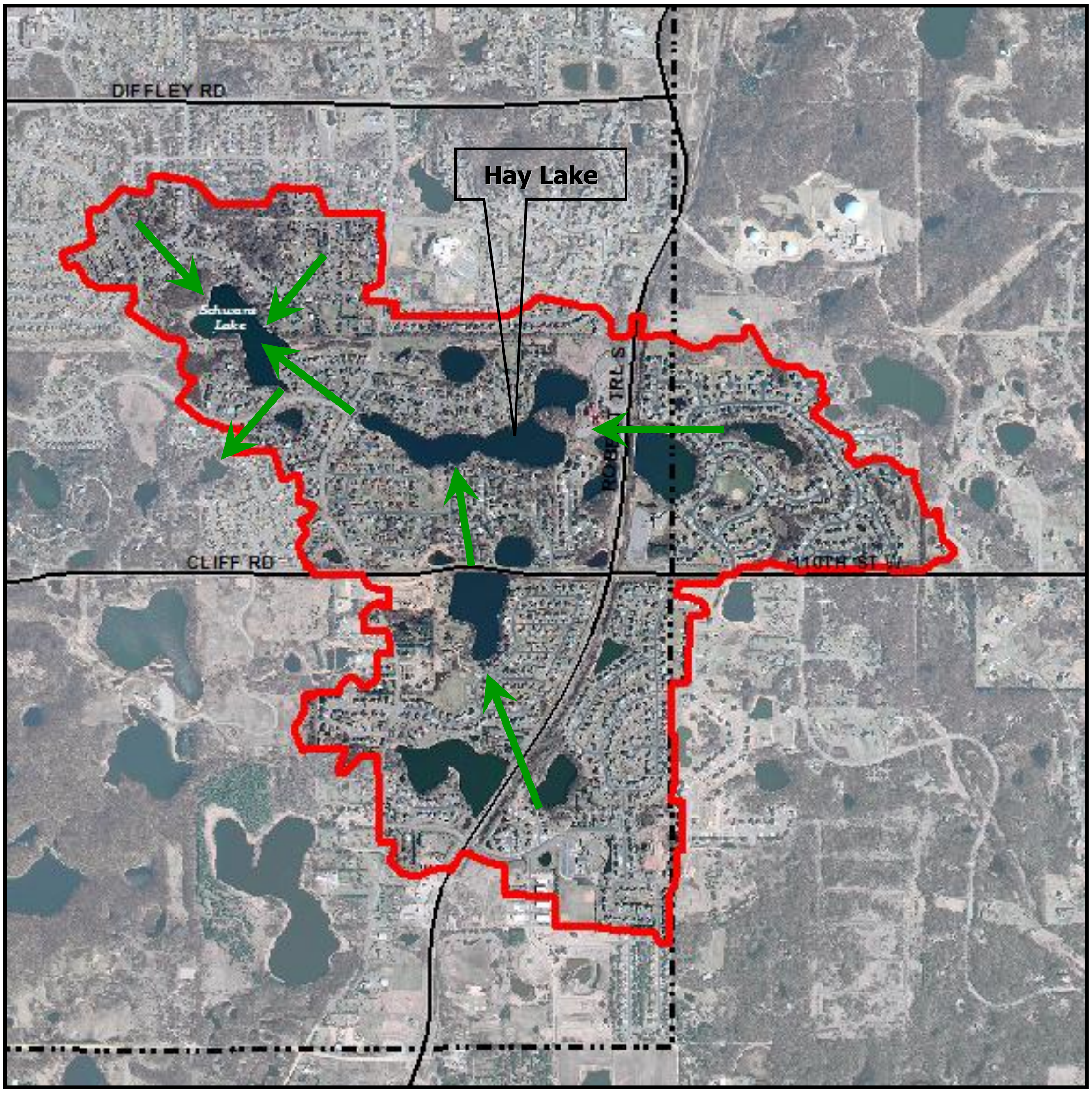


FIGURE 2.3– SCHWANZ LAKE WATERSHED

(arrows represent generalized stormwater flow directions)

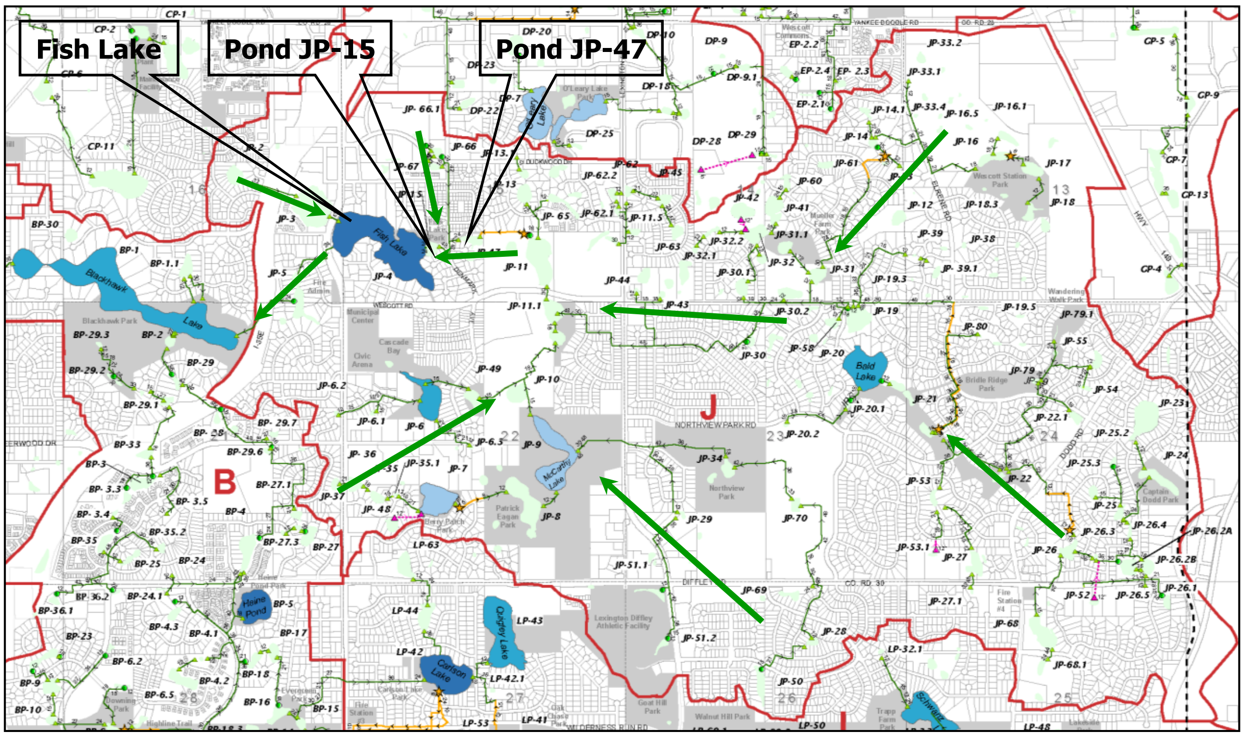


Each lake's watershed is mostly developed. The predominant land use is low- and medium-density single family residential, but there are also limited commercial, institutional, and park land uses. Impervious coverage in both watersheds is approximately 27%. There are no existing NPDES wastewater permittees. Almost all sanitary waste is conveyed outside the watershed and treated at the Metropolitan Council's Seneca regional wastewater treatment facility in northwest Eagan. There are currently approximately 45 Individual Sewage Treatment Systems (ISTS) in the Fish Lake watershed and 25 ISTS in the Schwanz Lake watershed. These ISTS are all outside of the direct drainage areas of the lakes (i.e., nearby subwatersheds that drain directly to the lakes without the stormwater runoff first routing through storm basins) and are being removed as redevelopment occurs in the City.

The City's stormwater ponding and conveyance system manages stormwater for the developed areas of the watershed. Much of the stormwater is routed through one or more natural lakes, wetlands, or constructed storm basins prior to discharge to either of the lakes. The Fish Lake watershed has over 150 such water bodies that are linked as shown in Figure 2.4. Most of the stormwater enters Fish Lake from the east first through Pond JP-47 and then Pond JP-15, which is adjacent to the lake and separated from it by a low-lying berm (see Figure 2.6). Fish Lake discharges to the southeast through a 24-inch diameter pipe to a small wetland, which drains to Blackhawk Lake. The City's Water Quality & Wetland Management Plan designates Blackhawk Lake as a Class L2 lake, the highest management goal of which is fishing and canoeing (City of Eagan, 2007c).

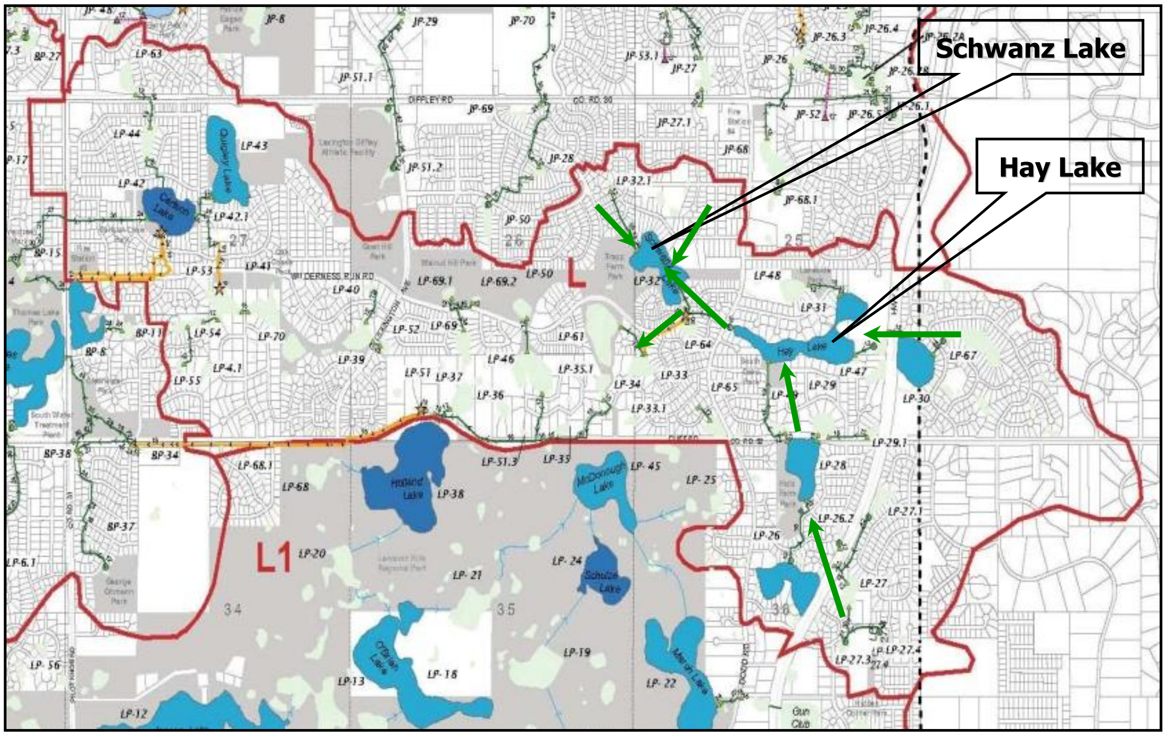
FIGURE 2.4– FISH LAKE STORM DRAINAGE SYSTEM

(arrows represent generalized stormwater flow directions)



The Schwanz Lake watershed has over 50 natural lakes, wetlands, and constructed storm basins as shown in Figure 2.5. Discharge from Schwanz Lake is controlled by a 5-cubic foot per second (cfs) capacity stormwater lift station.

FIGURE 2.5– SCHWANZ LAKE STORM DRAINAGE SYSTEM
(arrows represent generalized stormwater flow directions)



2.5 LAKE MORPHOMETRY AND HYDROLOGY

Fish and Schwanz lakes are both shallow. The MPCA defines a shallow lake as an enclosed basin with a maximum depth of 15 ft or less or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone). Fish Lake was classified as a deep lake in the City's Water Quality & Wetland Management Plan (City of Eagan, 2007c), but a subsequent review of bathymetric information showed that Fish Lake meets MPCA's definition of a shallow lake. Figure 2.6 shows the estimated bathymetry of Fish Lake, while Figure 2.7 shows the estimated bathymetry of Schwanz Lake. Table 2.1 summarizes key morphometric characteristics for each lake. Nearly all the water entering both lakes is surface water runoff from subwatersheds that have been artificially enlarged via connections to the storm drainage system (i.e., "storm trunk drainage"). So-called "direct drainage areas" are nearby the lakes and discharge stormwater runoff to them without first routing through storm basins.

FIGURE 2.6– FISH LAKE BATHYMETRY

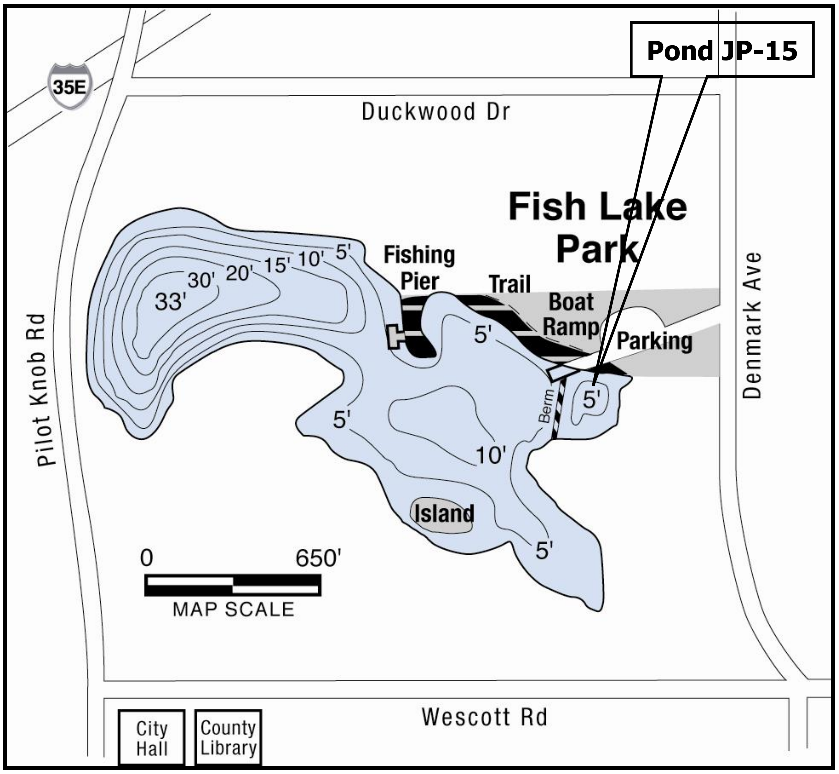


FIGURE 2.7– SCHWANZ LAKE BATHYMETRY

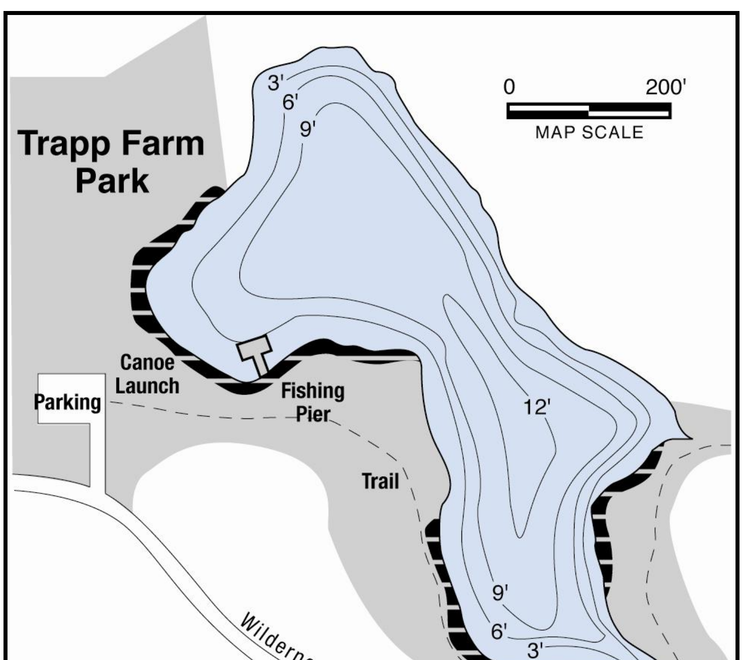


TABLE 2.1– FISH AND SCHWANZ LAKES CHARACTERISTICS

	Fish Lake	**Schwanz Lake**
DNR ID	19-0057-00	19-0063-00
Surface Area (ac)	28.7 [1]	11.5 [2]
Surface Area less than 15 ft depth (ac)	23.3	11.5
Surface Area less than 15 ft depth (%)	81	100
Volume (ac-ft)	239.3 [1]	79.2 [1]
Max. Depth (ft)	33.5 [1]	12 [1]
Mean Depth (ft)	8.3	6.9
Watershed Area (ac)	3,334 ^	763 ^
Direct Drainage (ac)	179	127
Storm Trunk Drainage (ac)	3,155	636
Watershed: Lake Ratio	116 : 1	66 : 1
Average Residence Time (yr)	0.14	0.23

^ Watershed area does not include landlocked areas or lake surface area
Data Sources:
[1] DNR Info and Bathymetric Maps
[2] Obtained from aerial photo using GIS

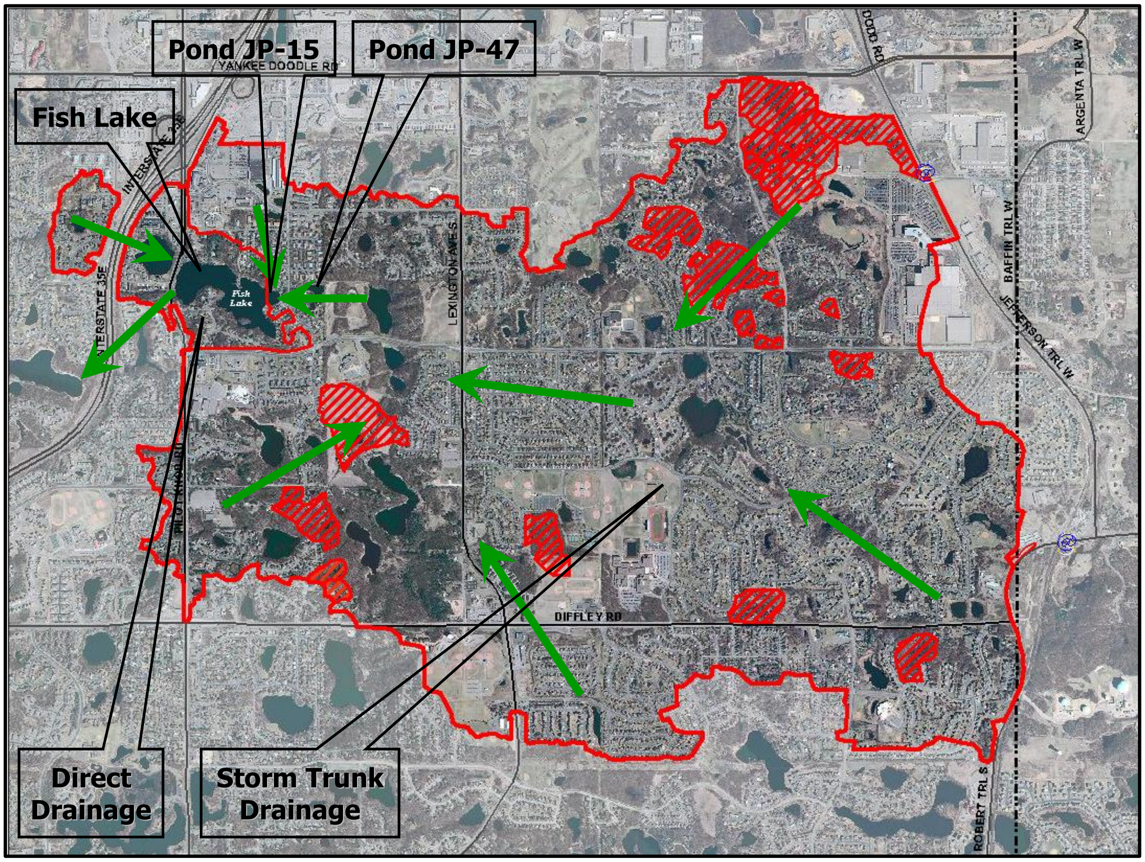
Figures 2.8 and 2.9 show the major subwatershed characteristics for Fish and Schwanz lakes, respectively. The Fish Lake watershed consists of direct drainage areas immediately around the lake and the storm trunk drainage, which is 95% of the total watershed area draining through a single stormwater inlet to Pond JP-47 and then through Pond JP-15 that is adjacent to the lake (City of Eagan, 2007b).

The landlocked subwatershed areas represented in the Figures 2.8 and 2.9 do not discharge water downstream and thus are not considered contributors of pollutant loadings to the lakes. These landlocked areas are relatively undeveloped with deep topographies that retain a significant volume of stormwater. There are no downstream stormwater impacts because these subwatershed areas are small compared to their available storage volumes. In most cases, it is also cost prohibitive, and in some cases infeasible, to consider discharging stormwater downstream from these areas to either of the lakes.

FIGURE 2.8– FISH LAKE SUBWATERSHEDS

(cross-hatched areas represent landlocked areas)

(arrows represent generalized stormwater flow directions)



Similar to Fish Lake, the major subwatersheds of Schwanz Lake include landlocked areas. The Schwanz Lake watershed consists of direct drainage areas immediately around the lake. The Golden Meadow watershed also is represented separately in Figure 2.9 because it is a significant area that has no pretreatment of stormwater prior to discharging to Schwanz Lake. The Hay Lake watershed constitutes 84% of the total area draining to Schwanz Lake.

FIGURE 2.9– SCHWANZ LAKE SUBWATERSHEDS
(cross-hatched areas represent landlocked areas)
(arrows represent generalized stormwater flow directions)

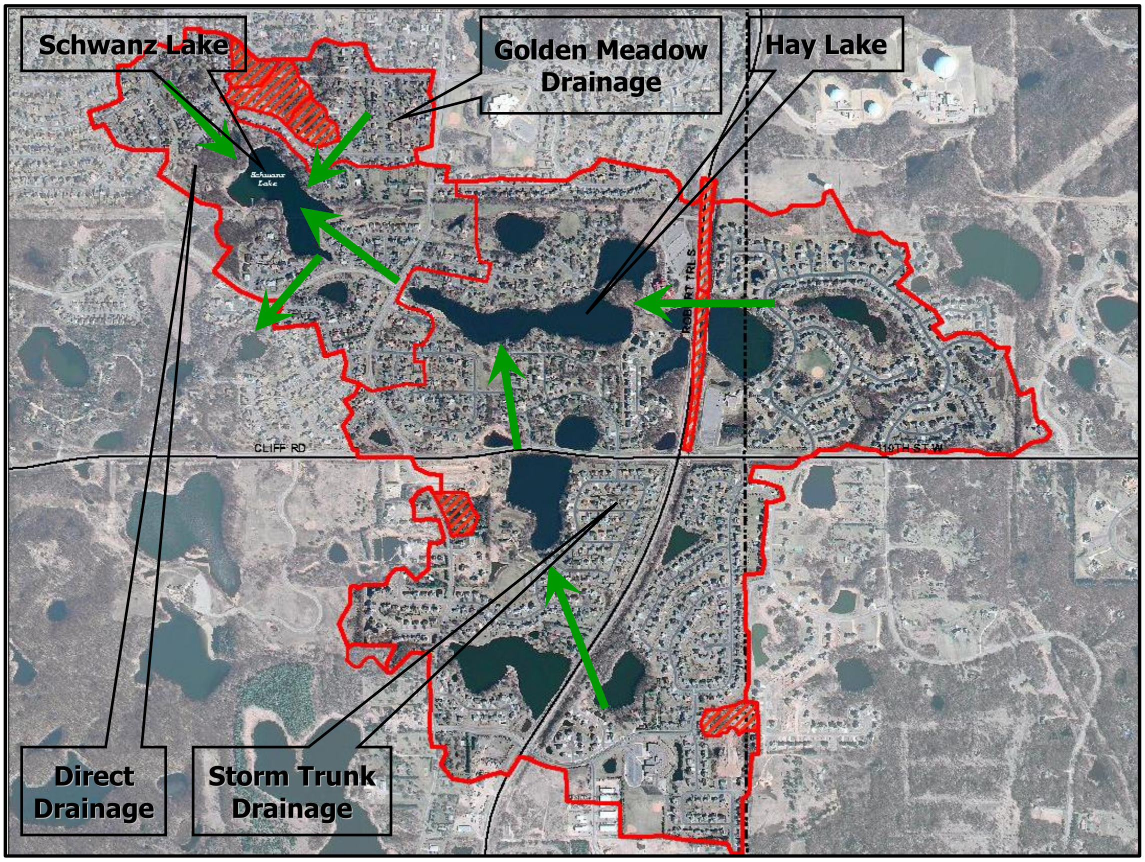


Figure 2.10 presents each lake's subwatershed components in graphic format.

FIGURE 2.10– COMPOSITION OF WATERSHED DRAINAGE AREAS
(Left: Fish Lake, Right: Schwanz Lake)

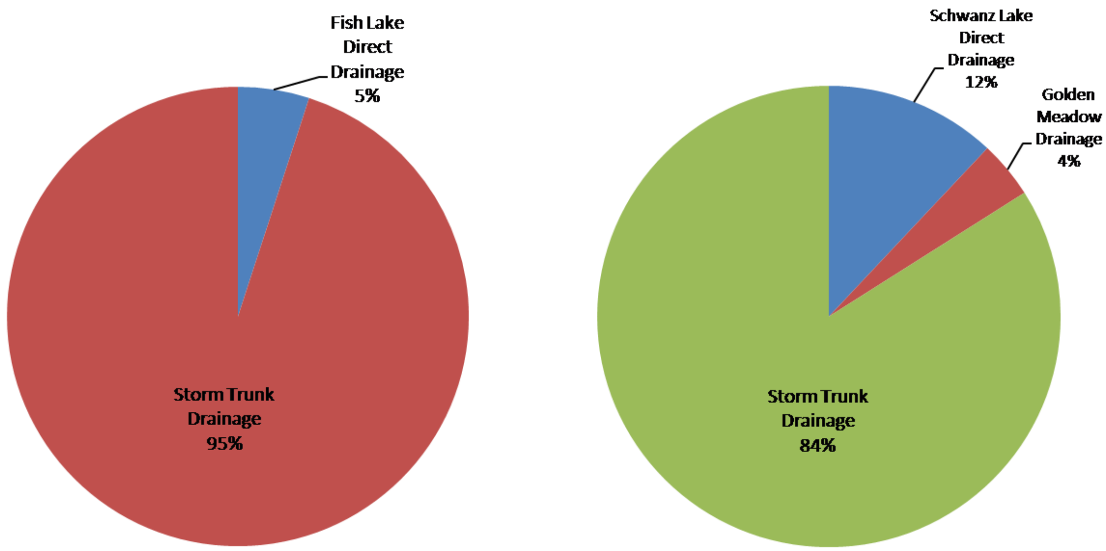


Table 2.2 presents data of each lake's subwatershed areas.

TABLE 2.2– SUMMARY OF DIRECT AND STORM TRUNK DRAINAGE AREAS FOR EACH LAKE

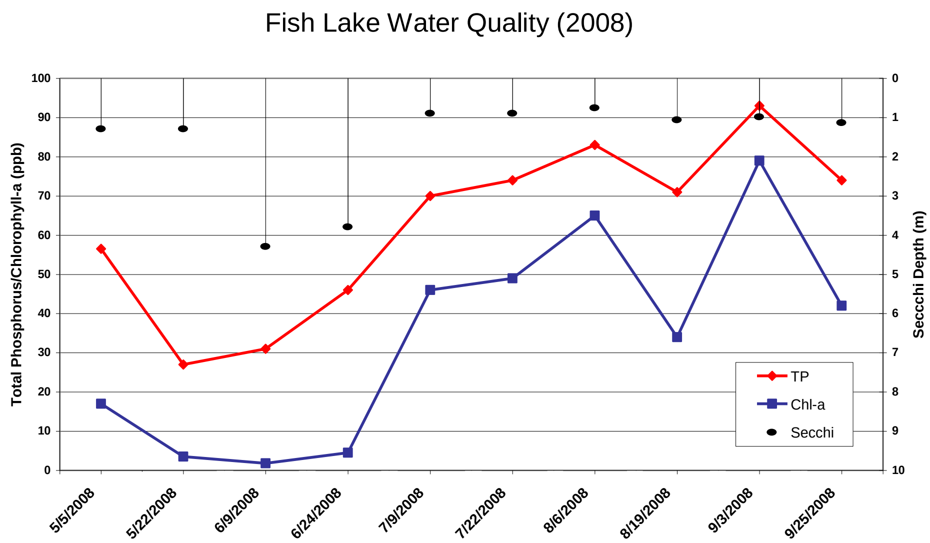
Subwatershed	Area (ac)
Fish Lake	
Direct drainage	179
Storm trunk drainage (through Pond JP-15)	3,155
Total	3,334
Schwanz Lake	
Direct drainage	94
Golden Meadow drainage	33
Storm trunk drainage (through Hay Lake)	636
Total	763

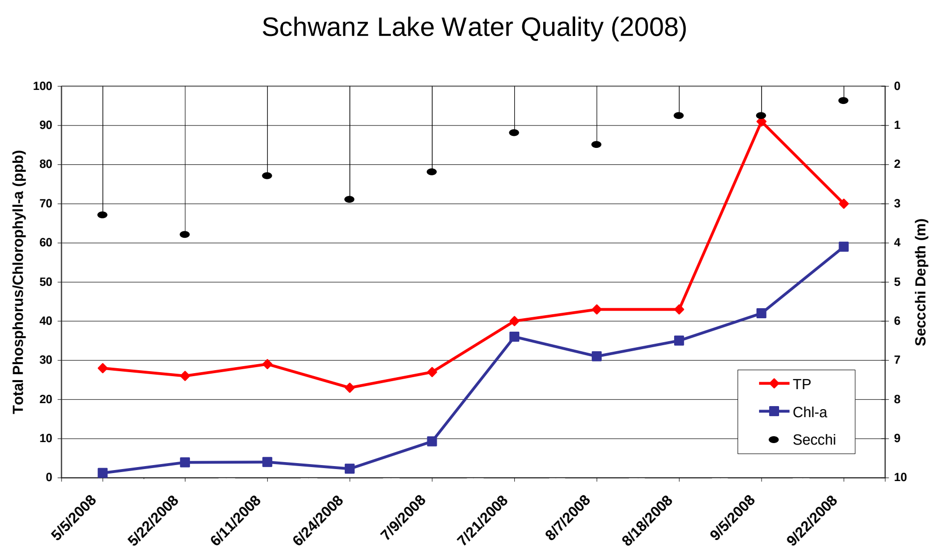
2.6 WATER QUALITY

From 2002 through 2008, mean June-September TP concentrations are just over 64 µg/L in Fish Lake and almost 52 µg/L in Schwanz Lake. The concentrations in Fish Lake are moderately above the MPCA NCHF Ecoregion shallow lake standard of 60 µg/L for Class 2B recreational waters, and those in Schwanz Lake are under this threshold. Both lakes have relatively large ratios of watershed area to lake surface area (i.e., Fish Lake = 116:1 and Schwanz Lake = 66:1). These large ratios suggest each lake is vulnerable to stress from watershed inputs, although the large number of constructed storm basins, stormwater wetlands, and small lakes in each watershed (over 150 in the Fish Lake watershed and over 50 in the Schwanz Lake watershed) appear to provide both significant load reductions and reduced TP concentrations. Based on the incoming average annual volume of stormwater runoff, the water in Fish Lake is replaced about seven times per year and in Schwanz Lake approximately four times per year. Therefore, each lake's water quality is strongly linked to the quality of stormwater entering the lake as well as in-lake biological processes. Internal TP loads are influenced partly by the accumulation of historical watershed loads, but also can be strongly affected by invasive aquatic plants and by high populations of rough fish, stunted panfish, and minnows.

Figure 2.11 shows significant seasonal variation in TP, chlorophyll-*a*, and water clarity measured as Secchi depth, for the 2008 growing season in Fish Lake and Schwanz Lake.

FIGURE 2.11– 2008 LAKE WATER QUALITY



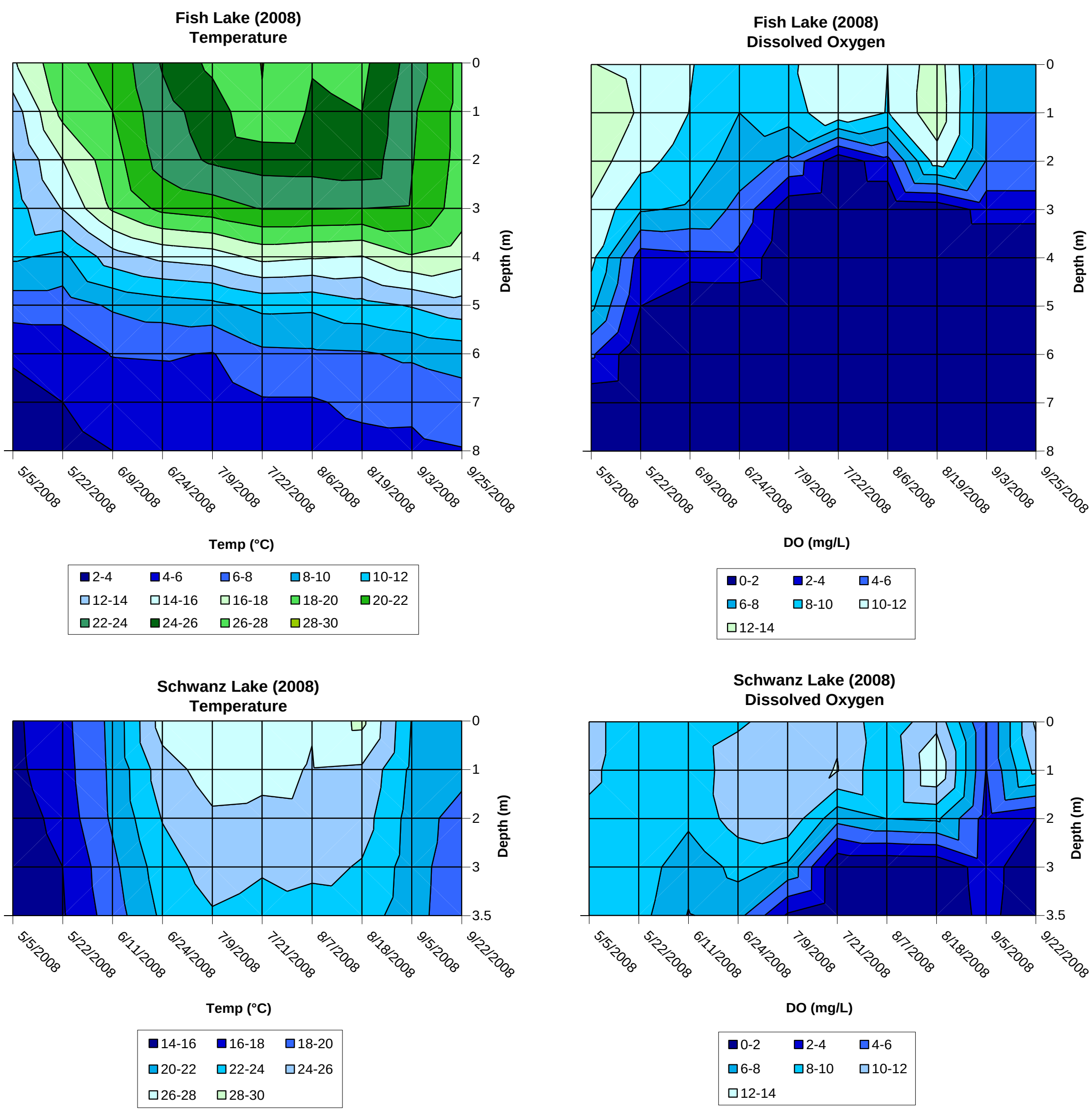


The data suggest a trend of degrading water quality throughout the growing season with improvement toward fall. Because Schwanz Lake is much smaller than Fish Lake, it is more susceptible to rapid changes in water quality due to runoff events. For example, the large spike in TP concentration in early September coincides with a 1.6-inch rainfall event over two days in late August, which was the largest rainfall event in almost three months and likely washed off much of the built-up TP from the watershed. A smaller spike is also evident in Fish Lake during this event.

Figure 2.12 shows temperature and dissolved oxygen measured in Fish and Schwanz lakes through the 2008 growing season. During peak summer growing conditions in late July, Fish Lake is highly stratified, leading to low dissolved oxygen levels (below 2 mg/L) occurring six ft above the lake bottom. Low oxygen levels indicate anoxia is likely, and the potential for sediment release of TP is high. In contrast, Schwanz Lake is much less stratified and low dissolved oxygen levels are measured approximately one-half foot above bottom sediments, indicating mildly anoxic conditions and low potential for release of TP into the water column.

FIGURE 2.12– TEMPERATURE AND DISSOLVED OXYGEN PROFILES FOR THE 2008 GROWING SEASON

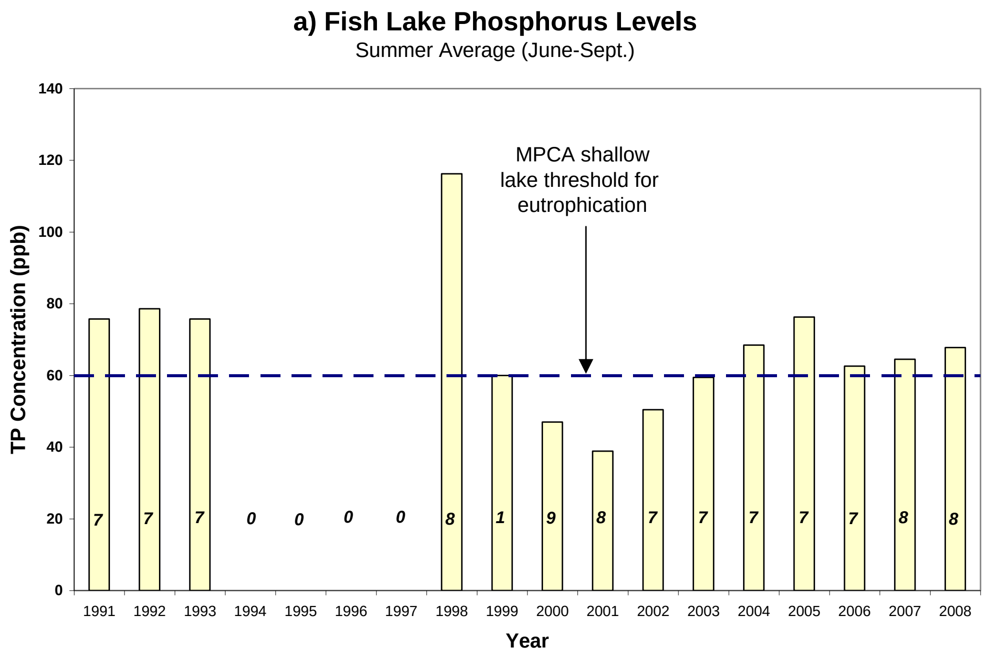
(Top: Fish Lake, Bottom: Schwanz Lake. Each grid point represents a field measurement. The vertical axis is water depth from the surface; the horizontal axis is the date of measurements.)

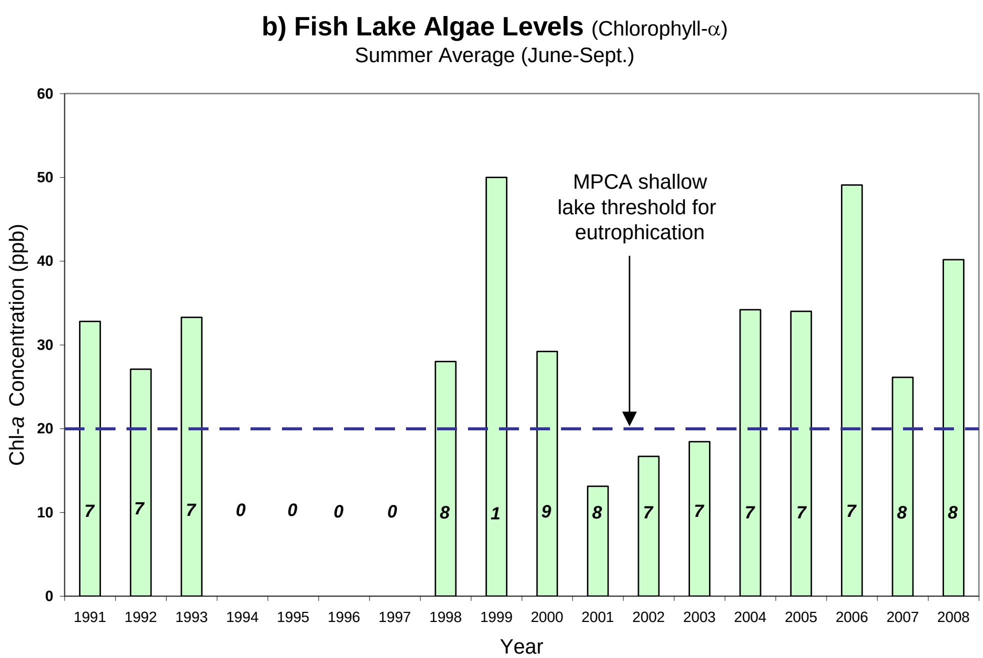


Figures 2.13 and 2.14 show lake water quality as seasonal (June-September) mean values for the period of record compiled by the City of Eagan for Fish and Schwanz lakes, respectively. The number annotations on the bars are data points included in each seasonal average value. These data can be used to detect variations and trends in lake water quality and were the basis for each lake's 303(d) listing.

FIGURE 2.13– AVERAGE ANNUAL SUMMER WATER QUALITY CONDITIONS FOR FISH LAKE

(numbers are samples included in the average value)





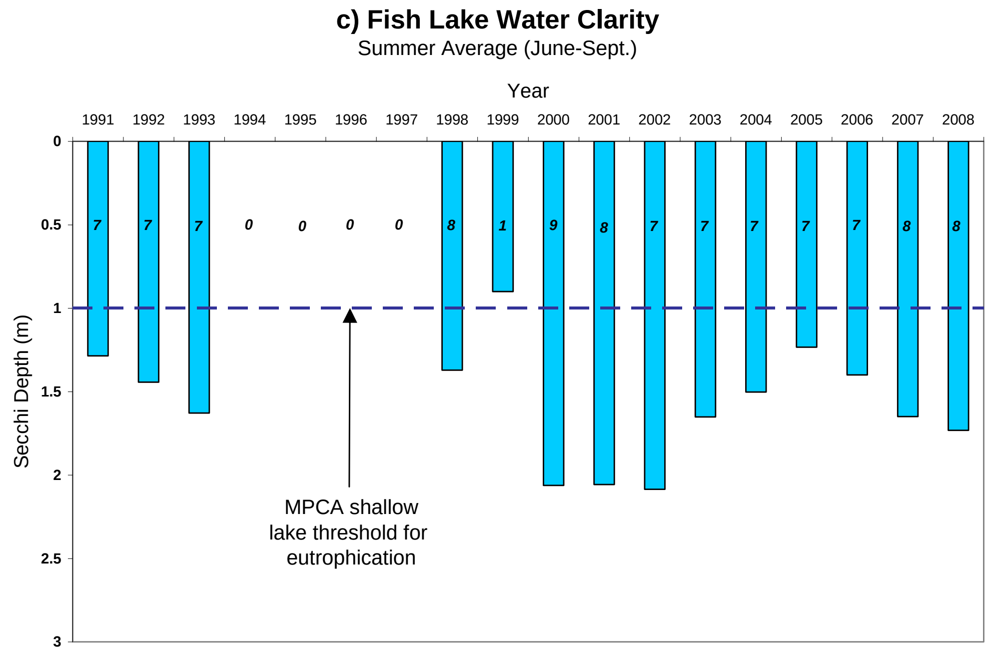
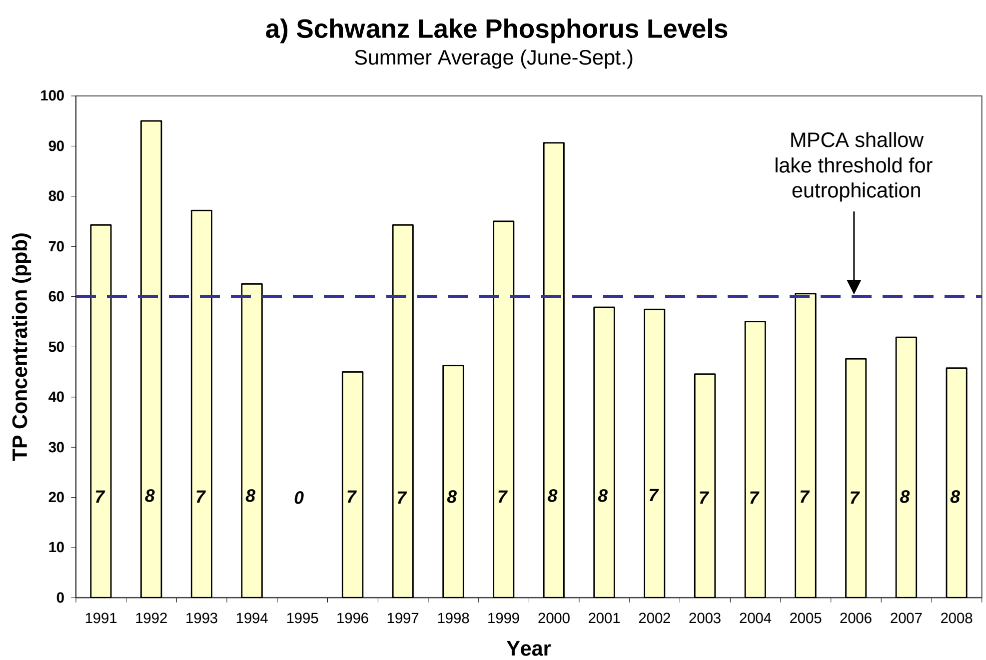
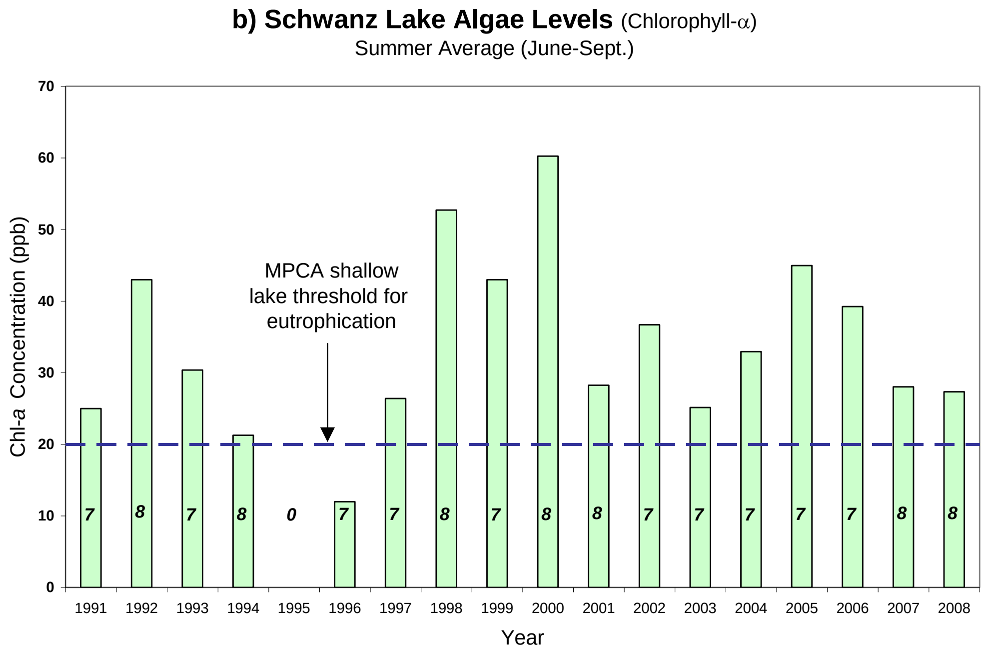
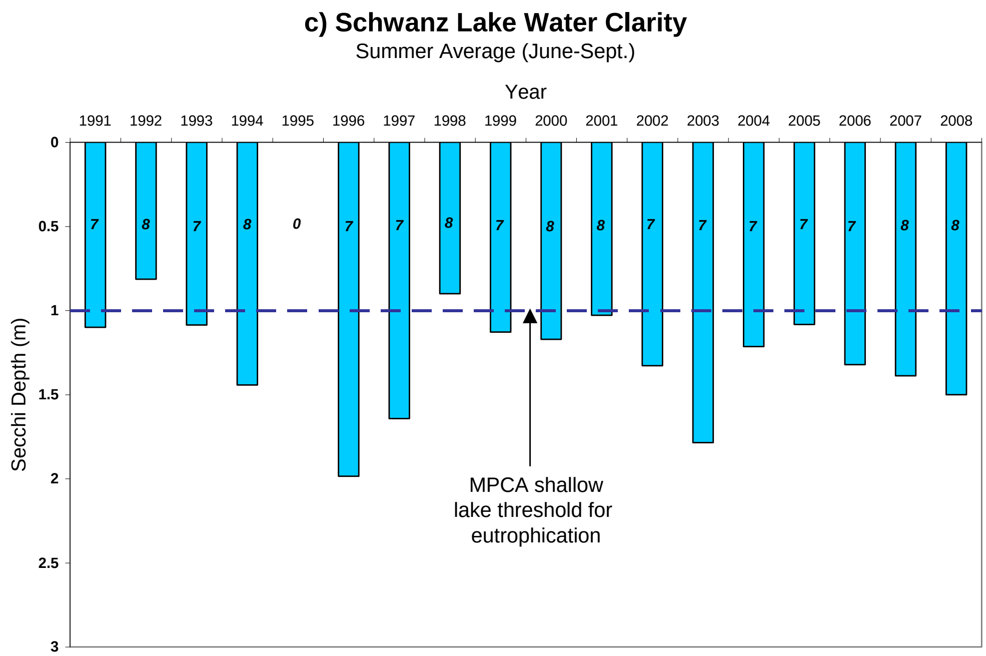


FIGURE 2.14– AVERAGE ANNUAL SUMMER WATER QUALITY CONDITIONS FOR SCHWANZ LAKE

(numbers are samples included in the average value)







2.7 HISTORICAL WATER QUALITY AND EVIDENCE OF IMPACTS FROM DEVELOPMENT

Diatom records from studies of sediment cores taken from Metropolitan area lakes (Lake Calhoun, Lake Harriet, Sweeney Lake, and Twin Lake) show a two- to three-fold increase in TP (MPCA, 2002) from pre-development to developed watershed conditions. Similar to Fish and Schwanz lakes, each of these lakes has a large, highly urbanized watershed that has expanded significantly compared to the pre-development condition, and the MPCA indicates the increase in fertility based on diatom records is correlated directly to watershed development. It is highly likely urban watershed development from the 1960s to the 1990s had similar effects on the water quality of Fish and Schwanz lakes.

Another means of predicting historical water quality is by utilizing the MINLEAP computer model (Wilson and Walker, 1989). This model was used to predict the expected water quality of Fish and Schwanz lakes for "typical" nutrient inflows similar to minimally impacted reference lakes within the NCHF Ecoregion, according to MPCA guidance (MPCA, 2005). The model shows that current water quality of Fish Lake is fairly degraded compared with non-urbanized reference lakes having similar basin morphometric characteristics. It can be reasonably concluded that Fish Lake's water quality degradation and its inability to meet state water quality standards are largely due to the expansion and development of the contributing watershed. The current water quality of Schwanz Lake actually exceeds what MINLEAP predicts for non-urbanized reference lakes having similar morphometric characteristics. Schwanz Lake's drainage area has not grown as rapidly or as expansively as that of Fish Lake, and this most likely accounts for the better than expected water quality seen in Schwanz. Table 2.3 shows a comparison between the current observed in-lake water quality to MINLEAP modeled water quality of the minimally impacted reference systems. (NOTE: The MINLEAP model was used only to help frame the eutrophication issue and is not the basis for developing Waste Load Allocations). The water quality MINLEAP predicts for Fish Lake actually exceeds that predicted for Schwanz Lake. The pre-urbanized watersheds for Fish and Schwanz lakes were very similar, and Fish Lake is both larger and deeper than Schwanz Lake. This leads the model to predict a lower in-lake concentration of TP in Fish Lake.

TABLE 2.3– OBSERVED SUMMER WATER QUALITY COMPARED WITH MINLEAP PREDICTED WATER QUALITY

Water Quality Parameters	Observed (2006)	Predicted *(MINLEAP)*
Fish Lake		
TP (μg/L)	63	38
Chlorophyll-*a* (μg/L)	49.1	13.4
Secchi depth (m)	1.4	1.7
Schwanz Lake		
TP (μg/L)	48	51
Chlorophyll-*a* (μg/L)	39.2	20.7
Secchi depth (m)	1.3	1.3

2.8 FISHERIES STATUS

Fish populations within each lake were evaluated. Of interest was whether there were high numbers of rough fish (i.e., carp and bullhead, which spend a majority of their time rooting in lake sediments searching for food), stunted panfish, or extremely high minnow populations and low numbers of game fish, which might suggest the structure of the fishery contributes to poor lake water quality. Bullheads, for example, often feed off bottom sediments, which can result in sediment resuspension and contribute to internal loading if the sediments are enriched with TP, as in both lakes. These and other rough fish also ingest sediment along with food particles and excrete most of the sediment, which also can introduce TP from the sediments to the water column. Equally important, stunted panfish and minnows in degraded systems show similar feeding behaviors, which can lead to these same impacts, namely increased internal TP loading

(McComas, 2004 and 2005). Stunted panfish and minnows are significant planktivores and can exert considerable pressure on the zooplankton (algae eaters) community (Zimmer et al., 2003). Reducing this pressure by fish is an important component of re-establishing zooplankton controls of nuisance algae populations.

The Minnesota Department of Natural Resources (MDNR) conducted a fish population survey of Fish Lake in July, 2008 (MDNR, 2008). Fish Lake has a healthy sport fish community of black crappie, bluegill, green sunfish, hybrid sunfish, largemouth bass, northern pike, pumpkinseed sunfish, and yellow perch. Trap net results showed somewhat high numbers (89 per set) of small- to medium-size bluegills (mean length of 5 inches) and smaller numbers of other sunfish and crappies (13 per set). Gill net results showed high numbers (14 per set) of small northern pike averaging just over 2 pounds. The survey found only small numbers of black bullheads of large average size (8.9 inches). The abundance of game fish and small number of bullheads, together with good aquatic plant coverage over much of the bottom of the lake (see Section 2.9) suggest the fish community does not pose a significant threat to water quality in Fish Lake.

The MDNR conducted a similar survey of Schwanz Lake in August, 2007 (MDNR, 2007). This sport fish community consists of black crappie, bluegill, hybrid sunfish, largemouth bass, pumpkinseed sunfish, and yellow perch. Largemouth bass were the only predator sampled during the survey. The abundant bass population (46 fish sampled) primarily consisted of fish less than 12 inches (though 15% were over this length). Of the 431 bluegills sampled using trap nets, 39% were over 7 inches and 84% were over 6.5 inches. Adult bluegills have been stocked intermittently since 1988. Black crappies have been stocked intermittently and were sampled in moderate numbers, with approximately 16% of the fish over 8 inches. Eight bullheads were netted averaging 10.6 inches and 0.5 pounds. As with Fish Lake, the high proportion of game fish and low proportion of bullheads in Schwanz Lake suggest that the fish community does not pose a significant threat to water quality in the lake.

2.9 AQUATIC VEGETATION

Aquatic plants were surveyed in Fish Lake in June and September 2005 and summarized by McComas (2008). The survey showed that aquatic plant diversity in Fish Lake is moderate, with a number of native plants present along with algae and invasive species. Non-native curlyleaf pondweed and native coontail are the dominant plants in early summer, each growing to depths of 10 ft. Shortly after the early summer plant survey, the City initiated its normal aquatic plant harvesting operation to remove as much of the curlyleaf pondweed as feasible prior to senescence. Another plant survey in late summer indicated coontail was the dominant plant followed by Eurasian watermilfoil (Note: This was the first observation of Eurasian watermilfoil in Fish Lake). In each case, plants were found to depths of 8 ft. Other species present in the late summer survey included Elodea, Northern water milfoil, and stringy pondweed.

Aquatic plant surveys of Schwanz Lake were conducted as part of a research project by the U.S. Army Corp of Engineer Research and Development Center on using early season, low-dose applications of Endothall to control curlyleaf pondweed selectively (Skogerboe et al., 2008). Schwanz Lake was one of several Metropolitan area lakes selected for this experimental treatment. The last plant survey conducted in 2004 indicated curlyleaf pondweed, the only invasive aquatic plant in the lake, occurred in 15% of the sample sites, but it was at an abundance far below nuisance conditions. Coontail, which continues to be the dominant native plant in the lake, can help reduce TP concentrations because it has a weak root system and takes most of its nutrients from the water column, effectively competing with algae and often reducing the amount of TP that would be used by algal production. Other native species found during the survey included leafy pondweed, sago pondweed, najas, horned pondweed, and Chara. In short, the survey indicated effective control of curlyleaf pondweed and a moderate diversity of native submergent plants.

2.10 WATER LEVEL

The outlet for Fish Lake is a 24-inch diameter reinforced concrete pipe at the west end of the lake. The elevation of Fish Lake is controlled by weir boards that, if removed, would lower the lake approximately 2 ft. The normal water level of Fish Lake, established with the weir boards in place, is 842.8 ft MSL, and hydrologic modeling indicates the lake level will rise to a peak elevation of 846.5 ft MSL for the 1% probability rainfall event (6 inches in 24-hours assuming a Type II rainfall distribution). There are no long term records for water level in Fish Lake.

The outlet for Schwanz Lake is a stormwater lift station with a maximum pumping capacity of 5 cfs. The normal water elevation of Schwanz Lake as determined by the lift station floats is 879.0 ft MSL. Hydrologic modeling indicates the lake level will rise to a peak elevation of approximately 883.0 ft MSL for the 1% probability rainfall event. As a result of both the restrictive outlet of the lift station and the large upstream drainage, the drawdown time for Schwanz Lake for large storms is relatively long. For the 1% probability event, the peak water surface elevation is reached approximately 9 days afterward, and the lake will take approximately 3 weeks to return to within 1 ft of the controlled water elevation. The long residence time within Schwanz Lake after large storms somewhat exacerbates lake water quality problems by allowing more time for TP runoff from the watershed to settle out and accumulate in lake sediments.

3 Water Quality Standards and Numeric Phosphorus Target

3.1 WATER QUALITY STANDARDS FOR DESIGNATED USES

Both Fish Lake and Schwanz Lakes are designated as Class 2B waters in Minnesota and are shallow lakes within the NCHF Ecoregion. The MPCA defines a shallow lake as an enclosed basin with a maximum depth of 15 ft or less or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone). In May, 2008, MPCA revised some of the water quality standards presented in Minn. Rules Ch. 7050 to include numeric targets for shallow lakes. The numeric TP, chlorophyll-*a*, and Secchi depth standards for Class 2B shallow lakes in the NCHF Ecoregion are ≤ 60 µg/L, ≤ 20 µg/L, and ≥ 1.0 m, respectively.

Minnesota's water quality standards for nutrients limit the quantity of nutrients that may enter waters of the state. The State's narrative water quality standards (Minn. Rules Ch. 7050.0150 Subp. 3 and Subp. 5) specify that all Class 2 waters shall be free from any material increase in undesirable slime growths or aquatic plants including algae. The MPCA numeric standards for these parameters are designed to meet the current applicable narrative water quality standards for the designated uses of shallow lakes and therefore will be used to determine the numeric target in calculating the Fish Lake TMDL and a numeric goal in managing Schwanz Lake, which will likely be removed from the 303(d) list.

3.2 ANALYSIS OF IMPAIRMENT

During the periods 1991-1993, 1998, and 2000-2008, the average summer (June-September) mean values for TP, chlorophyll-*a*, and Secchi depth in Fish Lake were 67.8 µg/L, 29.4 µg/L, and 1.6 m, respectively. These values do not meet water quality standards for TP or chlorophyll-*a*, but achieve the water quality standard for transparency. The mean seasonal concentrations were based on a minimum of seven samples in each year. Because values for TP and chlorophyll-*a* exceed the state standards, Fish Lake was placed on the 303(d) list of impaired waters.

Historical biweekly monitoring of in-lake water quality in Schwanz Lake by the City of Eagan indicates that between 2001 and 2008 (inclusive), June through September mean TP concentrations averaged 52.6 µg/L, with only one year slightly above the 60 µg/L NCHF Ecoregion shallow lakes standard. Secchi depths for the same period averaged 1.3 m, while chlorophyll-*a* values averaged 32.8 µg/L. Thus, values for TP and Secchi depth were equal to or better than the state NCHF Ecoregion standard for seven out of the last eight years. The improvement in water quality appears to be largely the result of a sustained management effort on the part of the City of Eagan to decrease watershed loads, protect the high quality of upstream water bodies that drain to Schwanz Lake, and control internal loading. Consequently, MPCA is recommending that Schwanz Lake be removed from the 303(d) list as an impaired waterbody, although the City intends to undertake further efforts to reduce watershed loadings and control internal loads.

At this time, the MPCA is not considering delisting Fish Lake as an impaired water because its monitored TP is consistently in excess of the 60 µg/L NCHF Ecoregion shallow lakes standard, and it has a history of exceeding the 20 µg/L NCHF Ecoregion standard for chlorophyll-*a*. MPCA guidance indicates that in order to provide adequate basis for delisting or removing a lake from the 303(d) list, one of the two following conditions relative to the eutrophication standards must be met for data in the most recent 10 years:

1. The monitored in-lake TP concentration and at least one of the other two parameters, chlorophyll-*a* or Secchi depth, must be equal to or better than the applicable standards.

2. The monitored values for both chlorophyll-*a* and Secchi depth must be equal to or better than the standard, even if the in-lake TP concentration does not meet the standard.

Fish Lake does not meet either condition. Conversely, Schwanz Lake's monitored TP concentrations are consistently below the 60 µg/L NCHF Ecoregion shallow lakes standard, and its Secchi depth is consistently greater than one meter. Only monitored chlorophyll-*a* does not meet the NCHF Ecoregion standard. Thus, Schwanz Lake meets condition one above and can be recommended to be removed from the 303(d) list.

4 Phosphorus Source Assessment

4.1 PHOSPHORUS SOURCE ASSESSMENT

The watershed modeling and lake response modeling as well as analysis of the in-lake water quality data indicated stormwater runoff and internal loading were the primary sources of nutrients to both Fish and Schwanz lakes. The models also showed the majority of external loading to the lakes can be attributed to urban runoff. Analyses of lake water quality data as well as modeling also showed there is likely a moderate internal TP load from curlyleaf pondweed senescence, and possibly sediment release of TP in Fish Lake. Internal loading in Schwanz Lake appears to be minor.

4.2 ANALYSIS OF PHOSPHORUS CONTRIBUTIONS

4.2.1 URBAN STORMWATER

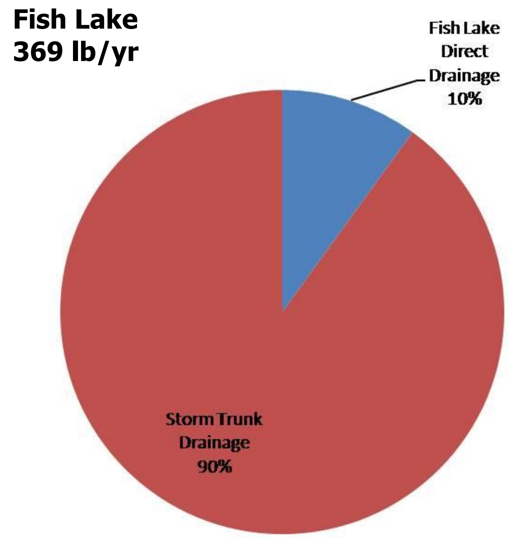
The spreadsheet model PONDNET (Walker, 1989) was used to estimate the load contribution of the major subwatersheds draining to Fish and Schwanz lakes. A detailed explanation of the PONDNET model, which focuses on linking water quality targets to source loads, follows in Section 5 of this report.

In each case, the basic PONDNET model used for this report was the same one used for the nondegradation loading assessment the City submitted to comply with nondegradation review requirements of the MPCA's Municipal Separate Storm Sewer System (MS4) General Permit. Documentation for the model is included in the City's nondegradation review (City of Eagan, 2007a). The model was accepted by MPCA as adequate for the loading assessment.

The watershed model for each lake was calibrated using water quality and flow monitoring data at key locations. For Fish Lake, outflows from Pond JP-47 on the main trunk of the stormwater drainage system just upstream of Pond JP-15 were monitored continuously from mid-March through mid-October 2008, and the hydrologic component of the model was calibrated to match the monitored flows at this point in the system. Further, data from biweekly monitoring of water quality in key ponds in the system during the growing season was checked against modeled values to assure reasonable agreement. For Schwanz Lake, outflows from Hay Lake on the main trunk of the storm drainage system just upstream of Schwanz Lake were also monitored continuously from mid-March through mid-October 2008. The monitored runoff coefficient matched the modeled runoff coefficient at this point in the storm sewer system, so no adjustments were made to the hydrologic component of the model. Biweekly monitoring of Hay Lake water quality was also conducted during 2008 as well as in some previous years, and the monitored in-lake quality was applied to the modeled outflow volume in the year of interest to derive the outflow load from Hay Lake.

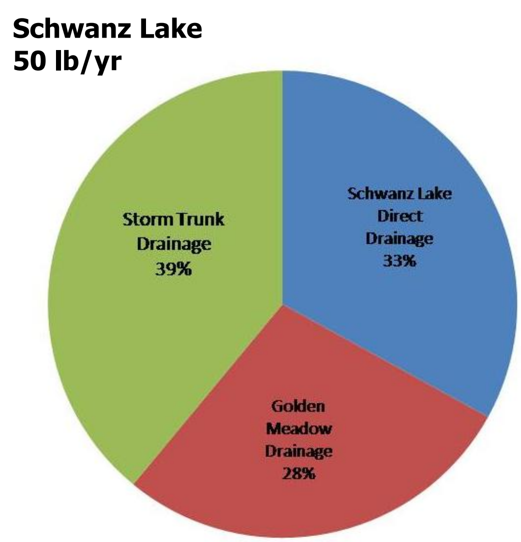
Loads for the storm drainage system component were calculated using the model calibrated as described above. Monitoring did not occur for areas directly tributary to Fish Lake, so the load from this area was estimated using the PONDNET model. The boundaries of the major subwatersheds draining to Fish Lake are shown on Figure 2.8, and the TP loads from those subwatersheds for an average precipitation year are shown on Figure 4.1 (see Appendix A.3 for summary PONDNET results).

FIGURE 4.1– PHOSPHORUS LOADS TO FISH LAKE BY SUBWATERSHED



The majority of TP load entering Schwanz Lake comes from the direct drainage of the lake (which includes both 'Schwanz Lake Direct Drainage' and 'Golden Meadow'), with the remaining external TP load coming from the main trunk of the storm drainage system exiting Hay Lake. Loads from the direct drainage to Schwanz Lake were estimated using the PONDNET model developed as described above. The Golden Meadow drainage area was separated out because it is a neighborhood the City is specifically targeting for water quality retrofits. The boundaries of the major subwatersheds draining to Schwanz Lake are shown on Figure 2.9, and the loads from those subwatersheds for an average precipitation year are shown in Figure 4.2 (see Appendix B.3 for summary PONDNET results).

FIGURE 4.2– PHOSPHORUS LOADS TO SCHWANZ LAKE BY SUBWATERSHED



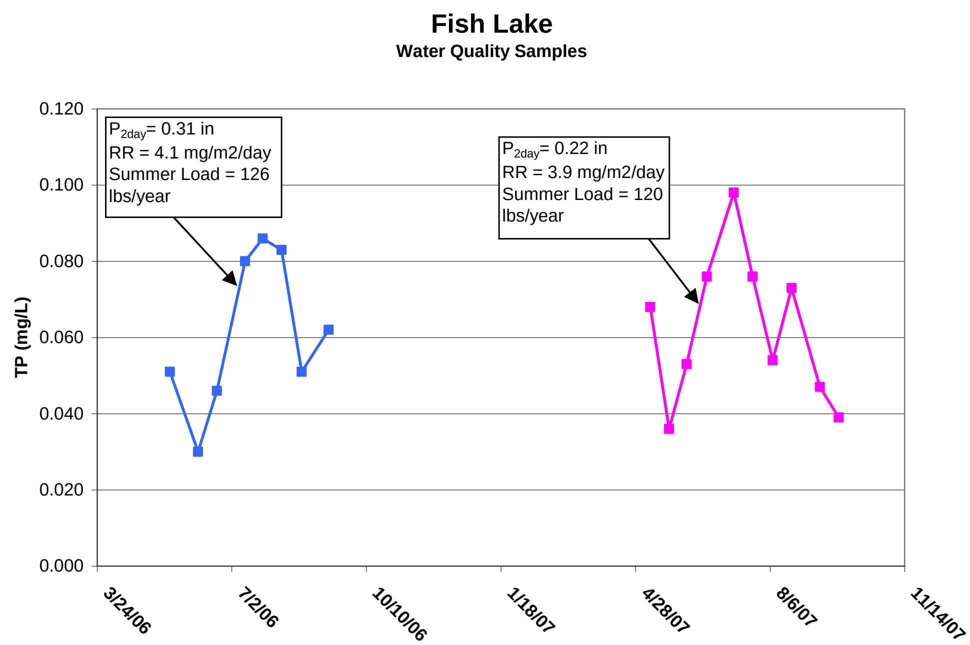
4.2.2 INTERNAL PHOSPHORUS RELEASE

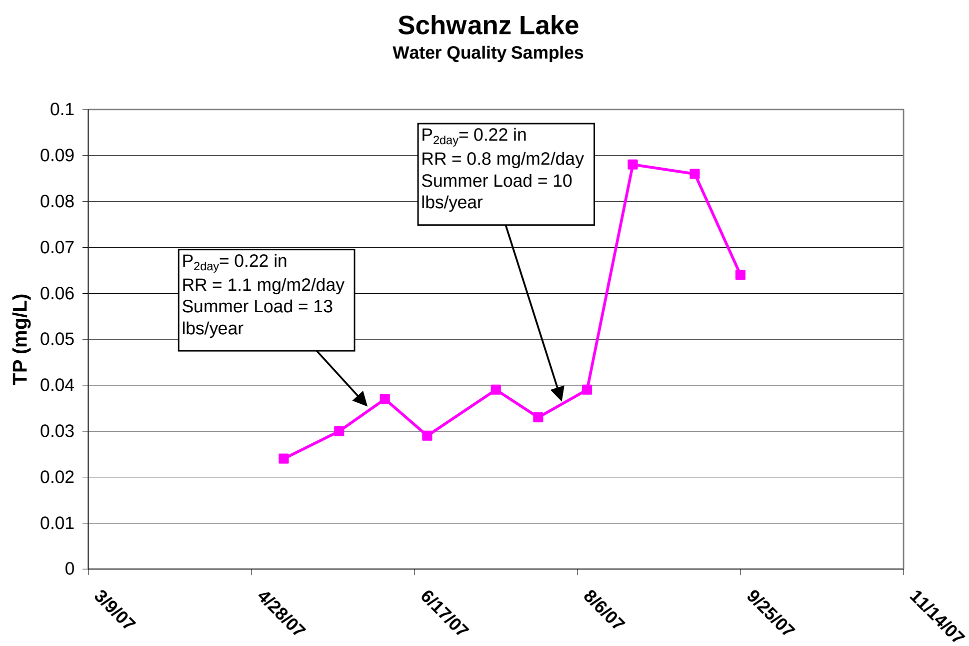
Fish and Schwanz lakes have been exposed to periodic nutrient loading that has been higher than their assimilative capacities. Much of this excess TP has likely found its way into the bottom sediments. This excess TP is now available to be released into the water column when conditions are favorable. This occurs when sediment is re-suspended by wind mixing and rough fish activity as well as when dissolved oxygen levels near the sediment water interface drop below 2 mg/L (as shown in Figure 2.11). TP is also released when the heavy growths of curlyleaf pondweed, characteristic of each lake, die back in early to mid summer. All of these mechanisms for internal loading of TP can occur in both lakes and are capable of contributing to conditions that promote algae growth, especially in mid to late summer.

Employing a "weight of evidence approach," two techniques were considered to determine to what level internal loading is affecting both lakes. A mass balance method using in-lake monitoring data was used to indirectly calculate internal loading during periods of little to no precipitation. This method was especially helpful at estimating internal loading rates during curlyleaf pondweed senescence and nutrient release. A reverse Canfield-Bachmann lake response model (Canfield and Bachmann, 1981) was also employed.

The mass balance method was used to determine the TP accumulation in the lakes during dry periods where runoff from the watershed was absent. Analysis was completed based on TP samples collected on a biweekly basis, where runoff was absent. A total of three biweekly periods from 2006 to 2008 were analyzed for Fish Lake, and four periods from 2006 to 2008 were analyzed for Schwanz Lake. The increase in TP concentrations in each lake was extrapolated over the entire summer and then converted to an average summertime loading rate based on lake volume. Using the three sample time periods for Fish Lake and four sample time periods for Schwanz Lake, the average calculated estimate for internal loading was 98 lb/yr for Fish Lake and 8 lb/yr for Schwanz Lake. Figure 4.3 shows examples of periods when TP concentrations increased and no runoff occurred (P2 day is the maximum 48-hour precipitation within the 2-week period and "RR" is the calculated internal release rate of TP).

FIGURE 4.3– PERIODS OF INTERNAL LOADING





Using the Canfield-Bachmann lake response model, the seasonal average TP concentration and the modeled external loads were used to estimate the internal component of the load based on the total load required to achieve the seasonal monitored concentrations for the average precipitation year of 2006. From this analysis, for 2006, the internal loading to Fish Lake was 59 lb/yr and the internal load to Schwanz Lake was 6 lb/yr.

Each of these methods provided an approximation of internal loading within both lakes. The mass balance approach provides site-specific and condition-specific information to estimate whether internal loading is a significant factor in epilimnetic TP concentration changes. It provides a fair estimate for net internal loading by direct measurement, but due to the small sample size it does not necessarily represent the average loading rate for the sampled years. The Canfield-Bachmann model used to back-calculate internal loading, knowing the in-lake concentration and calibrated model watershed loading and atmospheric loading, provided a reasonable estimate for internal loading that was similar to the mass balance loads and fell within the range provided by Nürnberg and Peters (1984). Therefore this approach was used for calculating internal loads for the dry, average, and wet scenarios.

4.2.3 ATMOSPHERIC DEPOSITION

The deposition of TP from the atmosphere over the surface of the lakes is accounted for in the modeling but is small in comparison to calculated external loads and internal TP recycling. An estimate based on average depositional rates in the area was used for both lakes. The rate is estimated to be 0.27 lb/acre/yr, which corresponds to the average value suggested in the BATHTUB lake response model (Walker, 1996) and yields an average annual mass load of 8 lb/yr for Fish Lake and 3 lb/yr for Schwanz Lake.

4.2.4 OTHER

The vast majority of dwellings in the watersheds of Fish and Schwanz lakes are served by sanitary sewer owned and operated by the City of Eagan. As of 2004, however, there were still a number of properties in the project area served by individual on-site wastewater disposal facilities (ISTS), 45 of these in the Fish Lake subwatershed and 25 in the Schwanz Lake subwatershed. The City has a permit program for ISTS to ensure all ISTS in the City are performing as expected. Even if there were a failing septic system, it would not be a statistically significant contributor of nutrient load to the lakes as compared to the watershed loads. Thus, there was no TP load from ISTS assigned to either lake.

5 Linking Water Quality Targets to Source Loads

5.1 INTRODUCTION

Detailed water balance and nutrient balance models were developed. The models were calibrated and validated based on multiple years of flow monitoring at important points in each watershed as well as water quality data. The models were used to analyze a range of precipitation conditions, including representative wet (2002), dry (2008), and average (2006) years. Technical modeling information and summaries are in the Appendix of this report.

5.2 SELECTION OF MODEL AND TOOLS

Models used to analyze TP loading to both lakes included a calibrated watershed water quality model, PONDNET (Walker, 1989) and the BATHTUB lake response model (Walker, 1996). PONDNET is a spreadsheet model that permits routing of flow and TP through networks of wet detention ponds. TP removal is predicted using an empirical TP retention function. The BATHTUB lake response model performs steady-state water and nutrient balance calculations that account for advective and diffusive transport, and nutrient sedimentation. Eutrophication-related water quality conditions (TP, total nitrogen, chlorophyll-*a*, transparency, and hypolimnetic oxygen depletion) are predicted using empirical relationships derived from assessments of reservoir data. The Canfield-Bachmann lake response model (Canfield and Bachmann, 1981) as found in the BATHTUB model was used to help estimate internal loading as well as lake TP concentrations for load allocation scenarios. Additionally, BATHTUB was used to model the chlorophyll-*a* and Secchi depth response based on TP concentration and lake characteristics.

5.3 PHOSPHORUS BUDGETS AND RECEIVING WATER RESPONSE

The PONDNET watershed model developed for the Fish and Schwanz Lake watersheds was based on readily available data of subwatershed areas, land use, and stormwater treatment ponds and used rainfall data collected at the Seneca WWTP in northwest Eagan. The hydrologic balance for the model was adjusted using monitored flow data for the trunk storm drainage system for each lake in 2008, a year with lower than average precipitation. The PONDNET model estimated TP loads to the lakes for wet, dry, and average year scenarios using the Seneca WWTP rainfall data.

Because approximately 95% of the watershed area draining to Fish Lake is routed through Ponds JP-47 and JP-15, characterization of the volume and quality of inflows to the lake from the trunk storm drainage system was a priority in watershed model calibration efforts. Consequently, outflows from Pond JP-47 on the main trunk of the stormwater drainage system were monitored continuously from March through October 2008, and the hydrologic component of the model was calibrated to match the monitored flows at this point in the system. The water quality of Ponds JP-47 and JP-15 also were monitored during the 2008 summer season to compare to model estimates. Modeled water quality for Pond JP-15 (the last pond before discharge to Fish Lake) was within 8% of the 2008 monitored water quality. This information supported the use of modeled flow volume and water quality to estimate watershed inputs. Using the calibrated PONDNET model, the load to Fish Lake from the storm trunk system was calculated to be 297 lb/yr for 2008 (the dry year). Inputs from the remainder of the watershed, most of which drains directly to Fish Lake, were quantified using the model.

Similarly, loads to Schwanz Lake were calculated for 2008 using the PONDNET model. The water loads flowing through Hay Lake according to the PONDNET model, when compared to monitored discharge data, agreed to within 3%. Therefore the modeled loads were used for Hay Lake discharge to Schwanz, as well as for the remainder of the watershed, most of which drains directly to Schwanz Lake.

As mentioned previously, 2008 was considered a dry year so 2006 data were used for the TMDL because they better represented average precipitation conditions. The calibrated model was applied to 2006 conditions because that year represents an average precipitation year (see Table 5.1).

TABLE 5.1– 2006 MODELED TP LOADS TO FISH AND SCHWANZ LAKES

Subwatershed	TP Load (lb/yr)
Fish Lake	
Storm trunk (through Pond JP-15)	332
Direct drainage to Fish Lake	37
Total	369
Schwanz Lake	
Storm trunk (through Hay Lake)	19
Golden Meadow direct drainage	14
Remaining drainage	17
Total	50

The Canfield-Bachmann lake response model was used to estimate in-lake TP concentrations based on the TP loads delivered to the lake from watershed, atmospheric, and internal sources on an average annual basis and based on mean lake depth and lake flushing rate. The model was calibrated to monitored in-lake TP to estimate internal TP loading for dry, average, and wet years. For Fish Lake, the model was then used to determine the reduction required to reach the target TP goal of 54 µg/L (the 60 µg/L NCHF Ecoregion standard minus an explicit Margin of Safety (MOS) of 10%, which is 6 µg/L). For Schwanz Lake, the in-lake TP concentration for the dry, average, and wet years was less than 60 µg/L, so no reduction is required. Even though Schwanz Lake meets the 60 µg/L standard for all three conditions, and MPCA is recommending removing this lake from the 303(d) list, the City is implementing improvement projects to reduce the amount of untreated runoff entering Schwanz Lake.

Using the BATHTUB model, estimates for chlorophyll-*a* and Secchi depth were determined for both lakes based on a TP concentration of 60 µg/L (and for Fish Lake for 54 µg/L as well, to reflect the 10% MOS), lake morphometry, and hydrology. Table 5.2 shows the results from the BATHTUB model for both lakes.

TABLE 5.2– BATHTUB MODEL FOR CHL-*A* AND SECCHI DEPTH

Fish Lake	Fish Lake	Schwanz Lake
TP = 60 µg/L	TP = 54 µg/L (10% MOS)	TP = 60 µg/L
Chl-*a* = 34 µg/L	Chl-*a* = 31 µg/L	Chl-*a* = 28 µg/L
Secchi depth = 1.08 m	Secchi depth = 1.17 m	Secchi depth = 1.28 m

As shown in table 5.2, even at the target TP goal of 60 μg/L, both lakes would likely remain in a turbid algal dominated state, with chlorophyll-*a* predicted to be above (or worse) than the MPCA eutrophication standard of 20 μg/L. Using the monitored TP value of 48 μg/L for the average year 2006 for Schwanz Lake, the BATHTUB lake response model still predicts the chlorophyll-*a* standard of 20 μg/L would not be met.

5.4 CONCLUSIONS

The current estimated TP load to Fish Lake based on field monitoring and computer modeling results is 436 lb/yr (369 lb/yr external, 59 lb/yr internal, and 8 lb/yr atmospheric) assuming normal annual precipitation. This is equivalent to 1.19 lb/day (1 lb/day external, 0.16 lb/day internal, and 0.02 lb/day atmospheric). To reach the goal of 54 μg/L for in-lake TP concentration, the Canfield-Bachmann lake response model predicts the annual TP load to Fish Lake would need to be reduced to 352 lb/yr (0.96 lb/day). As explained in the following section, the TMDL TP loading for Fish Lake is 407 lb/yr (352 lb/yr + 55 lb/yr for a 10% explicit MOS). This translates to a total reduction of 84 lb/yr, a 19% reduction from the current annual TP load estimate of 436 lb/yr or a 23% reduction from the current annual TP load estimate of 369 lb/yr from permitted sources.

The Canfield-Bachmann lake response model predicts that the annual TP load to Schwanz Lake could be up to 77 lb/yr (0.2 lb/day) and still meet the NCHF Ecoregion standard of 60 μg/L for in-lake TP concentration. The current estimated TP load to Schwanz Lake based on field monitoring and computer modeling results is 59 lb/yr (50 lb/yr external, 6 lb/yr internal, and 3 lb/yr atmospheric) assuming normal annual precipitation, approximately 23% below the load for the lake at the standard. This is equivalent to 0.16 lb/day (0.14 lb/day external, 0.02 lb/day internal, and 0.008 lb/day atmospheric). The results of this analysis, together with in-lake monitoring data, indicate the lake can be recommended for removal from the 303(d) list and that no TMDL is necessary. Thus, the following report section (Section 6 – TMDL Allocations) will develop a TMDL with Waste Load and Load Allocations for Fish Lake only.

6 TMDL Allocations

6.1 TOTAL MAXIMUM DAILY LOAD CALCULATIONS

The TMDL for Fish Lake was determined to be 407 lb/yr (1.11 lb/day). This reflects a TP goal of 54 µg/L based on the shallow lake eutrophication standard of 60 µg/L and an explicit Margin of Safety (MOS) of 10% (6 µg/L). The TMDL for Fish Lake was distributed into the Waste Load Allocation (WLA), the Load Allocation (LA), and the MOS, expressed as TP mass per unit time according to the following formula:

TMDL	=	WLA	+	LA	+	MOS
1.11 lb/day	=	0.78 lb/day	+	0.18 lb/day	+	0.15 lb/day
407 lb/yr	=	285 lb/yr	+	67 lb/yr	+	55 lb/yr

6.1.1 WASTE LOAD ALLOCATIONS (WLAS)

The MPCA has designated the City of Eagan, City of Inver Grove Heights, Dakota County, and Mn/DOT as operators of Municipal Separate Storm Sewer Systems (MS4s). As a result, the allowable discharge associated with these MS4s has been designated as WLA. Fish Lake's target TP reduction necessary to comply with the allowable WLA is 84 lb/yr from storm sewer systems, which is a 23% reduction in MS4 loading (or a 19% reduction from the current annual TP load estimate of 436 lb/yr). Table 6.1 summarizes the WLAs for Fish Lake applied to the MS4s in the tributary area.

There are no current wastewater discharges in the watershed. Therefore, wastewater activities are not given a WLA. Construction stormwater activities are considered to be less than one percent of the TMDL and difficult to quantify. Construction stormwater activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install and maintain all BMPs required under the permit, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit. Industrial stormwater activities are considered in compliance with provisions of the TMDL if they obtain an industrial stormwater general permit under the NPDES program and properly select, install, and maintain all BMPs required under the permit. Consequently, the WLA also includes pollutant loading from construction and industrial stormwater sources.

6.1.2 LOAD ALLOCATIONS (LAS)

Internal loading of TP has been designated as a LA. The loading of TP from atmospheric deposition onto the lake is also included as a LA.

The TMDL assumes the load reductions necessary to meet the in-lake water quality goal will come from reductions in the WLAs through watershed controls. Fish Lake's internal loading of TP is assumed to remain at 59 lb/yr and the atmospheric deposition is assumed to remain at 8 lb/yr. Table 6.1 summarizes the LAs for Fish Lake for internal loading and direct atmospheric loading.

6.1.3 SUMMARY OF TMDL ALLOCATIONS

In Table 6.1, the City of Eagan is the only regulated entity that has been assigned a load reduction. Eagan has by far the bulk of external loading to Fish Lake, and also has the greatest capability to provide the load reduction within the watershed. As additional data become available after U.S. EPA approval of the TMDL, WLAs for individual permitted sources may be modified, provided the overall WLA does not change. Modifications of individual WLAs will be publicly noticed.

TABLE 6.1– SUMMARY OF ASSIGNED SOURCE WASTE LOAD AND LOAD ALLOCATIONS FOR FISH LAKE

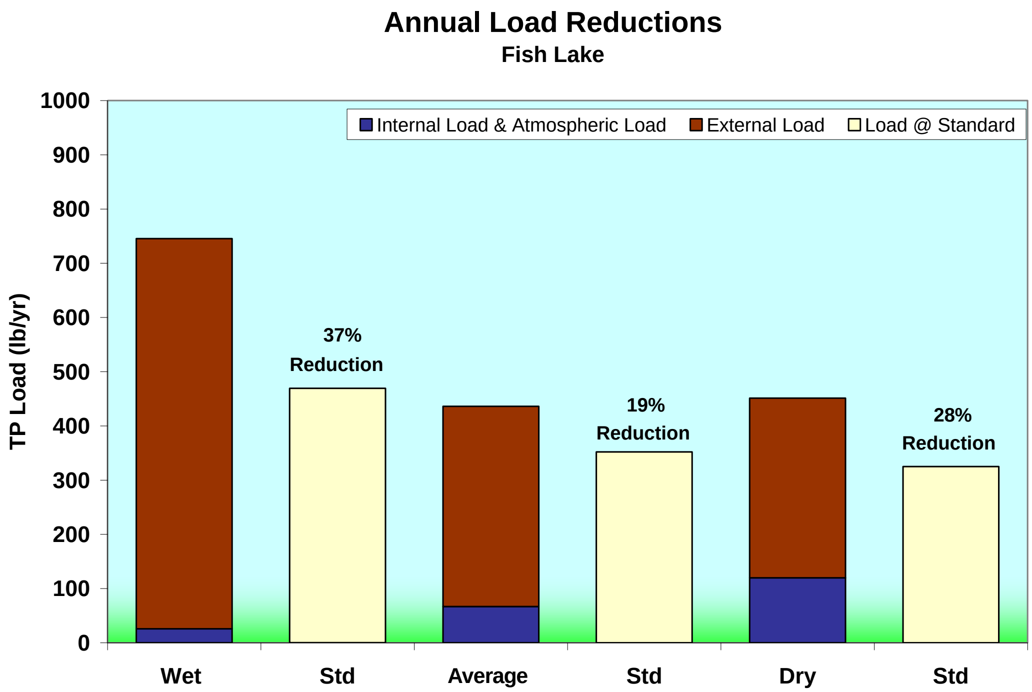
Assigned Source	Existing TP Loading		TP Allocations		Load Reduction
	(lb/yr)	(lb/day)	(lb/yr)	(lb/day)	(lb/yr)
City of Eagan (WLA)	348	.95	264	0.72	84
City of Inver Grove Heights (WLA)	1.0	0.003	1.0	0.003	0
Dakota County (WLA)	18	0.049	18	0.049	0
MnDOT (WLA)	1.9	0.005	1.9	0.005	0
Internal Loading (LA)	59	0.16	59	0.16	0
Atmospheric Loading (LA)	7.7	0.021	7.7	0.021	0
Margin of Safety (MOS)	-	-	55	0.15	0
Total	436	1.19	407	1.11	84

6.1.4 SEASONAL AND ANNUAL VARIATION

Nutrient loads and resultant in-lake TP concentrations for Fish Lake are influenced by annual precipitation patterns, which can be highly variable. TP loadings to the Lakes were estimated for dry (2008), average (2006), and wet (2002) years. The annual precipitation depths for the dry, average, and wet years were 22.7 inches, 25.3 inches, and 37.0 inches, respectively. The Canfield-Bachmann lake response model (Canfield and Bachmann, 1981) along with modeled watershed loads from PONDNET (Walker, 1989) were used to determine the total loads and the external and internal components of the loads for each scenario for Fish Lake. Figure 6.1 shows the seasonal variations for TP loads to Fish Lake with the standard load required to meet the TP target. The annotated percentages indicate the reduction of TP load to meet the standard.

The TMDL calculation for Fish Lake is based on the average year (2006) rainfall and monitored load. The average year conditions represent most rainfall years in Eagan, rather than the outliers of the wet and dry year conditions. In addition, the 10% MOS is included in the TMDL calculation, and the load allocations were developed for the summer growing season when lake water quality is worst and most sensitive to loads. These conservative measures mean that basing the calculation on the average year conditions should enable Fish Lake to meet the NCHF Ecoregion standards for shallow lakes for all years.

FIGURE 6.1– MODELED ANNUAL LOADS AND LOAD REDUCTIONS TO MEET THE FISH LAKE STANDARD



6.1.5 MARGIN OF SAFETY (MOS)

Both an explicit and implicit MOS have been used for this project. An explicit MOS has been provided by lowering the proposed in-lake TP goal by 10% to 54 μg/L. This MOS provides an extra assurance that Fish Lake will meet water quality standards by setting the TP allocations to a more stringent goal for the TMDL. The implicit MOS focused on the good calibration of the models with hydrologic and water quality data. As discussed in Section 5, the PONDNET-modeled runoff volume for the main inflow was calibrated to match the measured inflow volume, and the modeled water quality for stormwater runoff to Fish Lake was within 8% of the monitored data. Similarly, Appendix A shows the calibration of TP in the BATHTUB model matched the monitored summer average. This information supported the use of the modeled data to estimate watershed and in-lake TP inputs for the TMDL. The MOS was used to account for an inherently imperfect understanding of this highly dynamic shallow lake system and ultimately to ensure the nutrient reduction strategy is protective of the water quality standard.

6.2 FUTURE GROWTH AND NONDEGRADATION

The City of Eagan's Water Quality & Wetland Management Plan (City of Eagan, 2007c) includes nondegradation policies (Policies 3.1 and 3.2) for future land development and re-development. The policy requires any proposed new development within the watershed that creates over 0.5 acres of new impervious surface to achieve a minimum of no-net-increase in TP and total suspended solids loading compared to the condition of the site that existed immediately prior to the proposed alteration. In addition, all re-development will be required to achieve no-net-increase in TP and total suspended solids loading, no matter what the impervious coverage change. The City is implementing these and other related policies with promulgation in 2008 of a comprehensive set of stormwater management regulations.

7 Public Participation

7.1 SUMMARY OF PUBLIC PARTICIPATION

The determination of a target goal, the WLAs and LAs discussed above, and the implementation plan for achieving those goals were completed with the help of a stakeholders group representing a range of interests and responsibilities in managing and/or using the lake and its watershed. The following groups participated in the TMDL stakeholder process:

- At-large citizens
- City of Eagan
- City of Inver Grove Heights
- Dakota County Soil and Water Conservation District
- Gun Club Lake Watershed Management Organization
- Metropolitan Council
- Minnesota Board of Water and Soil Resources
- Minnesota Department of Natural Resources
- Minnesota Department of Transportation
- Minnesota Pollution Control Agency

Between June 2008 and January 2009, two meetings were held. Members of the stakeholder groups listed above were invited to the meetings. At the first meeting on June 18, 2008, the TMDL process was explained, information was presented on general concepts of shallow lakes ecology and restoration, the current conditions of the lakes compared with recommended Ecoregion-based eutrophication criteria was discussed, the concept of adaptive management was introduced, and a proposed public participation process and schedule for the remainder of the project was presented.

The second meeting on January 29, 2009 covered the results of the diagnostic study for both lakes, including external and internal loading estimates, load sources, lake response, and proposed TMDL endpoints and allocations. It also covered implementation options to achieve targeted reductions and offered the option of proceeding with the recommendation to remove Schwanz Lake from the 303(d) list for reasons previously explained.

A third, and final, stakeholder meeting was held on February 24, 2010. The draft TMDL document was presented to receive final comments and for endorsement. The draft report was sent to agency representatives and interested members of the stakeholders group for review in advance of the meeting.

The public comment period for this TMDL was from May 24, 2010 to June 23, 2010. One comment was received on the draft TMDL report, and a small change to the stakeholder list was made.

8 Implementation Strategy

8.1 RECOMMENDED PHOSPHORUS MANAGEMENT STRATEGIES

A TMDL implementation plan will be targeted for completion within a year of TMDL approval. It is a MPCA policy that implementation plans be completed within a year of EPA approval of the TMDL.

The implementation plan will focus on reducing the amount of TP entering Fish Lake from the watershed and reducing internal TP recycling in the lake, both of which should decrease algal production as defined by chlorophyll-*a* and increase water clarity (measured as Secchi depth) to meet the NCHF Ecoregion shallow lake criteria adopted by MPCA. Consistent with the philosophy of adaptive management outlined in Section 6.1, emphasis will be on assessing the impacts of management actions to a reasonable extent and applying lessons learned to guide future actions as progress is made toward goals.

Potential strategies to achieve the TP load reductions necessary to achieve in-lake standards center around the following:

1. Managing TP loading during future development and redevelopment
2. Continuing good housekeeping practices, including street sweeping, stormwater system maintenance, and public education
3. Pursuing stormwater retrofit activities as opportunities arise
4. Implementing in-lake management activities, chemical and biological, as appropriate

Overall costs for TMDL implementation are estimated to range from $300,000 to $1,000,000. Construction costs for capital projects may exceed $200,000, depending upon the specific projects that are implemented.

Potential actions to reduce TP load necessary to achieve in-lake standards include the following:

1. *Re-start operation of the alum dosing facility to treat inflows to Fish Lake from the storm trunk system.* This would involve constructing an alum floc settling basin on upland property, developing an operating plan for the treatment system, and obtaining and complying with an NPDES permit. Pilot operation of the system in 1998-2000 indicated TP removal efficiencies as high as 75% can be achieved. The system is very effective at improving lake water quality and is intended to be operated in close association with lake monitoring. This will likely mean intermittent operation in the indefinite short term; hopefully it will be temporary in the long term, depending on improvements in the watershed. An estimated TP removal efficiency of less than 40% would be needed to meet the goals in this TMDL.
2. *Assure no-net-increase in TP loading from future development and re-development*, in accordance with City policies and regulations. These actions will be taken indefinitely into the future.
3. *Continue enhanced street sweeping and public education*. These ongoing actions will be taken indefinitely into the future.

4. *Assess conditions of stormwater detention ponds in the watershed and conduct maintenance activities as warranted.* These ongoing actions will be taken indefinitely into the future.
5. *As opportunities arise, retrofit stormwater infiltration projects.* These ongoing actions will be taken indefinitely into the future.
6. *Control internal loading* through continued curlyleaf pondweed control efforts, fish management to control rough fish and stunted panfish, and chemical inactivation of TP in lake sediments. Curlyleaf pondweed control and fish management activities will take place throughout the project implementation time period. If chemical inactivation of TP is needed, it would take place during the project implementation time period.

8.2 REASONABLE ASSURANCE

When establishing a TMDL, reasonable assurances must be provided to demonstrate ability to reach and maintain water quality standards. Several factors control reasonable assurances including: a thorough knowledge of the overall effectiveness of Best Management Practices (BMPs) and the ability to allocate available resources, and state and local authority and regulatory controls. The City clearly demonstrated its commitment when it requested the start and completion dates of the TMDL be moved from 2017 and 2020 to 2007 and 2011, respectively, to accelerate the process significantly.

To maximize effectiveness, an adaptive management strategy will guide the development of the Implementation Plan for Fish Lake. This Plan will identify specific BMPs that will be implemented to reduce nutrient loading. Mid-course corrections may be necessary to adapt to interim conditions. In addition, as research and technology continue to advance, and as knowledge of and experience with new BMPs increase, actions and management plans may be changed to incorporate these advances.

There are three primary mechanisms assuring the implementation of improvements: the Gun Club Lake Watershed Management Plan (GCLWMO, 2007) and future revisions; the City of Eagan Comprehensive Water Management Plan (2007) and future revisions; and the City of Eagan Stormwater Pollution Prevention Program. Existing and future regulation, programs and capital projects will be prioritized to improve Fish Lake as described below.

8.2.1 THE GUN CLUB LAKE WATERSHED MANAGEMENT ORGANIZATION

The Gun Club Lake Watershed includes those parts of Eagan and Inver Grove Heights that drain to Fish Lake. The Gun Club Lake Watershed Management Organization is a joint powers organization between the cities of Eagan, Inver Grove Heights, and Mendota Heights and is administered by a 5-member Board of Managers.

The Metropolitan Area Surface Water Management Act requires local units of government in the Twin Cities Metropolitan Area to be managed by watershed management organizations through the development and implementation of watershed management plans, and states that the purposes of watershed management organizations and water management programs are (Minn. Stats. Ch. 103B.201) to:

1. protect, preserve, and use natural surface and groundwater storage and retention systems;
2. minimize public capital expenditures needed to correct flooding and water quality problems;
3. identify and plan for means to effectively protect and improve surface and groundwater quality;

4. establish more uniform local policies and official controls for surface and groundwater management;
5. prevent erosion of soil into surface water systems;
6. promote groundwater recharge;
7. protect and enhance fish and wildlife habitat and water recreational facilities; and
8. secure the other benefits associated with the proper management of surface and ground water.

One of the goals of the GCLWMO is to protect and enhance surface water quality in the watershed. To achieve this goal, the GCLWMO watershed plan establishes objectives and actions defining the GCLWMO's role in developing and implementing TMDLs for Impaired Waters within the watershed. The GCLWMO has been a participant in all aspects of the Fish and Schwanz Lake TMDL process.

8.2.2 The City of Eagan Local Surface Water Management Plan

The City of Eagan has developed a local surface water management plan that is compliant with State Statutes and Administrative Rules and the requirements of the GCLWMO. Eagan's local surface water management plan includes the Stormwater Management Plan (City of Eagan, 2007b), and the Water Quality & Wetland Management Plan (City of Eagan, 2007c). The Water Quality & Wetland Management Plan (City of Eagan, 2007c) includes Goals and Policies, Watershed Requirements, Agency Requirements, Best Management Practices, watershed descriptions, stormwater quality, and infrastructure improvement planning. The local surface water management plan is periodically updated to reflect changing conditions, new requirements, and watershed management plan revisions. The local surface water management plan sets forth the specific actions the City will undertake to achieve state, federal, watershed, and local goals for stormwater management. The City also has enacted ordinances requiring stormwater quantity and quality management for development and redevelopment activities; regulating erosion control; and prescribing shoreland management standards.

The local surface water management plan and regulatory controls can be amended if necessary to incorporate City activities identified in the TMDL Implementation Plan.

8.2.3 NPDES MS4 Stormwater Permits

The City of Eagan owns and operates a Municipal Separate Storm Sewer System (MS4) that is regulated through a State of Minnesota NPDES Phase II General Stormwater Permit. Under this permit, Eagan is required to develop and implement a Stormwater Pollution Prevention Program (SWPPP). 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 permit holder must identify BMPs and measurable goals associated with each minimum control measure.

According to federal regulations, NPDES permit requirements must be consistent with the assumptions and requirements of an approved TMDL and associated Waste Load Allocations.

To meet this regulation, Minnesota's General Permit requires the following:

> "If your **MS4** discharges to a **Water of the State** that appears on the current **USEPA** approved list of impaired waters under Section 303(d) of the Clean Water Act (33 U.S.C. § 303 (d)), You must review whether changes may be warranted in your **Storm Water Pollution Prevention Program** to **Reduce** the impact of your discharge. If a USEPA-approved **TMDL(s)** has been developed, you must review the adequacy of your **Storm Water Pollution Prevention Program** to meet the **TMDL's** Waste Load Allocation set for Storm Water sources. If the **Storm Water Pollution Prevention Program** is not meeting the applicable requirements, schedules and objectives of the **TMDL, You** must modify your Storm Water Pollution Prevention Program, as appropriate, within **18 months** after the **TMDL** Waste Load Allocation is approved."

The TMDL Implementation Plan, to be developed as a separate document, will identify specific BMPs and activities the City will undertake within the first five-year NPDES permit cycle following approval, as well as longer-term BMPs and activities that will be considered for implementation to achieve the Waste Load Allocations. The City's SWPPP will be amended as necessary to incorporate City activities identified in the TMDL Implementation Plan.

8.3 FOLLOW-UP MONITORING PLAN

The City's SWPPP Annual Report will be the mechanism by which the City will report on progress toward implementing the TMDL Implementation Plan. For this TMDL, the City of Eagan is expected to have all of the implementation responsibilities, though voluntary or collaborative activities on the parts of other MS4s will be encouraged.

8.3.1 FOLLOW-UP MONITORING

Adaptive Management requires ongoing monitoring to evaluate the effectiveness and impact of BMPs on water quality. The City plans are to continue its existing long-term water quality monitoring program. This includes collecting surface water temperature, pH, conductivity, and Secchi depth data as well as surface water samples between May and September. Water samples will be analyzed for TP and chlorophyll-*a*. Monitoring will also include depth profiles of temperature and dissolved oxygen. Monitoring of aquatic plant and fish community species composition and abundance will be conducted during the initial 5-year project implementation period. Inflow quantity and quality monitoring will also be carried out during and after implementation of this TMDL to quantify external load reductions. The City will analyze and summarize all data and will fund all monitoring efforts.

8.3.2 ADAPTIVE MANAGEMENT

The City will reconvene the stakeholders group near the beginning of the fourth year of the initial 5-year implementation period to review the monitoring data, evaluate project progress, and determine if the Implementation Plan should be amended. If the Implementation Plan needs to be amended, the City will incorporate changes into the five-year NPDES Phase II MS4 General Permit covering the period 2016 to 2021. The City will work with the stakeholders group and the MPCA to amend the Implementation Plan, obtain agency and stakeholder review and input on those amendments, and achieve final agency review and approval.

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Appendix – Modeling Results

Appendix A Summary of Fish Lake Modeling

Appendix A.1	Water and TP Budgets
Appendix A.2	Calibration of TP Concentration Against 2006 Data
Appendix A.3	Summary PONDNET Watershed Load Runs
Appendix A.4	Calibration of Chlorophyll-a Concentration Against 2006 Data
Appendix A.5	Calibration of Secchi Depth Against 2006 Data
Appendix A.6	Total Phosphorus Model for TMDL
Appendix A.7	Chlorophyll-a Model for TMDL
Appendix A.8	Secchi Depth Model for TMDL
Appendix A.9	Chlorophyll-a Model for TMDL with MOS
Appendix A.10	Secchi Depth Model for TMDL with 10% MOS

APPENDIX A.1

Fish Lake – Water and TP Budgets

Budget Component	Flow hm^3/yr	Load kg/yr	Conc mg/m^3
Precipitation	0.07	3.5	47.1
Tributary Inflow	0	--	--
Nonpoint Inflow	1.58	167.5	105.7
Point-Source Inflow	0	--	--
Internal Load	--	26.8	--
TOTAL INPUTS	**1.66**	**197.8**	**119.2**
Outflow	1.58	99.8	63.0
Evaporation	0.07	--	--
Retention	--	98.0	--
TOTAL OUTPUTS	**1.66**	**197.8**	**--**

APPENDIX A.2

Fish Lake – Calibration of TP Concentration Against 2006 Data

Canfield-Bachmann Lake Response Model (for reservoirs: BATHTUB Model #4)
Eq: P=Pi / (1 + K *0.114
((Wp/V)^0.589)*T) (from BATHTUB)
where:
P=total phosphorus concentration (mg/m^3)
Pi=inflow total P concentration (mg/m^3)
K=calibration factor=1
Wp=total phosphorus loading (kg/yr)
V=total volume (hm^3)
T=hydraulic residence time (yrs)

Inputs:		
Averaging Period (yrs)	1	
Precipitation (m)	0.64	
Evaporation (m)	0.64	
Atmos. P Loads (lb/ac/yr)	0.27	(average from WiLMS sources)
Atmos. P Loads ($kg/km^2/yr$)	30.26	(unit conversion)
Watershed P loading (lb/year)	369.29	(from PondNET, Appendix A.3)
Watershed P loading (kg/year)	167.51	(unit conversion)
Watershed water loading (ac-ft/year)	1284.32	(from PondNET)
Watershed water loading (m^3/year)	1584208.72	(unit conversion)
Lake Morphometry:		
Lake Area (ac)	28.70	
Lake Area (m^2)	116143.88	(unit conversion)
Lake Volume (af)	239.30	
Lake Volume (m^3)	295172.24	(unit conversion)
V (hm^3)	**0.30**	(unit conversion)
Mean depth (m)	2.54	
T (yrs)	**0.19**	
Observed Water Quality:		
Phosphorus (mg/m^3)	63	
Internal Load:		
Load (kg/yr)	26.76	(added load until modeled load=observed load)
Loading rate (mg/m^2/day)	0.63	
Calculations:		
Wp (kg/yr)	**197.79**	
Pi (mg/m^3)	**124.85**	
P (mg/m^3)=Pi / (1 + K *0.114 ((Wp/V)^0.589)*T)	**63.02**	Matches observed phosphorus concentration

APPENDIX A.3

Fish Lake – Summary PONDNET Watershed Load Runs

Scenario: Average Year 2006
Water Yr. Precip: 25.29

Pondnet Model

Subwatershed	Water Load	TP load
	(ac-ft/year)	(lbs/year)
JP-47	1224.12	325.76
JP-66	38.06	8.70
JP-15	1335.67	380.07
Remaining subs	71.06	38.03
External load TOTAL	1406.73	418.10

Monitored Values (June-September)

Fish Lake (W)	Parameter	
2006	TP (mg/l)	0.063
	Chlor a (ug/l)	49.071
	S.D. (meters)	1.4
Fish Lake (E)	Parameter	
2006	TP (mg/l)	0.078
	Chlor a (ug/l)	
	S.D. (meters)	
JP-47	Parameter	0.128
2006	TP (mg/l)	
JP-15	Parameter	
2008	TP (mg/l)	0.101

2006 BATHTUB Inputs

	Modeled	Adjusted loads		Rationale
	Water Load	Water Load	TP load	
	(ac-ft/year)	(ac-ft/year)	(lbs/year)	
JP-47 inflow to JP-15	1224.12	1101.71	382.59	2008 monitoring showed Rc of .18 vs. .2 in model for JP-47 subwatershed, used monitored TP value
JP-15 inflow to Fish Lake	1335.67	1213.26	331.26	Inflow from JP-15 to Fish Lake reduced to account for decreased inflow from JP-47; used monitored TP value
Remaining TP load to Fish Lake		71.06	38.03	As modeled
Adjusted loads to Fish Lake		**1284.32**	**369.29**	

APPENDIX A.4

Fish Lake – Calibration of Chlorophyll-*a* Concentration Against 2006 Data

Calculated from P, Light, Flushing (BATHTUB Model #2)
Eq: B = K Bp / [(1 + b Bp G) (1 + Ga)] (From BATHTUB)
Where:
B= Chlorophyll a Concentration (mg/m3)
K=calibration factor=1
b=Algal Light Extinction Coef = Slope of 1/Secchi vs. Chl-a [default = 0.025 1/m]
Bp=P^1.37/4.88
P=total phosphorus concentration (mg/m3)
G = Zmix (0.19 + 0.0042 Fs)
Zmix=Mean Depth of Mixed Layer (m)
Fs=Summer Flushing Rate = (Inflow + Precip -Evaporation)/Volume (yr^{-1})
a=Non-Algal Turbidity (1/m) [minimum value = 0.08 1/m]
S=Secchi Depth (m)

Inputs:		
P (mg/m3)	63	2006 phosphorus conc.
Fs (yr^{-1})	5.37	1/residence time
Zmix (m)	2.00	
b (1/m)	**0.025**	default
a (1/m)	**0.08**	minimum
Observed:		
Chlorophyll-a (mg/m^3)	49.1	
Calculations:		
Bp (mg/m^3)	**59.80**	
G	**0.43**	
B (mg/m^3)= K Bp / [(1 + b Bp G) (1 + Ga)]	**35.36**	

APPENDIX A.5

Fish Lake – Calibration of Secchi Depth Against 2006 Data

vs. Chl a and Turbidity (BATHTUB M (From BATHTUB)
Eq: S = K / (a + b B)
Where:
S=Secchi Depth (m)
K=calibration factor=1
a=Non-Algal Turbidity (1/m) [minimum value = 0.08 1/m]
b=Algal Light Extinction Coef = Slope of 1/Secchi vs. Chl-a [default = 0.025 1/m]
B= Chlorophyll a Concentration (mg/m^3)

Inputs:	**0.025**	default
b (1/m)	**0.08**	minimum
a (1/m)	**35.36**	modeled 2006 concentration
B (mg/m^3)		

Observed:	1.4
Secchi depth (m)	

Calculations:	**1.04**
S (m) = K / (a + b B)	

APPENDIX A.6

Fish Lake – TP Model for TMDL - Average year 2006

Canfield - Bachmann Reservoir Phosphorus Model

TP Load	**369.294**	**lb/yr**		
Water Load	**1284.320**	**AF/yr**		
Water out flow	**1284.320**	**AF/yr**		
Areal Load	0.27	lb/ac/yr	average from WiLMS sources	
Atm. Load of TP	7.75	lb/yr		
Total TP Load	436.04	lb/yr		
TP Load	1472.52	$mg/m^2/yr$	based on lake area	
Total TP Load	1702.94	$mg/m^2/yr$	based on lake area	
Water Load	1584186	m^3/yr		
Water Out	1584186	m^3/yr		
z (lake mean depth)	2.541	m		
p (lake flushing rate)	5.37	yr^{-1}		
Conversion	*453592.4*	*mg/lb*		
Conversion	*1233.482*	*m^3/AF*		
Modeled Mixed Lake [TP]	**56.8**	**ppb**	C - B Model based on watershed load only	
Total Modeled In-Lake TP	**63.0**	**ppb**	w/ Int. Load	
[TP] from CAMP	**63**	**ppb**	GSM (June - Sept)	**2006 Data**
Internal Load	**59**	**lb/yr**	**Add Load until Model matches CAMP data**	

Lake Characteristics

Lake Area	**28.7**	**ac**	116143.88 m^2
Lake Volume	**239.3**	**AF**	295172.24 m^3

Percent of Total Load from sediments

14%

Reduced External Load (lb/yr): **369.294** — **% Reduction in Ext. Load**: **0.0%**

Total TP Load	In-lake TP	% Reduction	TP External Load (	In-lake TP	% Reduction	TP Int. Load (lb/yr)	In-lake TP	% Reduction
436.043	63.0	0.0%	369.294	63.0	0.0%	59	63.0	0.0%
434.043	62.8	0.5%	367.294	62.8	0.5%	58	62.9	1.7%
432.043	62.6	0.9%	365.294	62.6	1.1%	57	62.8	3.4%
430.043	62.4	1.4%	363.294	62.4	1.6%	56	62.7	5.1%
428.043	62.2	1.8%	361.294	62.2	2.2%	55	62.6	6.8%
426.043	62.0	2.3%	359.294	62.0	2.7%	54	62.5	8.5%
424.043	61.8	2.8%	357.294	61.8	3.2%	53	62.4	10.2%
422.043	61.6	3.2%	355.294	61.6	3.8%	52	62.3	11.9%
420.043	61.4	3.7%	353.294	61.4	4.3%	51	62.2	13.6%
418.043	61.2	4.1%	351.294	61.2	4.9%	50	62.1	15.3%
416.043	61.0	4.6%	349.294	61.0	5.4%	49	62.0	16.9%
414.043	60.7	5.0%	347.294	60.7	6.0%	48	61.9	18.6%
412.043	60.5	5.5%	345.294	60.5	6.5%	47	61.8	20.3%
410.043	60.3	6.0%	343.294	60.3	7.0%	46	61.7	22.0%
408.043	60.1	6.4%	341.294	60.1	7.6%	45	61.6	23.7%
406.043	59.9	6.9%	339.294	59.9	8.1%	44	61.5	25.4%
404.043	59.7	7.3%	337.294	59.7	8.7%	43	61.4	27.1%
402.043	59.5	7.8%	335.294	59.5	9.2%	42	61.3	28.8%
400.043	59.3	8.3%	333.294	59.3	9.7%	41	61.2	30.5%
398.043	59.1	8.7%	331.294	59.1	10.3%	40	61.1	32.2%
396.043	58.8	9.2%	329.294	58.8	10.8%	39	61.0	33.9%
394.043	58.6	9.6%	327.294	58.6	11.4%	38	60.8	35.6%
392.043	58.4	10.1%	325.294	58.4	11.9%	37	60.7	37.3%
390.043	58.2	10.5%	323.294	58.2	12.5%	36	60.6	39.0%
388.043	58.0	11.0%	321.294	58.0	13.0%	35	60.5	40.7%
386.043	57.8	11.5%	319.294	57.8	13.5%	34	60.4	42.4%
384.043	57.6	11.9%	317.294	57.6	14.1%	33	60.3	44.1%
382.043	57.3	12.4%	315.294	57.3	14.6%	32	60.2	45.8%
380.043	57.1	12.8%	313.294	57.1	15.2%	31	60.1	47.5%
378.043	56.9	13.3%	311.294	56.9	15.7%	30	60.0	49.2%
376.043	56.7	13.8%	309.294	56.7	16.2%	29	59.9	50.8%
374.043	56.5	14.2%	307.294	56.5	16.8%	28	59.8	52.5%
372.043	56.3	14.7%	305.294	56.3	17.3%	27	59.7	54.2%
370.043	56.0	15.1%	303.294	56.0	17.9%	26	59.6	55.9%
368.043	55.8	15.6%	301.294	55.8	18.4%	25	59.5	57.6%
366.043	55.6	16.1%	299.294	55.6	19.0%	24	59.4	59.3%
364.043	55.4	16.5%	297.294	55.4	19.5%	23	59.3	61.0%
362.043	55.2	17.0%	295.294	55.2	20.0%	22	59.2	62.7%
360.043	54.9	17.4%	293.294	54.9	20.6%	21	59.1	64.4%
358.043	54.7	17.9%	291.294	54.7	21.1%	20	58.9	66.1%
356.043	54.5	18.3%	289.294	54.5	21.7%	19	58.8	67.8%
354.043	54.3	18.8%	287.294	54.3	22.2%	18	58.7	69.5%
352.043	54.0	19.3%	285.294	54.0	22.7%	17	58.6	71.2%
350.043	53.8	19.7%	283.294	53.8	23.3%	16	58.5	72.9%
348.043	53.6	20.2%	281.294	53.6	23.8%	15	58.4	74.6%
346.043	53.4	20.6%	279.294	53.4	24.4%	14	58.3	76.3%
344.043	53.2	21.1%	277.294	53.2	24.9%	13	58.2	78.0%
342.043	52.9	21.6%	275.294	52.9	25.5%	12	58.1	79.7%
340.043	52.7	22.0%	273.294	52.7	26.0%	11	58.0	81.4%
338.043	52.5	22.5%	271.294	52.5	26.5%	10	57.9	83.1%
336.043	52.2	22.9%	269.294	52.2	27.1%	9	57.8	84.7%
334.043	52.0	23.4%	267.294	52.0	27.6%	8	57.7	86.4%
332.043	51.8	23.9%	265.294	51.8	28.2%	7	57.6	88.1%
330.043	51.6	24.3%	263.294	51.6	28.7%	6	57.4	89.8%
328.043	51.3	24.8%	261.294	51.3	29.2%	5	57.3	91.5%
326.043	51.1	25.2%	259.294	51.1	29.8%	4	57.2	93.2%
324.043	50.9	25.7%	257.294	50.9	30.3%	3	57.1	94.9%
322.043	50.6	26.1%	255.294	50.6	30.9%	2	57.0	96.6%
320.043	50.4	26.6%	253.294	50.4	31.4%	1	56.9	98.3%
318.043	50.2	27.1%	251.294	50.2	32.0%	0	56.8	100.0%
316.043	49.9	27.5%	249.294	49.9	32.5%			

APPENDIX A.7

Fish Lake – Chlorophyll-*a* Model for TMDL - Based on Model #2 from BATHTUB

(P, Light, Flushing)

P (ppb)	60.0	phosphorus conc.
Bp (ppb)	55.93	phosphorus-potential Chl-a conc.
Fs (yr-1)	5.37	flushing rate
Zmix (m)	2	mean mixed layer depth
b (1/m)	0.025	default algal light extinction coeff. (default value = 0.025)
G	0.43	kinetic factor
S (m)	1.59	2002 measured SD
B (ppb)	32.2	2002 measured B (chlorophyll-a concentration)
a (1/m)	0.08	non-algal turbidity (min. val. = 0.08 m-1)
B (ppb)	**33.9**	**Chl-a conc.**

APPENDIX A.8

Fish Lake – Secchi Depth Model for TMDL - Based on Model #1 from BATHTUB

vs. Chl a and Turbidity

b (1/m)	**0.025**	default
a (1/m)	**0.08**	minimum
B (mg/m^3)	**33.93**	modeled 2006 concentration

$$S = \frac{1}{a + bB}$$

Calculations:

S (m)	1.08

APPENDIX A.9

Fish Lake – Chlorophyll-a Model for TMDL - (BATHTUB Model #2) with MOS

(P, Light, Flushing)

P (ppb)	54.0	phosphorus conc.
Bp (ppb)	48.41	phosphorus-potential Chl-a conc.
Fs (yr-1)	5.37	flushing rate
Zmix (m)	2	mean mixed layer depth
b (1/m)	0.025	default algal light extinction coeff. (defult value = 0.025)
G	0.43	kinetic factor
S (m)	1.59	2002 measured SD
B (ppb)	32.2	2002 measured B (clorophyll a concentration)
a (1/m)	0.08	non-algal turbidity (min. val. = 0.08 m-1)
B (ppb)	**30.9**	**Chl-a conc.**

APPENDIX A.10

Fish Lake – Secchi Depth Model for TMDL - (BATHTUB Model #1) with MOS

vs. Chl a and Turbidity

b (1/m)	**0.025**	default
a (1/m)	**0.08**	minimum
B (mg/m^3)	**30.92**	modeled 2006 concentration

$$S = \frac{1}{a + bB}$$

Calculations:

S (m) 1.17

Appendix B Summary of Schwanz Lake Modeling

APPENDIX B.1

Schwanz Lake – Water and TP Budgets

Budget Component	Flow hm^3/yr	Load kg/yr	Conc mg/m^3
Precipitation	0.07	1.4	18.9
Tributary Inflow	0	--	--
Nonpoint Inflow	0.35	22.7	65.2
Point-Source Inflow	0	--	--
Internal Load	--	2.5	--
TOTAL INPUTS	**0.42**	**26.6**	**62.9**
Outflow	0.35	16.7	48.0
Evaporation	0.07	--	--
Retention	--	9.9	--
TOTAL OUTPUTS	**0.42**	**26.6**	**--**

APPENDIX B.2

Schwanz Lake – Calibration of TP Concentration Against 2008 Data

Canfield-Bachmann Lake Response Model (for lakes: BATHTUB Model #8)
Eq: P=Pi / (1 + K *0.162 ((Wp/V)^0.458)*T) (from BATHTUB)
where:
P=total phosphorus concentration (mg/m^3)
Pi=inflow total P concentration (mg/m^3)
K=calibration factor=1
Wp=total phosphorus loading (kg/yr)
V=total volume (hm^3)
T=hydraulic residence time (yrs)

Inputs:		
Averaging Period (yrs)	1	
Precipitation (m)	0.64	
Evaporation (m)	0.64	
Atmos. P Loads (lb/ac/yr)	0.27	(average from WiLMS sources)
Atmos. P Loads ($kg/km^2/yr$)	30.26	(unit conversion)
Watershed P loading (lb/year)	50.06	(from PondNET, Appendix B.3)
Watershed P loading (kg/year)	22.71	(unit conversion)
Watershed water loading (ac-ft/year)	282.27	(from PondNET)
Watershed water loading (m^3/year)	348180.05	(unit conversion)
Lake Morphometry:		
Lake Area (ac)	11.50	
Lake Area (m^2)	46538.49	(unit conversion)
Lake Volume (af)	79.20	
Lake Volume (m^3)	97691.77	(unit conversion)
V (hm^3)	**0.10**	(unit conversion)
Mean depth (m)	2.10	
T (yrs)	**0.28**	
Observed Water Quality:		
Phosphorus (mg/m^3)	48	
Internal Load:		
Load (kg/yr)	2.49	(added load until modeled load=observed load)
Loading rate (mg/m^2/day)	0.15	
Calculations:		
Wp (kg/yr)	**26.61**	
Pi (mg/m^3)	**76.43**	
P (mg/m^3)=Pi / (1 + K *0.114 ((Wp/V)^0.589)*T)	**47.99**	Matches observed phosphorus concentration

APPENDIX B.3

Schwanz Lake – Summary PONDNET Watershed Load Runs

Scenario: Average Year 2006
Water Yr. Precip: 25.29

PondNET Model

Subwatershed	Water Load	Monitored	TP Load
	in/out	[TP]	in/out
Hay Lake	237.26	0.030	19.11
Golden Meadow	13.77		14.27
Remaining subs	31.24		16.69
Subwatershed TOTAL	282.27		50.06

Monitored Values (June-September)

Schwanz Lake (2006)	Parameter	Value	
2006	TP (mg/l	0.048	
	Chlor a (ug/l)	39.243	
	S.D. (meters)	1.3	
Hay Lake	Parameter	Value	Source
2006	S.D. (meters)	1.9	CLMP

APPENDIX B.4

Schwanz Lake – Calibration of Chlorophyll-a Concentration Against 2008 Data

Calculated from P, Light, Flushing (BATHTUB Model #2)
Eq: B = K Bp / [(1 + b Bp G) (1 + Ga)] (From BATHTUB)
Where:
B= Chlorophyll a Concentration (mg/m3)
K=calibration factor=1
b=Algal Light Extinction Coef = Slope of 1/Secchi vs. Chl-a [default = 0.025 1/m]
Bp=P^1.37/4.88
P=total phosphorus concentration (mg/m3)
G = Zmix (0.19 + 0.0042 Fs)
Zmix=Mean Depth of Mixed Layer (m)
Fs=Summer Flushing Rate = (Inflow + Precip -Evaporation)/Volume (yr^{-1})
a=Non-Algal Turbidity (1/m) [minimum value = 0.08 1/m]
S=Secchi Depth (m)

Inputs:		
P (mg/m3)	48	2006 phosphorus conc.
Fs (yr^{-1})	3.56	1/residence time
Zmix (m)	2.00	
b (1/m)	**0.025**	default
a (1/m)	**0.08**	minimum
Observed:		
Chlorophyll-a (mg/m^3)	39.2	
Calculations:		
Bp (mg/m^3)	**41.20**	
G	**0.41**	
B (mg/m^3)= K Bp / [(1 + b Bp G) (1 + Ga)]	28.05	

APPENDIX B.5

Schwanz Lake – Calibration of Secchi Depth Against 2008 Data

vs. Chl a and Turbidity (BATHTUB Model #1)
Eq: S = K / (a + b B) (From BATHTUB)
Where:
S=Secchi Depth (m)
K=calibration factor=1
a=Non-Algal Turbidity (1/m) [minimum value = 0.08 1/m]
b=Algal Light Extinction Coef = Slope of 1/Secchi vs. Chl-a [default = 0.025 1/m]
B= Chlorophyll a Concentration (mg/m^3)

Inputs:

b (1/m)	**0.025**	default
a (1/m)	**0.08**	minimum
B (mg/m^3)	**28.05**	modeled 2006 concentration

Observed:

Secchi depth (m)	1.3

Calculations:

S (m) = K / (a + b B	**1.28**