Crystal, Keller, and Lee Lakes Nutrient Impairment Total Maximum Daily Load Report and Earley Lake Water Quality Assessment

Prepared for
Black Dog Watershed Management Organization and the Minnesota Pollution Control Agency

October 2011

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303(d) Listing Information	**Waterbody: Crystal Lake DNR ID 19-0027-00** Impaired Beneficial Use: Aquatic Recreation Impairment/TMDL Pollutant of Concern: Excess Nutrients (Phosphorus) as set forth in Minnesota Rules 7050.0150. 2008 Priority Ranking: 2006 Target Start, 2011 Target Completion Original Listing Year: 2002	1
	Waterbody: Keller Lake DNR ID 19-0025-00 Impaired Beneficial Use: Aquatic Recreation Impairment/TMDL Pollutant of Concern: Excess Nutrients (Phosphorus) as set forth in Minnesota Rules 7050.0150. 2008 Priority Ranking: 2004 Target Start, 2008 Target Completion Original Listing Year: 2002	1
	Waterbody: Lee Lake DNR ID 19-0029-00 Impaired Beneficial Use: Aquatic Recreation Impairment/TMDL Pollutant of Concern: Excess Nutrients (Phosphorus) as set forth in Minnesota Rules 7050.0150. 2008 Priority Ranking: 2006 Target Start, 2011 Target Completion Original Listing Year: 2002	1

EPA TMDL Summary Table		
EPA/MPCA Required Elements	**Summary**	**TMDL Page #**
	Waterbody: Earley Lake DNR ID 19-0033-00 Impaired Beneficial Use: Aquatic Recreation Impairment/TMDL Pollutant of Concern: Excess Nutrients (Phosphorus) as set forth in Minnesota Rules 7050.0150. 2008 Priority Ranking: MPCA is in the process of removing Earley Lake from the 2010 303(d) Impaired Waters List Original Listing Year: 2002	2
Applicable Water Quality Standards/Numeric Targets	**Waterbody: Crystal Lake** **MPCA Deep Lake Eutrophication Standards (North Central Hardwood Forest Ecoregion):** ≤ 40 μg/L Total Phosphorus ≤ 14 μg/L Chlorophyll *a* ≥ 1.4 m Secchi disc transparency Source: Minnesota Rule 7050.0222 Subp. 4. Class 2B Waters	14
	Waterbodies: Keller, Lee, and Earley Lakes **MPCA Shallow Lake Eutrophication Standards (North Central Hardwood Forest Ecoregion):** ≤ 60 μg/L Total Phosphorus ≤ 20 μg/L Chlorophyll *a* ≥ 1.0 m Secchi disc transparency Source: Minnesota Rule 7050.0222 Subp. 4. Class 2B Waters	14
Loading Capacity **(expressed as daily load)**	**Waterbody: Crystal Lake** Total Phosphorus Loading Capacity for critical condition 2.361 lbs/day Critical condition summary: MPCA's eutrophication standard is compared to the growing season (June through September) average. Daily loading capacity for critical condition is based on the total annual load.	65 and 71

EPA TMDL Summary Table		
EPA/MPCA Required Elements	**Summary**	**TMDL Page #**
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Wasteload Allocation (WLA)	**Waterbody: Crystal Lake** Burnsville (MS400076) = 0.183 lbs/day Lakeville (MS400099) = 0.630 lbs/day Dakota County (MS400132) = 0.022 lb/day MnDOT (MS400170) = 0.049 lb/day	66-68,71
	Waterbody: Keller Lake Apple Valley (MS400074) = 0.312 lbs/day Burnsville (MS400076) = 0.225 lbs/day Dakota County (MS400132) = 0.016 lb/day	74-76,78
	Waterbody: Lee Lake Lakeville (MS400099) = 0.101 lbs/day Dakota County (MS400132) = 0.005 lb/day MnDOT (MS400170) = 0.016 lb/day	81-83,85

EPA TMDL Summary Table		
EPA/MPCA Required Elements	**Summary**	**TMDL Page #**
Load Allocation (LA)	**Waterbody: Crystal Lake** Atmospheric Deposition = 0.186 lbs/day Keller Lake = 0.110 lbs/day Lee Lake = 0.005 lb/day Internal Load = 1.175 lb/day	68-71
	Waterbody: Keller Lake Atmospheric Deposition = 0.033 lbs/day Internal Load = 0.159 lb/day	76-78
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Margin of Safety	**Waterbody: Crystal, Keller, and Lee Lakes** The margin of safety for this TMDL is largely provided implicitly and explicitly through use of calibrated input parameters and conservative modeling assumptions in the development of allocations.	88
Seasonal Variation	**Waterbody: Crystal, Keller, and Lee Lakes** TP concentrations in each of the lakes can vary significantly during the growing season, typically peaking in late summer. The TMDL guideline for TP is defined as the growing season (June through September) mean concentration (MPCA, 2009). The critical period (growing season) was used to estimate the required reduction of watershed and internal sources of phosphorus so that the predicted growing season average met the MPCA lake standard.	88-89

EPA TMDL Summary Table		
EPA/MPCA Required Elements	**Summary**	**TMDL Page #**
Reasonable Assurance	**Waterbody: Crystal, Keller, and Lee Lakes** The overall implementation strategies (Section 7.0) are multifaceted, with various projects put into place over the course of many years, allowing for monitoring and reflection on project successes and the chance to change course if progress is exceeding expectations or is unsatisfactory. Additionally, the BDWMO and member cities currently have water management plans in place that direct water management and includes runoff water quality and quantity standards. Also, each MS4 is currently permitted and has developed and implements the required Stormwater Pollution Prevention Programs (SWPPP).	89-91
Monitoring	The monitoring plan to track TMDL effectiveness is described in Section 6.0 of this TMDL report.	92-93
Implementation	1. The implementation strategy to achieve the load reductions described in this TMDL is summarized in Section 7.0 of this TMDL report. 2. A cost estimate of all of the activities involved in implementing this TMDL is described in Section 7.0 of this report.	94-103
Public Participation	A public meeting was held on February 10, 2010 at Burnsville's City Hall. To date, nine technical and stakeholder meetings have been conducted since the start of this TMDL study, which included BDWMO staff and representatives from the various MS4 permittees that are responsible for loads within the Crystal, Keller, and Lee Lake watersheds. Other technical agencies were also involved including representatives from the MPCA, Metropolitan Council, and the Minnesota DNR. The Public Comment period for this TMDL was from March 14, 2011 – April 13, 2011. Fourteen comments were received on the Draft TMDL Report.	104-105

Executive Summary

The federal Clean Water Act requires states to adopt water quality standards to protect waters from pollution. The Minnesota Pollution Control Agency (MPCA) has developed water quality standards, and these standards are outlined in Minnesota Rules, Chapter 7050 (Standards for the Protection of Waters of the State). When water bodies fail to meet the standards established by the MPCA, they become listed on the 303(d) Impaired Waters List, requiring the completion of a Total Maximum Daily Load (TMDL) study that establishes the pollutant reduction goal needed to restore waters.

The MPCA's projected schedule for TMDL report completions, as indicated on Minnesota's 2008 303(d) Impaired Waters List, implicitly reflects Minnesota's priority ranking of this TMDL. The TMDL for Crystal and Lee Lakes was scheduled to begin in 2006 and be completed in 2011. The TMDL for Keller Lake was scheduled to begin in 2004 and be completed in 2008. And the TMDL for Earley Lake was scheduled to begin in 2007 and be completed in 2011. Ranking criteria for scheduling TMDL projects include, but are not limited to:

- Impairment impacts on public health and aquatic life;
- Public value of the impaired water resource;
- Likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody;
- Technical capability and willingness locally to assist with the TMDL; and
- Appropriate sequencing of TMDLs within a watershed or basin.

Crystal Lake

Crystal Lake is currently listed on the Minnesota Pollution Control Agency's (MPCA) Draft 2010 303(d) Impaired Waters List due to excess nutrients (phosphorus). Crystal Lake is a 292-acre lake located in the cities of Burnsville and Lakeville in Dakota County, MN. Overall, the lake has 5.3 miles of shoreline, a mean depth of 10 feet, and a maximum depth of 35 feet. The lake is a major recreational resource for the area. The Crystal Lake watershed consists of 3667 acres (including the lake surface area) and is almost fully developed. Several other lakes are also located within the Crystal Lake watershed, including Keller Lake, and Lee Lake; however, the Lee Lake watershed often acts as a landlocked portion of the Crystal Lake watershed.

By MPCA definition, Crystal Lake is considered to be a deep lake (a maximum depth of greater than 15 feet). Crystal Lake is a dimictic lake; it mixes two times each year (during the spring and fall turnover events), with the lake thermally stratifying throughout the growing season. Crystal Lake is located in the North Central Hardwood Forests (NCHF) ecoregion. The lake's historical growing season water quality (10-year average) compared to the MPCA's deep lake eutrophication standards for this ecoregion are shown in Table EX-1 below.

Table EX-1 Crystal, Keller, Lee, and Early Lakes' 10-Year Average Water Quality Parameters

Water Quality Parameter	MPCA Lake Eutrophication Standards (NCHF)	10-Year (1999-2008) Growing Season Average
Crystal Lake		
Total Phosphorus (µg/L)	≤ 40	41.8
Chlorophyll *a* (µg/L)	≤ 14	24.5
Secchi disc (m)	≥ 1.4	1.7
Keller Lake		
Total Phosphorus (µg/L)	≤ 60	83.9
Chlorophyll a (µg/L)	≤ 20	28.5
Secchi disc (m)	≥ 1.0	1.2
Lee Lake		
Total Phosphorus (µg/L)	≤ 60	66.4
Chlorophyll a (µg/L)	≤ 20	24.3
Secchi disc (m)	≥ 1.0	1.3
Earley Lake		
Total Phosphorus (µg/L)	≤ 60	51.4
Chlorophyll a (µg/L)	≤ 20	12.7
Secchi disc (m)	≥ 1.0	1.5

The TMDL equation is defined as follows:

TMDL = Wasteload Allocation (WLA) + Load Allocation (LA) + Margin of Safety (MOS) + Reserve Capacity.

For Crystal Lake, the Load Capacity is 862 pounds (lbs) of total phosphorus (TP) annually.

The TMDL equation used to distribute this Load Capacity for Crystal Lake is:

Expressed as annual (October through September) totals:

TMDL = 323 lbs TP (WLA) + 539 lbs TP (LA) + 0 lbs TP (MOS) + 0 lbs (Reserve Capacity)

= 862 lbs per year

Expressed in daily terms (annual load/365)

TMDL = 0.884 lbs (WLA) + 1.476 lbs (LA) + 0 lbs (MOS) + 0 lbs (Reserve Capacity)

= 2.361 lbs per day

The margin of safety for this TMDL is largely provided implicitly and explicitly through use of calibrated input parameters and conservative modeling assumptions in the development of allocations (e.g. estimating the Load Capacity to achieve a growing season mean TP concentration 10 percent better than the MPCA goal).

The Wasteload Allocation (WLA) represents a 4% reduction in the external load from the tributary area to Crystal Lake.

The Load Allocation (LA) represents a 41% total phosphorus reduction.

Keller Lake

Keller Lake is currently listed on the MPCA Draft 2010 303(d) Impaired Waters List due to excess nutrients (phosphorus). Keller Lake is a 52-acre lake (at normal water level) located in the cities of Burnsville and Apple Valley in Dakota County, MN. Keller Lake has an average depth of 4.8 feet and a maximum depth of about 8 feet. By MPCA definition, Keller Lake is considered a shallow lake (a maximum depth of 15 feet or less or with at least 80 percent of the lake shallow enough to support emergent and submerged rooted aquatic plants (littoral)). The lake is used primarily for fishing, canoeing, and wildlife viewing by the local residents. There is a park on Keller Lake but no beach or public access. The Keller Lake watershed is 1447 acres (including the lake surface area), is fully-developed, and is part of the larger Crystal Lake watershed with Keller Lake discharging into the northeast side of Crystal Lake.

Because the lake is so shallow, aquatic plants can grow over the entire lake bed and a summer thermocline is not usually present. The lake may also be subject to intermittent wind mixing, meaning the lake is polymictic (mixes several times per year). Keller Lake is located in the NCHF ecoregion. The lake’s historical growing season water quality (10-year average) compared to the MPCA’s shallow lake eutrophication standards for this ecoregion are shown in Table EX-1.

The TMDL equation is defined as follows:

TMDL = Wasteload Allocation (WLA) + Load Allocation (LA) + Margin of Safety (MOS) + Reserve Capacity.

For Keller Lake, the Load Capacity is 272 pounds (lbs) of total phosphorus (TP) annually.

The TMDL equation used to distribute this Load Capacity for Keller Lake is:

Expressed as annual (October through September) totals:

TMDL = 202 lbs TP (WLA) + 70 lbs TP (LA) + 0 lbs TP (MOS) + 0 lbs (Reserve Capacity)

= 272 lbs per year

Expressed in daily terms (annual load/365)

TMDL = 0.553 lbs (WLA) + 0.192 lbs (LA) + 0 lbs (MOS) + 0 lbs (Reserve Capacity)

= 0.745 lbs per day

The margin of safety for this TMDL is largely provided implicitly and explicitly through use of calibrated input parameters and conservative modeling assumptions in the development of allocations (e.g. estimating the Load Capacity to achieve a growing season mean TP concentration 10 percent better than the MPCA goal).

The Wasteload Allocation (WLA) represents a 52% reduction in the external load from the tributary area to Keller Lake.

The Load Allocation (LA) represents a 77% total phosphorus reduction.

Lee Lake

Lee Lake is currently listed on the Minnesota MPCA Draft 2010 303(d) Impaired Waters List due to excess nutrients (phosphorus). Lee Lake is an 18.6-acre water body located entirely within the City of Lakeville in Dakota County, MN. The average depth of the lake is 7 feet and the maximum depth is about 15 feet (from the average water level). Because the entire lake is less than 15 ft deep, the lake is 100 percent littoral area. The lake has no public swimming beaches or public access.

The Lee Lake watershed is fully-developed and the 206 acres (including the lake surface area) is part of the larger Crystal Lake watershed. However Lee Lake often acts as a landlocked basin, only discharging during high water levels,

By MPCA definition, Lee Lake is considered a shallow lake. Lee Lake is a dimictic lake; it mixes two times each year (during the spring and fall turnover events). The lake thermally stratifies throughout the growing season. Lee Lake is located in the NCHF ecoregion. The lake's historical growing season water quality (10-year average) compared to the MPCA's shallow lake eutrophication standards for this ecoregion are shown in Table EX-1. Since the start of this TMDL study, two additional years of water quality monitoring data have been collected for Lee Lake (2009 and 2010), and based on this more recent data, the City of Lakeville is considering pursuing the delisting of Lee Lake from the 303(d) Impaired Waters List.

The TMDL equation is defined as follows:

TMDL = Wasteload Allocation (WLA) + Load Allocation (LA) + Margin of Safety (MOS) + Reserve Capacity.

For Lee Lake, the Load Capacity is 84 pounds (lbs) of total phosphorus (TP) annually.

The TMDL equation used to distribute this Load Capacity for Lee Lake is:

<u>Expressed as annual (October through September) totals:</u>

TMDL = 45 lbs TP (WLA) + 39 lbs TP (LA) + 0 lbs TP (MOS) + 0 lbs (Reserve Capacity)
= 84 lbs per year

<u>Expressed in daily terms (annual load/365)</u>

TMDL = 0.122 lbs (WLA) + 0.107 lbs (LA) + 0 lbs (MOS) + 0 lbs (Reserve Capacity)
= 0.229 lbs per day

The margin of safety for this TMDL is largely provided implicitly and explicitly through use of calibrated input parameters and conservative modeling assumptions in the development of allocations ((e.g. estimating the Load Capacity to achieve a growing season mean TP concentration 10 percent better than the MPCA goal).

The Wasteload Allocation (WLA) represents a 31% reduction in the external load from the tributary area to Lee Lake.

The Load Allocation (LA) represents a 51% total phosphorus reduction.

Earley Lake

The MPCA is currently in the process of removing Earley Lake from the 303(d) Impaired Waters List. Originally the lake was listed due to excess nutrients (phosphorus). Earley Lake (DNR ID: 19-0033-00) is a 23-acre water body located entirely within the City of Burnsville in Dakota County, MN. The average depth of the lake is 3.8 feet and the maximum depth is about 7.8 feet. The lake has no public swimming beaches or public access, and is used primarily for aesthetic viewing and wildlife observation.

The Earley Lake watershed is 757 acres (including the lake surface area) and is almost fully developed. It also receives flows from Twin Lake located upstream (total watershed area including the Twin Lake subwatershed is 1367 acres).

By MPCA definition, Earley Lake is considered a shallow lake. Earley Lake is polymictic lake, mixing several times each year. Earley Lake is located in the NCHF ecoregion. The lake's historical growing season water quality (10-year average) compared to the MPCA's shallow lake eutrophication standards for this ecoregion are shown in Table EX-1. Because Early Lake is meeting the MPCA shallow lake standard for all three water quality parameters, the MPCA is removing it from the 303(d) Impaired Waters List and it was not modeled or assigned phosphorus load allocations as part of this TMDL study.

1.0 Introduction

The Black Dog Watershed Management Organization (BDWMO) is located in northwestern Dakota County and a portion of northeastern Scott County, covering an area of 16,600 acres (25.9 square miles). The Crystal, Keller, Lee, and Earley Lakes' watersheds are located within the Dakota County portion of the BDWMO, within the cities of Apple Valley, Burnsville, and Lakeville (see Figure 1-1). This watershed is part of the larger Minnesota River Basin which ultimately drains to the Mississippi River. Crystal Lake (DNR ID: 19-0027-00) is primarily located within the City of Burnsville with a small, southern portion in the City of Lakeville. Keller Lake (DNR ID: 19-0025-00) is located within the Crystal Lake watershed, and is in the City of Burnsville with a small, eastern portion of the lake within the City of Apple Valley. Lee Lake (DNR ID: 19-0029-00) is also within the Crystal Lake watershed, and the lake is located entirely within the City of Lakeville. Earley Lake (DNR ID: 19-0033-00) is located downstream and northwest of the Crystal Lake watershed, and the lake is located entirely within the City of Burnsville.

The BDWMO's goals are outlined in the 2002 *Watershed Management Plan (*Barr, 2002). In general, the goals of the BDWMO are to keep regulation at the local level, assist and mediate issues regarding intercommunity flows, monitor strategic water bodies within the watershed, develop policies to be implemented by member cities to protect water resources, and to educate both member cities as well as watershed citizens about water resource issues.

Crystal, Keller, and Lee Lakes are listed on the Minnesota Pollution Control Agency's (MPCA) 2008 303(d) Impaired Waters List due to excess nutrients (phosphorus) which requires the development of a Total Maximum Daily Load (TMDL) report. All of these lakes were first listed on the MPCA's 303(d) list in 2002. The anticipated Nutrient TMDL start and completion dates, according to the 2008 303(d) list, for Crystal, Keller, and Lee Lakes are summarized in Table 1-1. Additionally, since the start of this TMDL study, two additional years of water quality monitoring data have been collected for Lee Lake (2009 and 2010), and based on this more recent data, the City of Lakeville is considering pursuing the delisting of Lee Lake from the 303(d) Impaired Waters List. Crystal Lake was also listed on the MPCA's 303(d) list for Mercury in 1998. However, this impairment was addressed as part of the statewide mercury TMDL study.

Table 1-1 Crystal, Keller, and Lee Lakes' Target Nutrient TMDL Start and Completion Dates, according to the 2008 303(d) List

Lake	Target Start Date	Target Completion Date
Crystal Lake	2006	2011
Keller Lake	2004	2008
Lee Lake	2006	2011

Earley Lake was listed on the MPCA's 2008 303(d) Impaired Waters List due to excess nutrients (phosphorus) and required a TMDL report. The lake was first listed on the MPCA's 303(d) list in 2002, prior to the MPCA establishing water quality standards specifically for shallow lakes. However, based on the most recent 10-years of water quality data, Earley Lake has met the MPCA's shallow lake standards, and the MPCA is in the process of removing Earley Lake from the 303(d) Impaired Waters list. As a result, Earley Lake was not modeled or assigned phosphorus load allocations as part of this TMDL study.

The MPCA's projected schedule for TMDL completions, as indicated on Minnesota's 303(d) Impaired Waters List, implicitly reflects Minnesota's priority ranking of this TMDL. Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

From 2001 through 2003, the BDWMO completed a study that resulted in the development of a Use Attainability Analysis (UAA)[1] for Crystal and Keller Lakes and their watersheds entitled *Crystal and Keller Lake Use Attainability Analysis Diagnostic-Feasibility Study: Water Quality Issues and Potential Restorative Measures* (Barr, 2003). Additionally, in 2007, the City of Burnsville completed a study that resulted in the development of a UAA for Twin and Earley Lakes entitled *Twin and Earley Lake Use Attainability Analysis Diagnostic-Feasibility Study: Water Quality Issues and Potential Restorative Measures* (Barr, 2007).

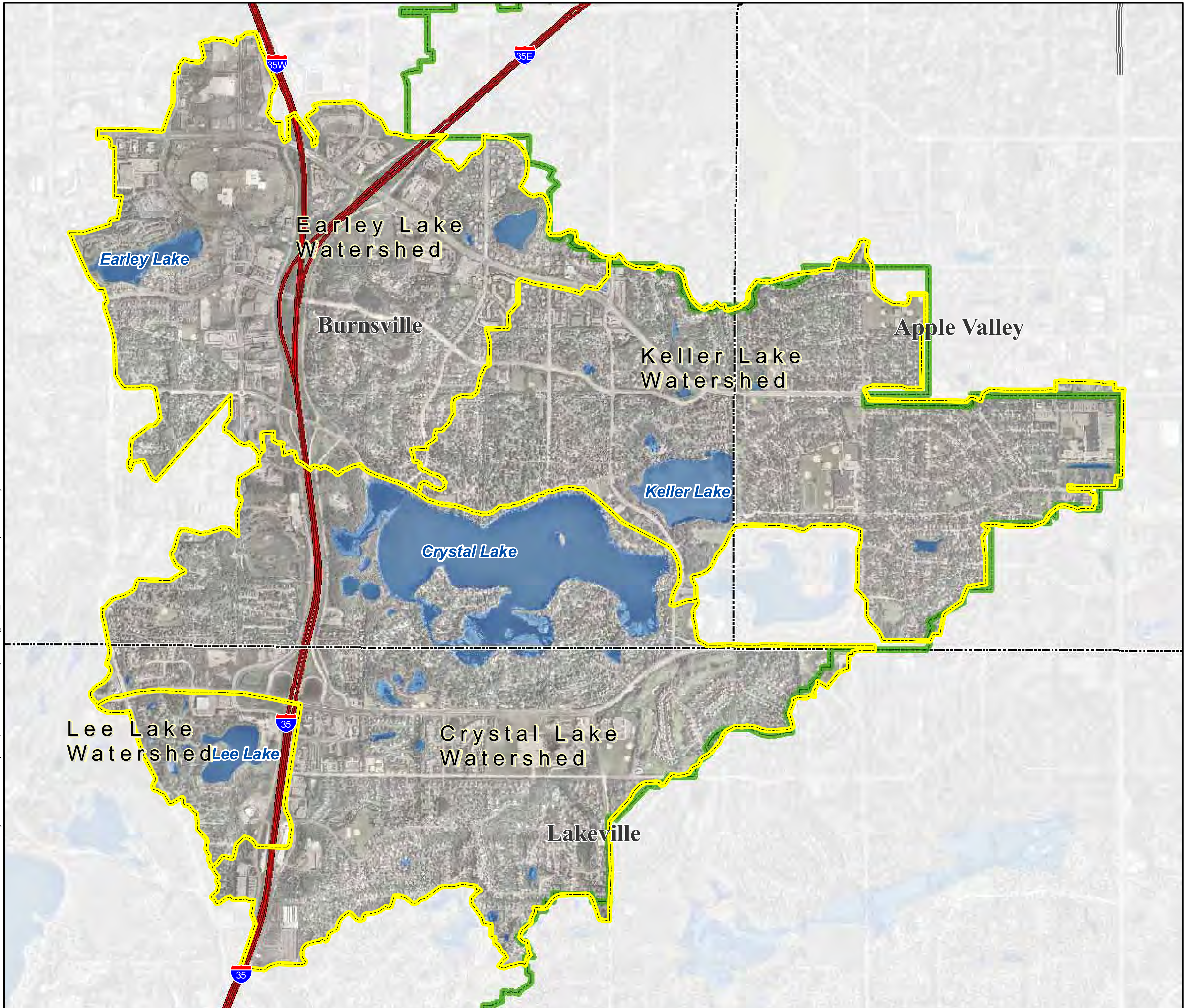
The purpose of the UAAs were to perform a scientific assessment of a water body's physical, chemical, and biological conditions and address current water quality issues. The 2003 UAA

[1] For purposes of this report the term Use Attainability Analysis (UAA) means a scientific assessment similar to a diagnostic-feasibility study and not the more formal EPA report.

includes a water quality analysis and prescription of protective measures for Crystal and Keller Lakes and their contributing watersheds, based on historical water quality data, intensive lake water quality monitoring, as well as predictive computer modeling scenarios to evaluate impacts on overall lake water quality. The study helped establish priorities and recommended best management practices (BMPs) to meet the water quality goals set for the Crystal and Keller Lakes. Similarly, the 2007 UAA for Twin and Earley Lakes performed an assessment of the water quality in Twin and Earley Lakes and helped establish priorities and guidelines to improve water quality in these lakes.

As a part of the 2003 UAA developed for Crystal and Keller Lakes, as well as the 2007 UAA for Earley and Twin Lakes, an inventory was completed of all ponds and wetlands throughout the watershed tributary to the lakes to assess the available storage volumes, overflow elevations, and inlet and outlet pipelines and channels. In addition, the study evaluated the existing and future land uses throughout the tributary watershed. All of this information was used to create water quality models for the lakes and their watersheds. The results of the modeling were used to identify watershed BMPs and in-lake management practices that would help achieve the water quality goals for each lake. Costs were estimated for various management practices and recommendations were made for the most cost-effective improvements and practices.

Because the MPCA is in the process of removing Earley Lake from the 303(d) Impaired Waters List, the focus of this TMDL study will be on Crystal, Keller, and Lee Lakes. For this TMDL study, the watershed pollutant loading model developed for the 2003 UAA was updated to incorporate any changes to the watershed (development, maintenance, changes to existing ponds, and construction of new water quality treatment systems, etc.) since 2002. A water quality assessment was done for the data available for Earley Lake.



Crystal, Keller, Lee, and Earley Lakes TMDL Watersheds

Black Dog WMO Boundary

Municipal Boundary

N

Feet

0 1,000 2,000 4,000

Figure 1-1
Site Location Map

Crystal, Keller, and Lee Lakes
Nutrient Impairment TMDL and Earley Lake
Water Quality Assessment Report
BDWMO & MPCA

2.0 Description of the Water Body, Pollutant of Concern and Pollutant Sources

2.1 Overview of Crystal, Keller, Lee, and Earley Lakes and their Watersheds

2.1.1 Crystal Lake

Crystal Lake (DNR ID: 19-0027-00) is a 292-acre lake located in the cities of Burnsville and Lakeville in Dakota County, MN. The lake is a major recreational resource for the area. A public beach and public boat landing provide opportunities for swimming, fishing, water skiing and aesthetic viewing.

Crystal Lake consists of five basins: Bluebill Bay, Mystic Bay, Maple Island Bay, Buckhill Bay, and the main lake basin. The lake outlet is located at the northwest end of the lake in Buckhill Bay, and consists of a box weir with an overflow elevation of 933.5 feet NGVD29. Overall, the lake has 5.3 miles of shoreline, a mean depth of 10 feet, and a maximum depth of 35 feet. The area of the lake shallow enough for aquatic plants to grow (the littoral zone) is approximately 208 acres. By MPCA definition, Crystal Lake is considered to be a deep lake (a maximum depth of greater than 15 feet). Crystal Lake is dimictic lake; it mixes two times each year (during the spring and fall turnover events). The lake thermally stratifies throughout the growing season. Figure 2-1 shows the bathymetry of Crystal Lake.

The Crystal Lake total watershed consists of 3667 acres (including the lake surface area). Several other lakes are also located within the Crystal Lake watershed, including Keller Lake and Lee Lake. Lee Lake does have an outlet structure; however, lake levels rarely reach the outlet elevation except during flood conditions. Therefore, the Lee Lake watershed often acts as a landlocked portion of the Crystal Lake watershed. The lake's tributary watershed area (minus the Lee Lake watershed area) in comparison to the lake's surface area is approximately 12:1.

The Crystal Lake watershed (including both the Keller and Lee Lake watersheds) is almost fully-developed, with only a few small parcels available for new development. Low density residential land use is the major land use (41%), followed by highway (20%) and open water (11%). Other land uses include: medium density residential (4%), natural, park, and open space (6%), commercial (7%), developed parks (0.5%), golf course (2%), high density residential (2%), institutional (6%), and industrial/office (0.5%). Figure 2-2 shows the land use of the Crystal Lake watershed. The portion of the subwatershed located in Lakeville has developed since the completion of UAA[1], with the most intense development occurring along I-35, where the undeveloped land was converted to commercial use. For the commercial area of Lakeville within the Crystal Lake Subwatershed, the city restricts the maximum amount of impervious cover to 70% for new development sites.

As previously mentioned, the Crystal Lake watershed is entirely within the Cities of Burnsville and Lakeville. The City of Burnsville Comprehensive Plan (2008 (draft)) expects the current population of Burnsville (61,400) to increase by 6 percent in the next 20 years. Additionally, the City of Lakeville Comprehensive Plan (2008) expects the current population of Lakeville (59,500) to increase by 50 percent in the next 20 years. However, because the Crystal Lake watershed is almost fully-developed, the expected growth in the Cities of Burnsville and Lakeville will likely not be occurring within the Crystal Lake watershed.

The Crystal Lake watershed was divided into three drainage districts and numerous smaller subwatershed areas to facilitate hydrologic and phosphorus modeling. The drainage districts are defined based on the receiving waterbody: Crystal Lake, Keller Lake, and Lee Lake. Figure 2-3 shows the drainage districts in the Crystal Lake watershed as well as the drainage area for Earley Lake. Each district is described below:

- **Crystal Lake Drainage District—** The Crystal Lake drainage district does not include the Keller Lake and Lee Lake watersheds, as the loads from these watersheds will be addressed in separate TMDL phosphorus allocations. This 2013-acre drainage district (including the Crystal Lake basin water surface area) includes the area directly tributary to Crystal Lake. Discharges to Crystal Lake enter the lake at various points around the lake including the several bays (Mystic Bay, Bluebill Bay, Maple Island Bay, Buckhill Bay) on the lake as well as the main Crystal Lake Basin.

- **Keller Lake Drainage District—**The Keller Lake drainage district is 1447-acres (including the Keller Lake basin water surface area) and represents roughly 40 percent of the Crystal Lake watershed. Runoff from this district enters Keller Lake prior to being conveyed to the northeast corner of Crystal Lake through a 72-inch RCP arch pipe. Roughly 44 percent of this drainage district is within the City of Burnsville while the remaining area (56 percent) is within the City of Apple Valley. Because of the timing of their development, the Cities of Burnsville and Apple Valley were allowed to use Keller Lake for stormwater detention and water quality treatment. As a result, runoff from roughly 46 percent of this drainage district enters Keller Lake without first passing through some form of water quality treatment. See Section 2.1.2 for more information about Keller Lake and its watershed.

- **Lee Lake Drainage District—** The Lee Lake drainage district is 206-acres (including the Lee Lake surface area) and represents about 5 percent of the overall Crystal Lake watershed. Although there is a stoplog weir followed by a 36 inch gated outlet structure, lake levels in Lee Lake rarely reach the outlet elevation. Therefore the lake typically acts as a landlocked area within the Crystal Lake watershed. This district is entirely within the City of Lakeville. If Lee Lake would discharge, it would discharge to Mystic Bay on the south side of Crystal Lake. See Section 2.1.3 for more information about Lee Lake and its watershed.

2.1.2 Keller Lake

Keller Lake (DNR ID: 19-0025-00) is a 52-acre lake (at normal water level) located in the cities of Burnsville and Apple Valley in Dakota County, MN. The lake is used primarily for fishing, canoeing, and wildlife viewing by the local residents. There is a park on Keller Lake but no beach or public access.

Keller Lake currently discharges to the northeast side of Crystal Lake over a weir structure, at an elevation of 934.3 feet NGVD29, through a 72-inch RCP arch. Keller Lake has an average depth of 4.8 feet and a maximum depth of about 8 feet. By MPCA definition, Keller Lake is considered a shallow lake (a maximum depth of 15 feet or less or with at least 80 percent of the lake shallow enough to support emergent and submerged rooted aquatic plants (littoral area)). Because the lake is so shallow, aquatic plants can grow over the entire lake bed and a summer thermocline is not usually present. The lake may also be subject to intermittent wind mixing, meaning the lake is polymictic (mixes several times per year). Figure 2-1 shows the bathymetry of Keller Lake.

The Keller Lake watershed is 1447 acres (including the lake surface area). Roughly 44 percent of this drainage district is within the City of Burnsville while the remaining area (56 percent) is within the City of Apple Valley. Because of the timing of their development, the Cities of Burnsville and Apple Valley were allowed to use Keller Lake for stormwater detention and water quality treatment. As a result, runoff from roughly 46 percent of this drainage district enters Keller Lake without first passing through some form of water quality treatment. The lake's existing tributary watershed area in comparison to the lake's surface area is approximately 31:1, as the result of the current storm sewer configuration in the watershed.

The Keller Lake watershed is fully-developed. Low density residential land use is the major land use (52.6%), followed by highway (20.5%) and natural, park, and open space (8%). Other land uses include: medium density residential (1.8%), open water (5%), commercial (3.6%), developed parks (0.5%), high density residential (1.5%), and institutional (6.5%). Figure 2-2 shows the land use of the Keller Lake watershed. As previously mentioned, the Keller Lake watershed is fully-developed, the expected growth in the Cities of Burnsville and Apple Valley will likely not be occurring within the Keller Lake watershed.

2.1.3 Lee Lake

Lee Lake (DNR ID: 19-0029-00) is an 18.6-acre water body (at water elevation 946.1 feet NGVD29 (Lakeville, 2008)) located entirely within the City of Lakeville in Dakota County, MN. The lake has no public swimming beaches or public access. The lake is surrounded by privately owned property.

The Lee Lake outlet is located on the east side of the lake and is a stop log weir (at elevation 948.5 feet NGVD29) followed by a 36 inch gated structure (at an elevation of 947 feet NGVD29). The outlet was installed in 1993 to alleviate high flood levels. Water level monitoring shows that the lake levels are typically a foot to several feet below the installed outlet (948.5 feet NGVD29), with an average water level at 946.7 feet NGVD29 (based on available lake level data). The average depth of the lake is 7 feet and the maximum depth is about 15 feet (from the average water level). Because the maximum depth of Lee Lake is 15 feet, the entire lake is considered littoral area. As a result, by MPCA definition, Lee Lake is a shallow lake. Lee Lake is dimictic lake; it mixes two times each year (during the spring and fall turnover events). The lake thermally stratifies throughout the growing season. Figure 2-1 shows the bathymetry of Lee Lake.

The Lee Lake watershed is 206 acres (including the lake surface area). This entire drainage district is located within the City of Lakeville. The lake's tributary watershed area in comparison to the lake's surface area is approximately 10:1.

The Lee Lake watershed is nearly fully-developed. Low density residential land use is the major land use (38%), followed by highway (29%) and open water (12%). Other land uses include: natural, park, and open space (1%), commercial (11%), and institutional (9%). Figure 2-2 shows the land use of the Lee Lake watershed.

2.1.4 Earley Lake

Earley Lake (DNR ID: 19-0033-00) is a 23-acre water body located entirely within the City of Burnsville in Dakota County, MN. The lake has no public swimming beaches or public access, and is used primarily for aesthetic viewing and wildlife observation.

The Earley Lake outlet is located on the southwest side of the lake and is a 12-foot, three-sided box weir (at an elevation of 905.0 feet NGVD29) followed by a 36 inch RCP pipe. The average depth of the lake is 3.8 feet and the maximum depth is about 7.8 feet. By MPCA definition, Earley Lake is considered a shallow lake. Earley Lake is polymictic lake, mixing several times each year. Figure 2-1 shows the bathymetry of Earley Lake.

The Earley Lake watershed is 757 acres (including the lake surface area) and it also receives flows from Twin Lake located upstream (total watershed area including the Twin Lake subwatershed is 1367 acres). Modifications were made to the storm sewer system in 2002 to divert some of the stormwater runoff around Earley Lake to alleviate flooding issues. The entire drainage district is located within the City of Burnsville. The lake's direct tributary watershed area in comparison to the lake's surface area is approximately 33:1. Figure 2-3 includes the Earley Lake drainage area. Flows to Earley Lake ultimately include discharges from Crystal, Keller, Twin and Lee Lakes.

The Earley Lake watershed is fully-developed. Commercial land use is the major land use (37%), followed by highway and right-of-way (23%) and low density residential (14%). Other land uses include: natural, park, and open space (3%), open water (4%), industrial/office (0.8%), golf course (0.5%), institutional (0.7%), very low density residential (1%), medium density residential (4%), and high density residential (12%). Figure 2-2 shows the land use of the Earley Lake watershed.

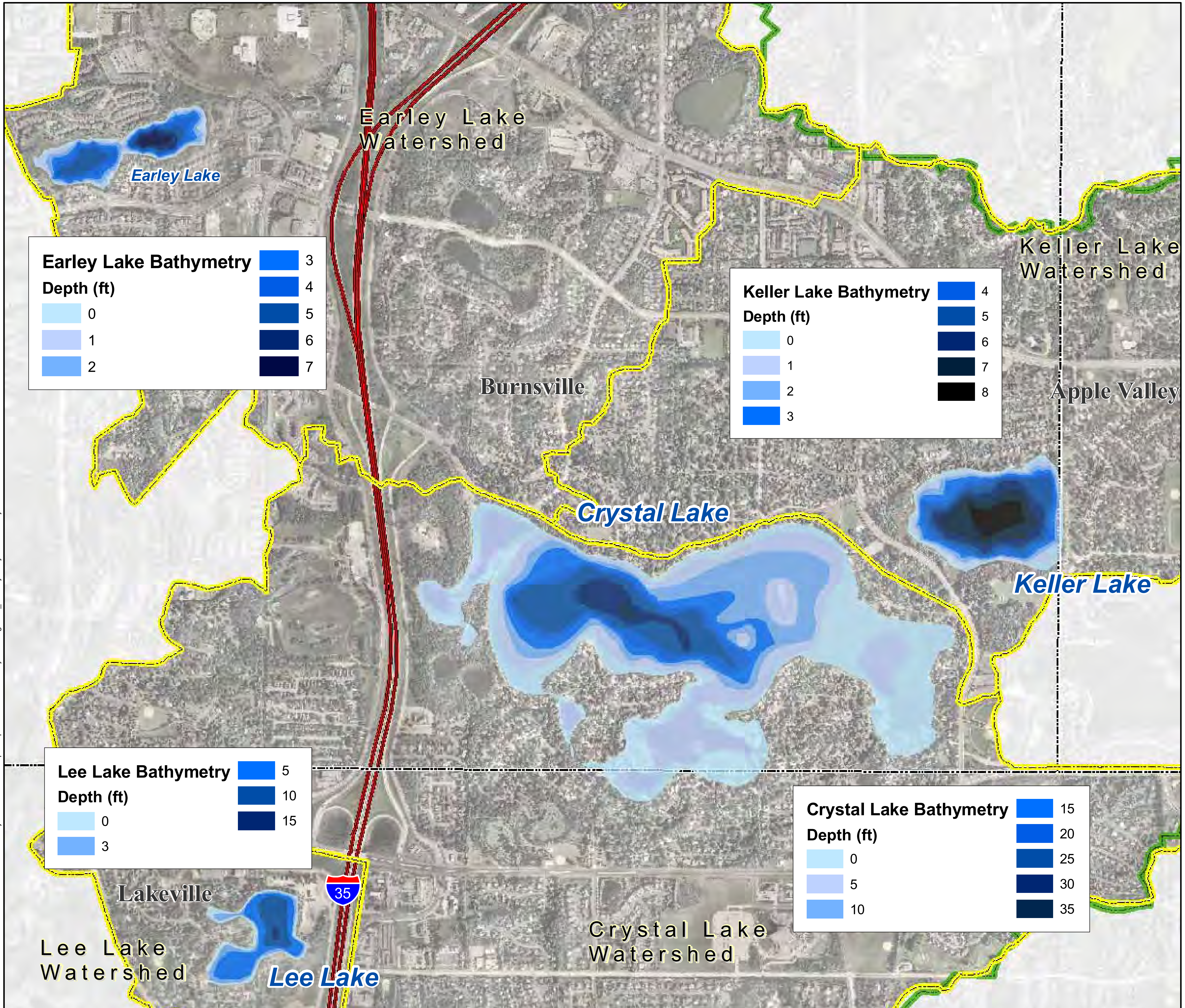


Figure 2-1
Crystal, Keller, Lee, and Earley Lakes'
Bathymetry

Crystal, Keller, and Lee Lakes
Nutrient Impairment TMDL and Earley Lake
Water Quality Assessment Report
BDWMO & MPCA

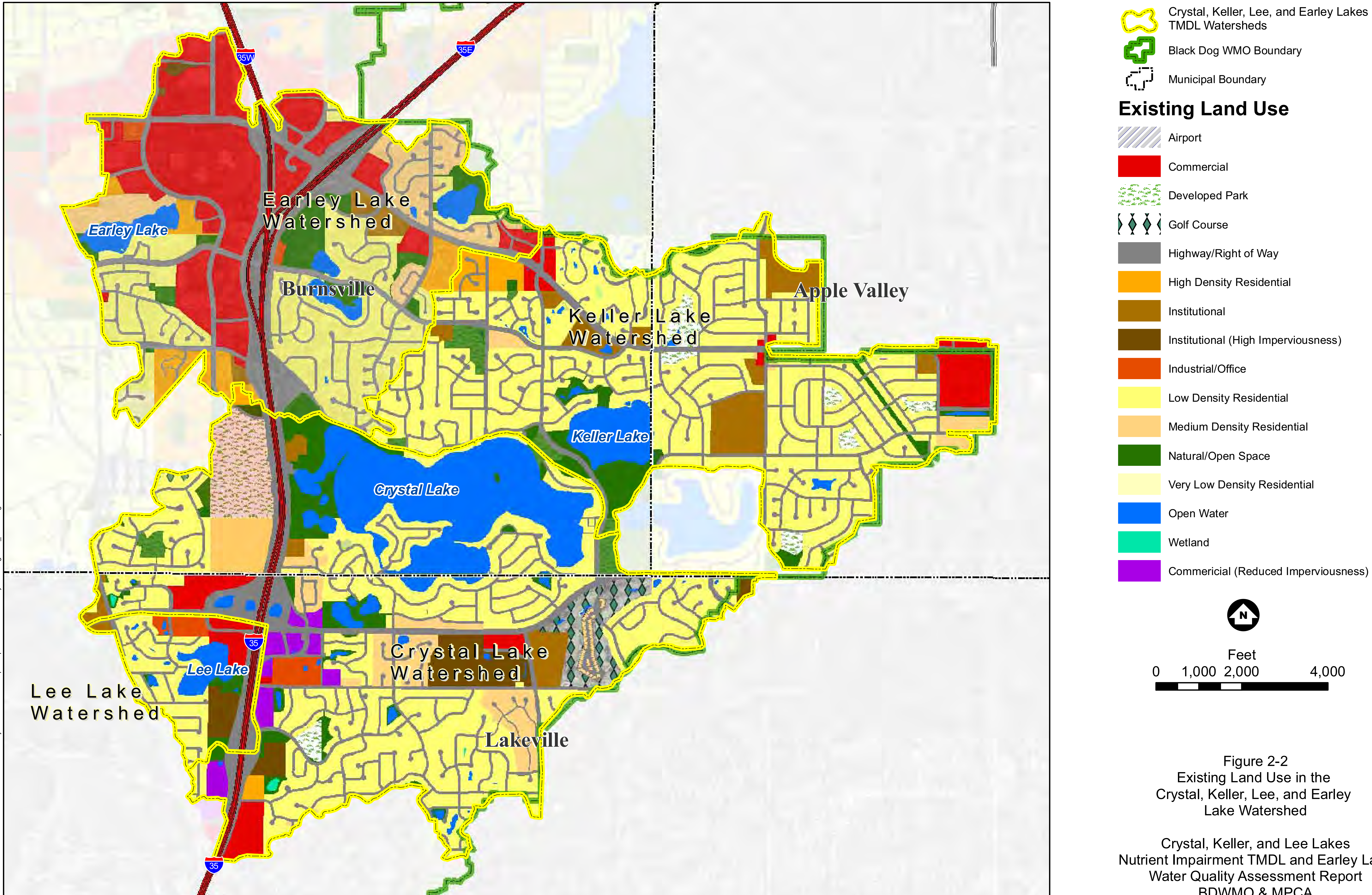
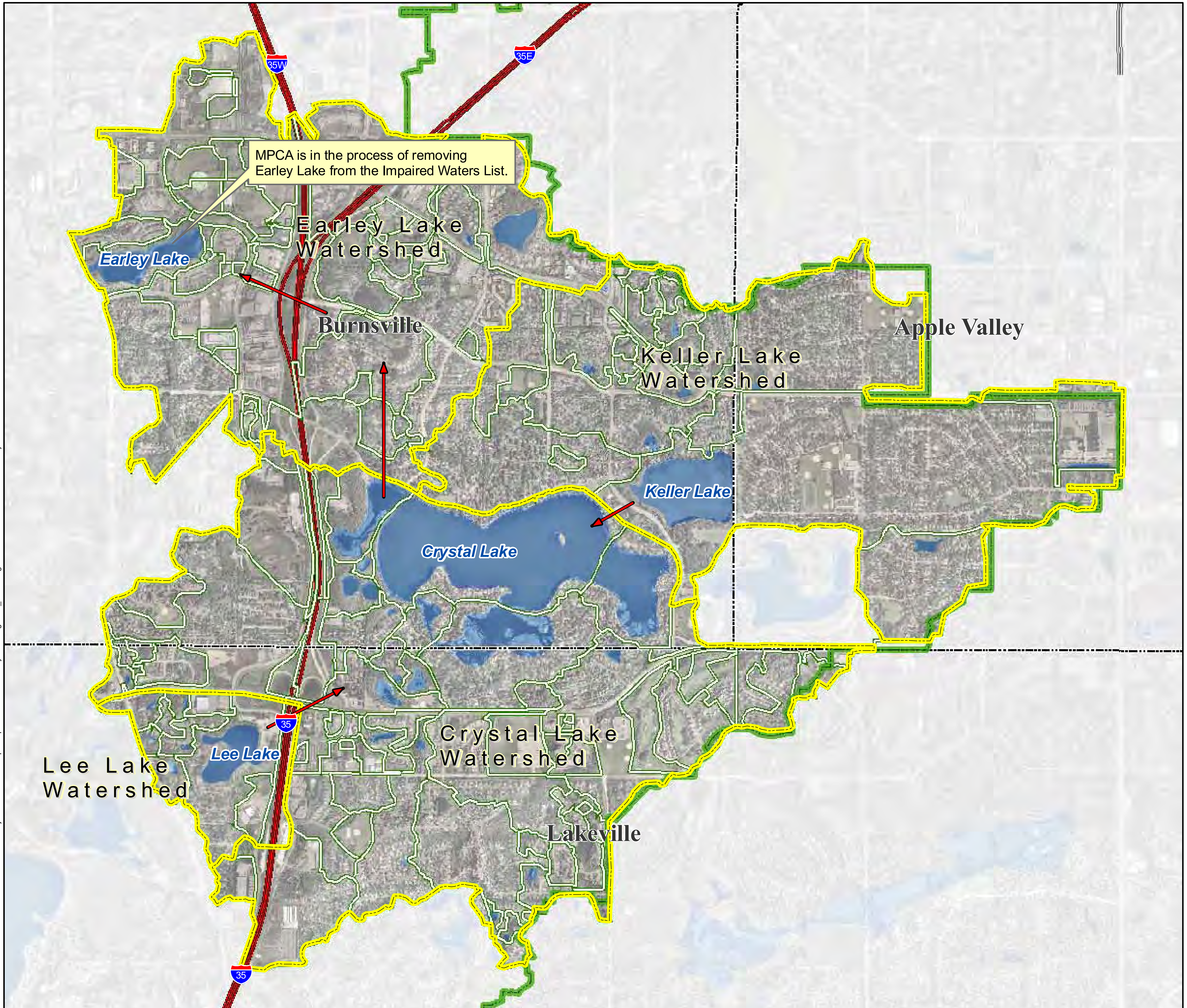


Figure 2-2
Existing Land Use in the
Crystal, Keller, Lee, and Earley
Lake Watershed

Crystal, Keller, and Lee Lakes
Nutrient Impairment TMDL and Earley Lake
Water Quality Assessment Report
BDWMO & MPCA



Flow Arrows

Crystal, Keller, Lee, and Earley Lakes TMDL Watersheds

Black Dog WMO Boundary

Subwatersheds

Municipal Boundary

N

Feet

0 1,000 2,000 4,000

Figure 2-3
Drainage Areas and Drainage Patterns for Crystal, Keller, Lee, and Earley Lakes

Crystal, Keller, and Lee Lakes
Nutrient Impairment TMDL and Earley Lake
Water Quality Assessment Report
BDWMO & MPCA

2.2 Pollutant of Concern and Pollutant Sources

The pollutant of concern in Crystal, Keller, Lee and Earley Lakes is phosphorus, measured as Total Phosphorus (TP). During the growing season (i.e., representative average of concentrations or measurements of nutrient enrichment factors, taken over one summer growing season from June 1 through September 30), the main source of phosphorus to lakes appear to be from stormwater runoff from each lakes' tributary watershed, as well as internal loads of phosphorus from the lake sediment, senescing macrophytes (Curlyleaf pondweed), and resuspension by other physical mixing processes (i.e. wind driven mixing, benthivorous and planktivorous fish activity). However, the water quality in Earley Lake is currently meeting the MPCA shallow lake standards for the three key water quality parameters (TP, Chlorophyll-*a,* and Secchi depth) and the MPCA is in the process of removing Earley Lake from the 303(d) Impaired Waters list. See Section 3.4 for more information about the water quality in Earley Lake.

3.0 Description of Applicable Water Quality Standards and Numerical Water Quality Target

Impaired waters are listed and reported to the citizens of Minnesota and to the EPA in the 305(b) report and the 303(d) list, named after relevant sections of the Clean Water Act. Assessment of waters for the 305(b) report identifies candidates for listing on the 303(d) list of impaired waters. The purpose of the 303(d) list is to identify impaired water bodies for which a plan will be developed to remedy the pollution problem(s) (the TMDL—this document).

In Minnesota, excess nutrients from anthropogenic (human) sources contribute to cultural eutrophication of lakes. Excess nutrient loads, in particular total phosphorus (TP), lead to increased algae blooms and reduced transparency – both of which may significantly impair or prohibit the designated use of aquatic recreation. According to Minn. Rules Ch. 7050.0222, shallow and deep lake water quality standards for Class 2B waters, and the MPCA's assessment guidance (MPCA, 2007), there are three lake water quality criteria for excess nutrients that must be met on a growing season mean (June-September) basis. The MPCA's deep and shallow lake eutrophication standards for the North Central Hardwood Forests (NCHF) ecoregion are shown in Table 3-1. To be listed as impaired by MPCA, the monitoring data must show that the standards for both total phosphorus (the causal factor) and either chlorophyll *a* or Secchi disc depth (the response factors) are not met (MPCA, 2009).

Table 3-1 MPCA Deep and Shallow Lake Eutrophication Standards for Total Phosphorus, Chlorophyll *a* and Secchi Disc (North Central Hardwood Forest Ecoregion)

Water Quality Parameter	MPCA Lake Eutrophication Standard (NCHF)	
	Deep Lake	Shallow Lake
Total Phosphorus (µg/L)	≤ 40	≤ 60
Chlorophyll-a (µg/L)	≤ 14	≤ 20
Secchi disc (m)	≥ 1.4	≥ 1.0

Source: Minnesota Rule 7050.0222 Subp. 4. Class 2B Waters

3.1 Historical Water Quality in Crystal Lake

Crystal Lake's historical (1974-2008) concentrations of TP, chlorophyll *a* (Chl *a*) and Secchi disc (SD) are discussed below. For the purposes of this TMDL report, growing season mean (June through September) concentrations of TP, Chl *a* and SD were used to evaluate water quality in Crystal Lake. This time period was chosen because it spans the months in which the lakes are most used by the public, and the months during which water quality is the most likely to suffer due to algal growth. Figures 3-1 through 3-3 show the growing season means of Crystal Lake's TP, Chl *a,* and SD measurements, respectively.

Historic TP data for Crystal Lake were available for 1974, 1979-1981, 1983, 1987, 1989, and 1994 – 2008. The growing season mean surface water concentrations of TP in Crystal Lake have ranged from 21 µg/L (in 1979) to 57 µg/L (in 1974). These TP concentrations typically fall within the eutrophic range. The growing season mean TP concentration over the last 10 years (1999 to 2008) is 41.8 µg/L.

Historic Chl *a* data for Crystal Lake were available for 1980, 1983, 1987, 1989, and 1994 – 2008. The growing season mean surface water concentrations of Chl *a* in Crystal Lake have ranged from 12 µg/L (in 1979) to 42 µg/L (in 1998). These Chl *a* concentrations fall within the eutrophic to hypereutrophic range. The growing season mean Chl *a* concentration over the last 10 years (1999 to 2008) is 24.5 µg/L.

Historic SD data for Crystal Lake were available for 1973-1992 and 1994 – 2008. The growing season mean surface water SD depths in Crystal Lake have ranged from 1.2 m (in 1975) to 3.5 m (in 1979). These SD depths fall within the mesotrophic to eutrophic range. The growing season mean SD depth over the last 10 years (1999 to 2008) is 1.7 m.

Figure 3-4 shows the relationship between SD and TP based on the growing season averages in Crystal Lake. At lower TP concentrations (less than 40 µg/L), changes in the lake's TP result in significant changes in the lake's transparency. At higher TP concentrations, changes in lake TP result in relatively smaller changes in the lake's transparency. Figure 3-5 shows the relationship between Chl *a* and TP concentrations based on the growing season averages in Crystal Lake.

Isopleth diagrams represent the change in a parameter relative to depth and time. For a given time period, vertical isopleths indicate complete mixing and horizontal isopleths indicate stratification. Isopleth diagrams can be particularly useful in visually detecting the presence (or absence) of an internal load of phosphorus in a lake. In 2006 (critical climatic conditions) and 2008, more rigorous lake water quality surveys provided enough samples to create isopleth diagrams of Crystal Lake's TP concentrations, indicating the dynamic nature of TP in the lake throughout the growing season (Figure 3-6a and Figure 3-6b). The isopleths show the increase of phosphorus concentrations seen during the stratified conditions in both 2006 and 2008, indicating the presence of internal sediment loading in Crystal Lake.

The BDWMO began operating a ferric chloride treatment system in 1996 to remove phosphorus from the deepest part of Crystal Lake. The treated water was then discharged to a nearby storm sewer and conveyed to Keller Lake. The Crystal Lake water quality demonstration project was a cooperative venture of the BDWMO, the MPCA, and the United States Environmental Protection Agency (U.S. EPA) under the Clean Lakes Program. The system operated during the 1996 and 1997 recreation seasons and half of the 1998 season. A side effect of the phosphorus removal system was a "rotten egg" odor. Operation was suspended in July 1998 after strong neighborhood opposition to the odor. The BDWMO decided to discontinue operation of the treatment system in April 1999. The BDWMO reached this decision after considering public input, the seasonal operating costs of $20,000, and the marginal improvements to the water quality of Crystal Lake during the recreation season.

A recommendation of the Crystal & Keller Lake UAA was to modify the ferric chloride treatment system to withdraw surface waters and resume operating the system. The recommendation implemented to reduce the TP concentration and suppress the growth of Curlyleaf pondweed in Keller Lake was an effort to reduce the phosphorus loading to Crystal Lake. Operation of the ferric chloride treatment system was resumed for varying time periods during the summers of 2003, 2004, 2005, 2006, 2007, and 2008. The system only operated for a short period during the summer of 2008 due to low water levels in Crystal Lake.

Lake monitoring data suggest that operation of the ferric chloride treatment system was successful in reducing the total phosphorus concentration in the deepest portions of Crystal Lake. However, the overall benefit to Crystal Lake water quality was insignificant. The decrease in phosphorus in the lower lake levels did not affect the phosphorus concentrations at the lake surface, nor did it increase the water clarity during the summer season. The operation of the hypolimnetic withdrawal system did however, play a significant role in maintaining water levels and improving water quality in Keller Lake.

Table 3-2 summarizes this historical water quality information compared to the recommended deep lake listing criteria. Because the causal water quality factor (TP) and one of the response factors

(Chl *a*) exceed the Listing Criteria on average over the last 10 years, Crystal Lake is listed as "Impaired" on the 303(d) list (Crystal Lake was first listed in 2002.)

Table 3-2 Crystal Lake Historical Nutrient Related Water Quality Parameters

Water Quality Parameter	MPCA's Deep Lake Eutrophication Standards (NCHF)	Crystal Lake Historical (Entire Record) Growing Season Average	Crystal Lake 10-Year (1999-2008) Growing Season Average
Total Phosphorus (µg/L)	≤ 40	40.4	41.8
Chlorophyll *a* (µg/L)	≤ 14	24.5	24.5
Secchi disc (m)	≥ 1.4	2.0	1.7

3.1.1 Baseline Water Quality Modeling

Several methods have been developed by the MPCA and other researchers to assess minimally impacted and presettlement water quality conditions for lakes. The MPCA developed the Minnesota Lake Eutrophication Analysis Procedure (MnLEAP). MnLEAP is intended to be used as a screening tool for estimating lake conditions and for identifying "problem" lakes. MnLEAP is particularly useful for identifying lakes requiring "protection" versus those requiring "restoration" (Heiskary and Wilson, 1990). In addition, MnLEAP modeling has been done in the past to identify Minnesota lakes which may be in better or worse condition than they "should be" based on their location, watershed area and lake basin morphometry (Heiskary and Wilson, 1990).

Results of MnLEAP modeling done for Crystal Lake suggests that Crystal Lake could achieve "better" water quality than is currently observed (Heiskary and Lindbloom, 1993). MnLEAP predicts TP concentrations of approximately 48 µg/L. The predicted phosphorus concentration has a standard error of 17 µg/L. The MPCA's eutrophication criteria are at the lower end of this range.

Vighi and Chiaudani (1985) developed a method to determine the phosphorus concentration in lakes that are not affected by anthropogenic (human) inputs. As a result, the phosphorus concentration in a lake resulting from natural, background phosphorus loadings can be calculated from information about the lake's mean depth and alkalinity or conductivity. Alkalinity is considered more useful for this analysis because it is less influenced by the modifying effect of anthropogenic inputs. Using the long-term average alkalinity values from the main basin of Crystal Lake, the predicted TP concentration from natural, background loadings are estimated to be 20-27 µg/L.

Figure 3-1
CRYSTAL LAKE
Summer Average (June through September)
Mean Total Phosphorus Concentrations
1974, 1979-1981, 1983, 1987, 1989, 1994-2008

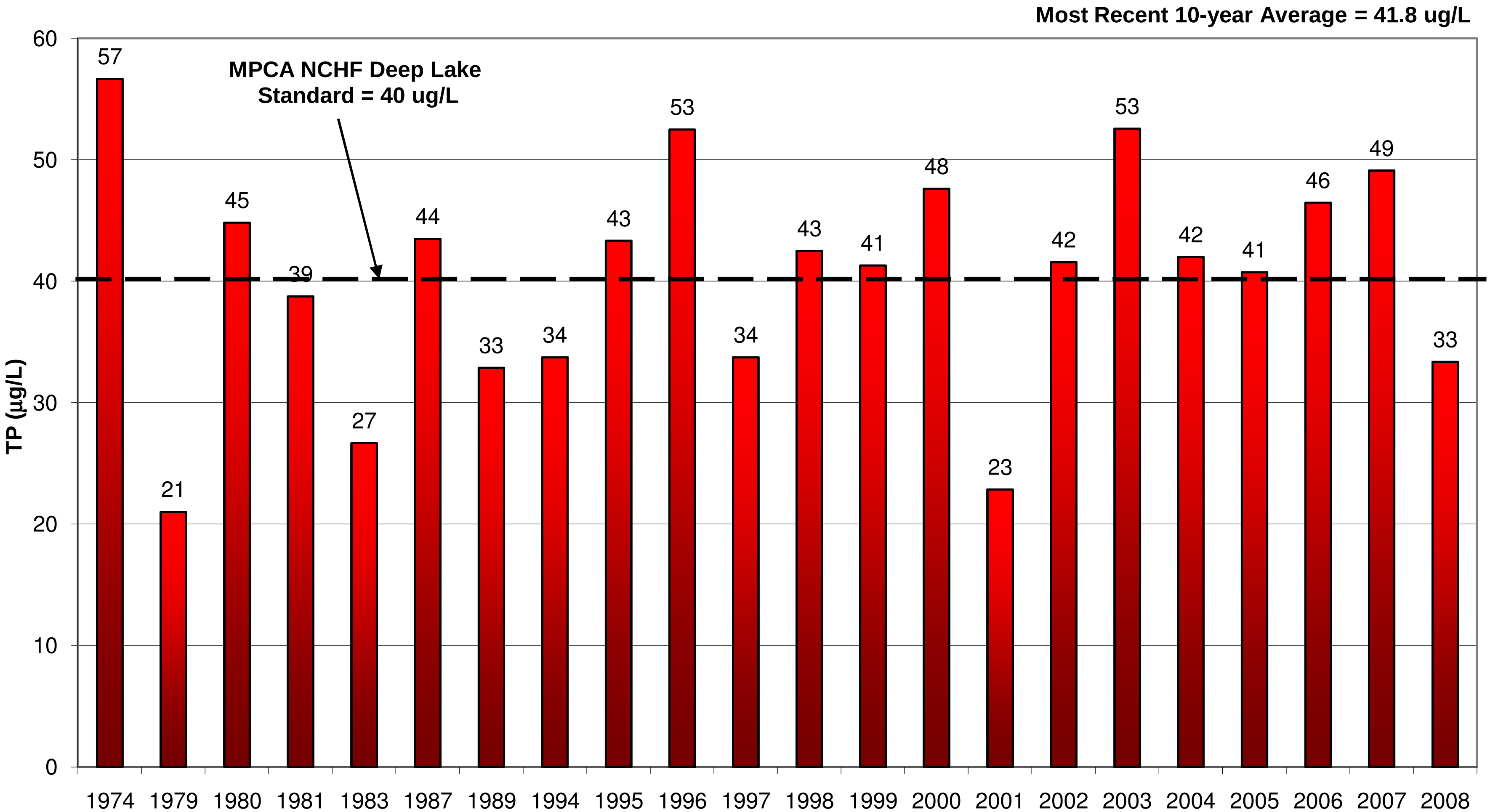


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Figure 3-2
CRYSTAL LAKE
Summer Average (June through September)
Mean Chlorophyll a Concentrations
1980, 1983, 1987, 1989, 1994-2008

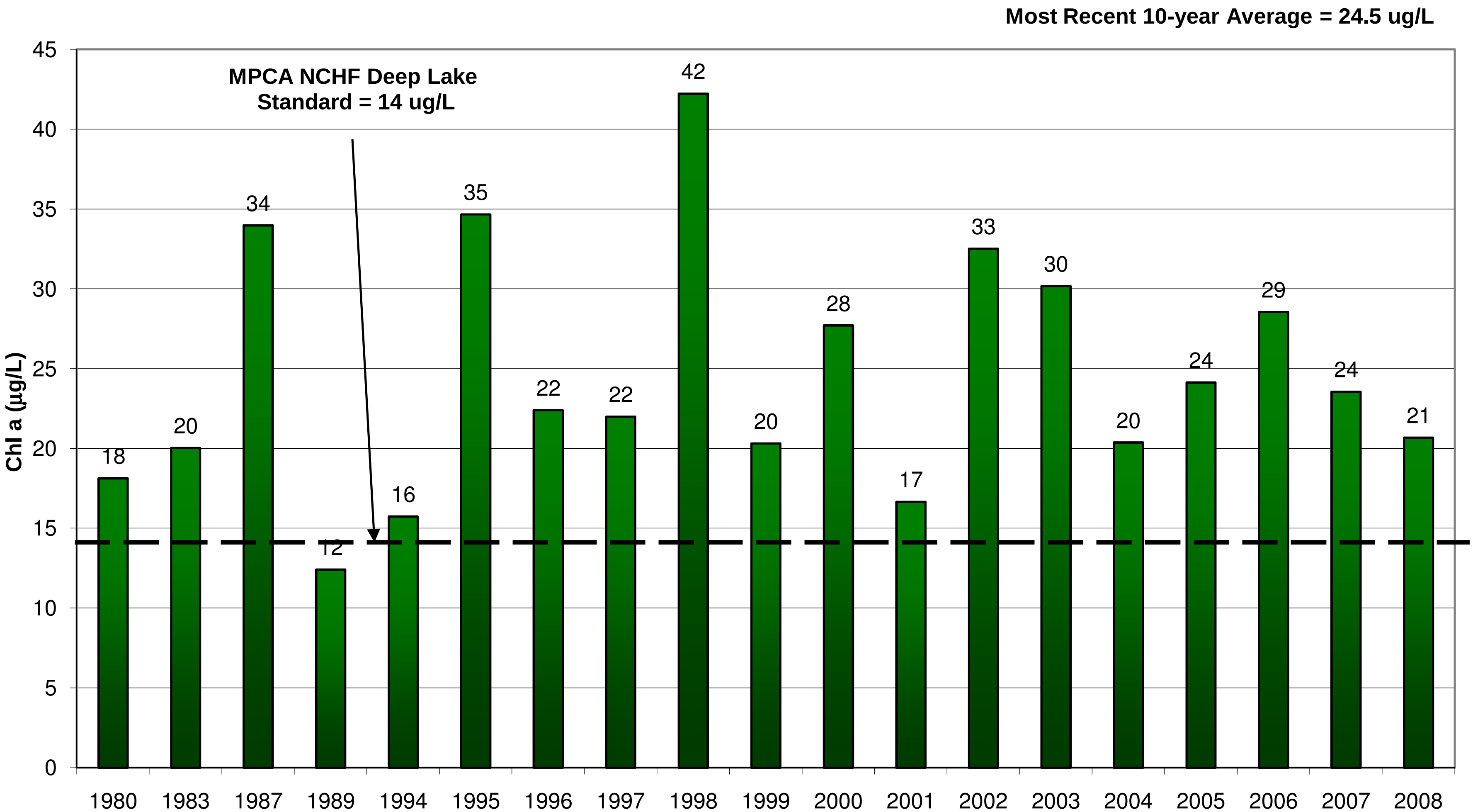

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Figure 3-3
CRYSTAL LAKE
Summer Average (June through September)
Mean Secchi Disc Transparencies
1973-1992, 1994-2008

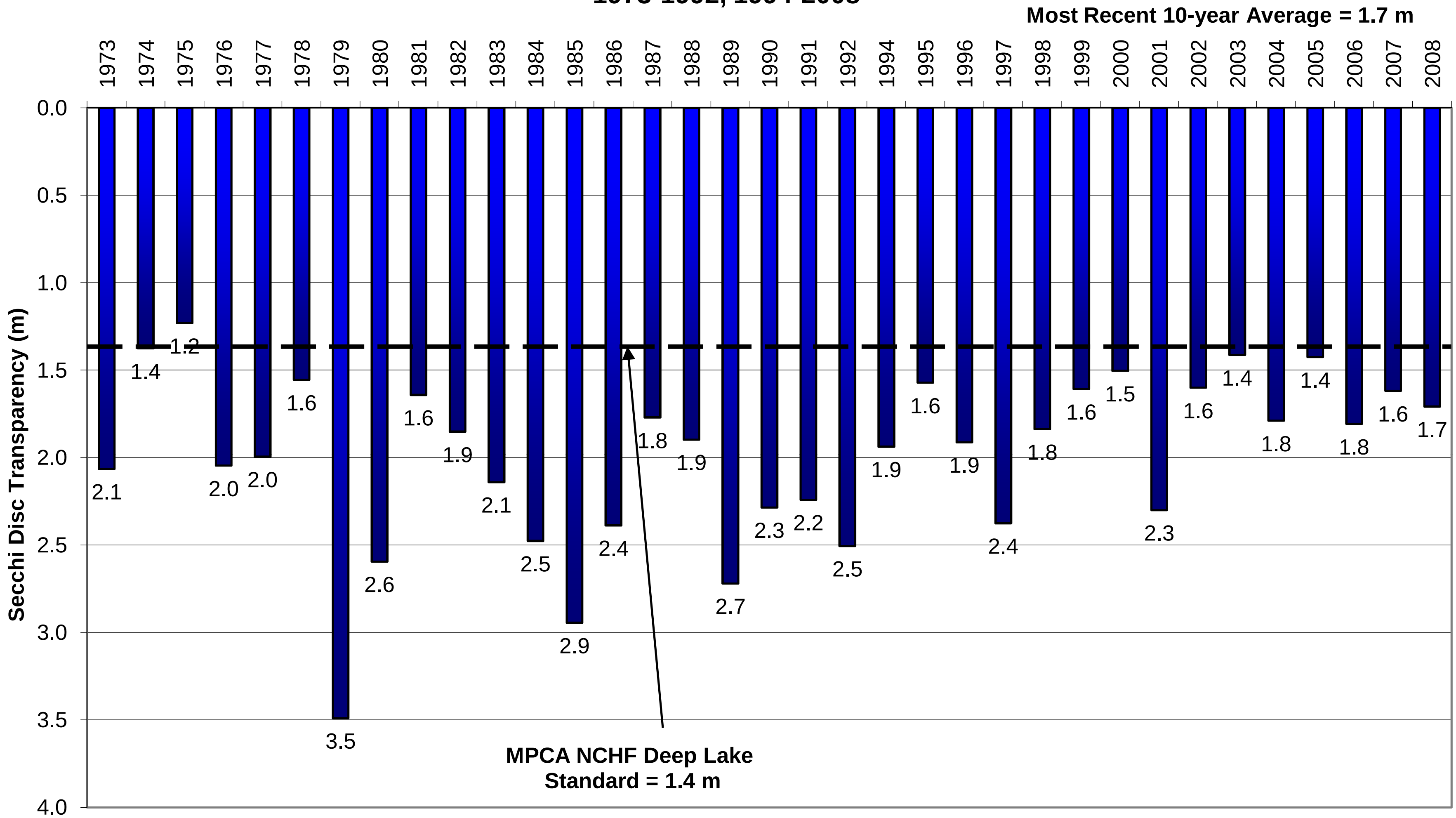

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Figure 3-4
Crystal Lake Growing Season Water Quality Relationships
Secchi Disc Transparency-Total Phosphorus Relationship

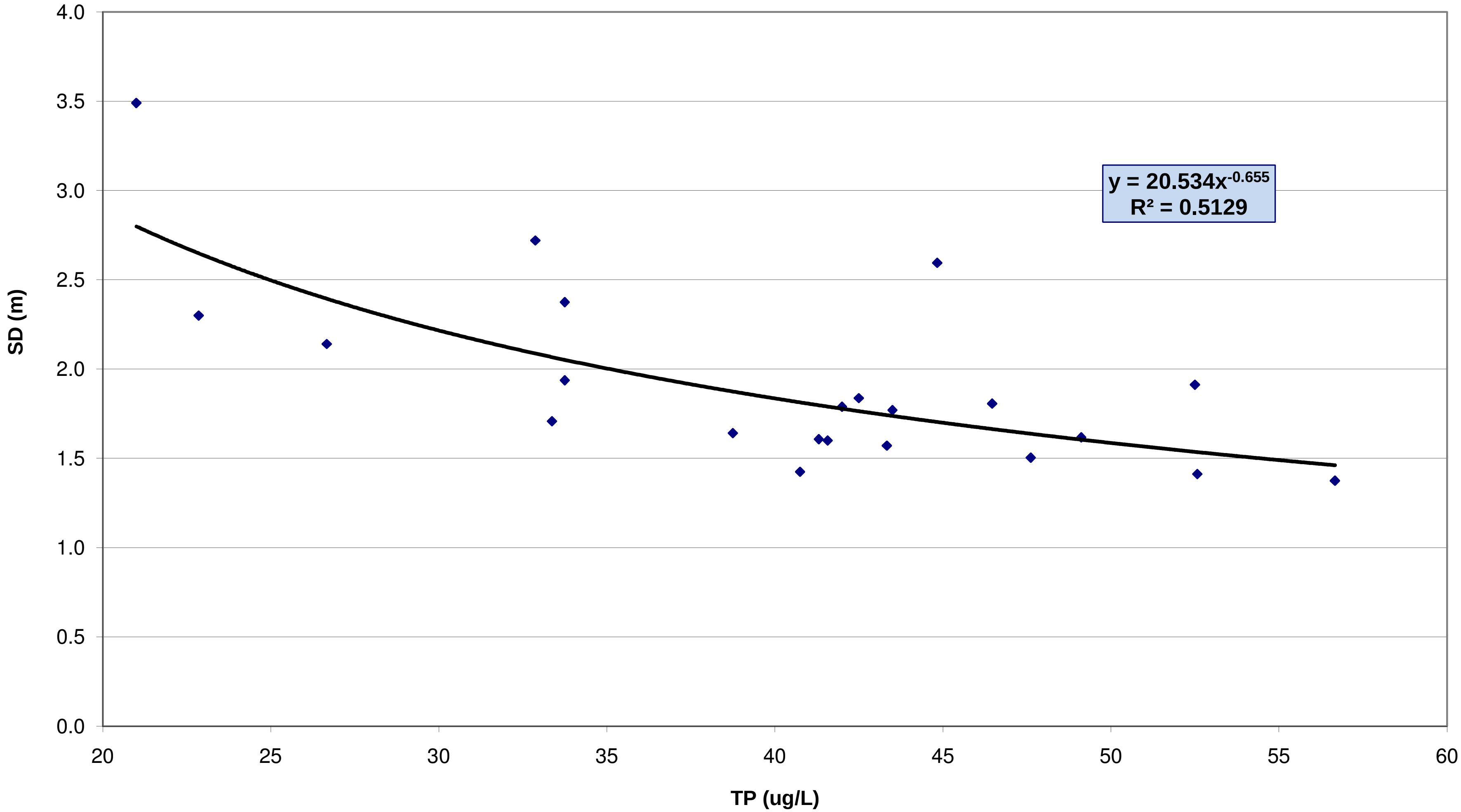

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Figure 3-5
Crystal Lake Growing Season Water Quality Relationships
Chlorophyll a-Total Phosphorus Relationship

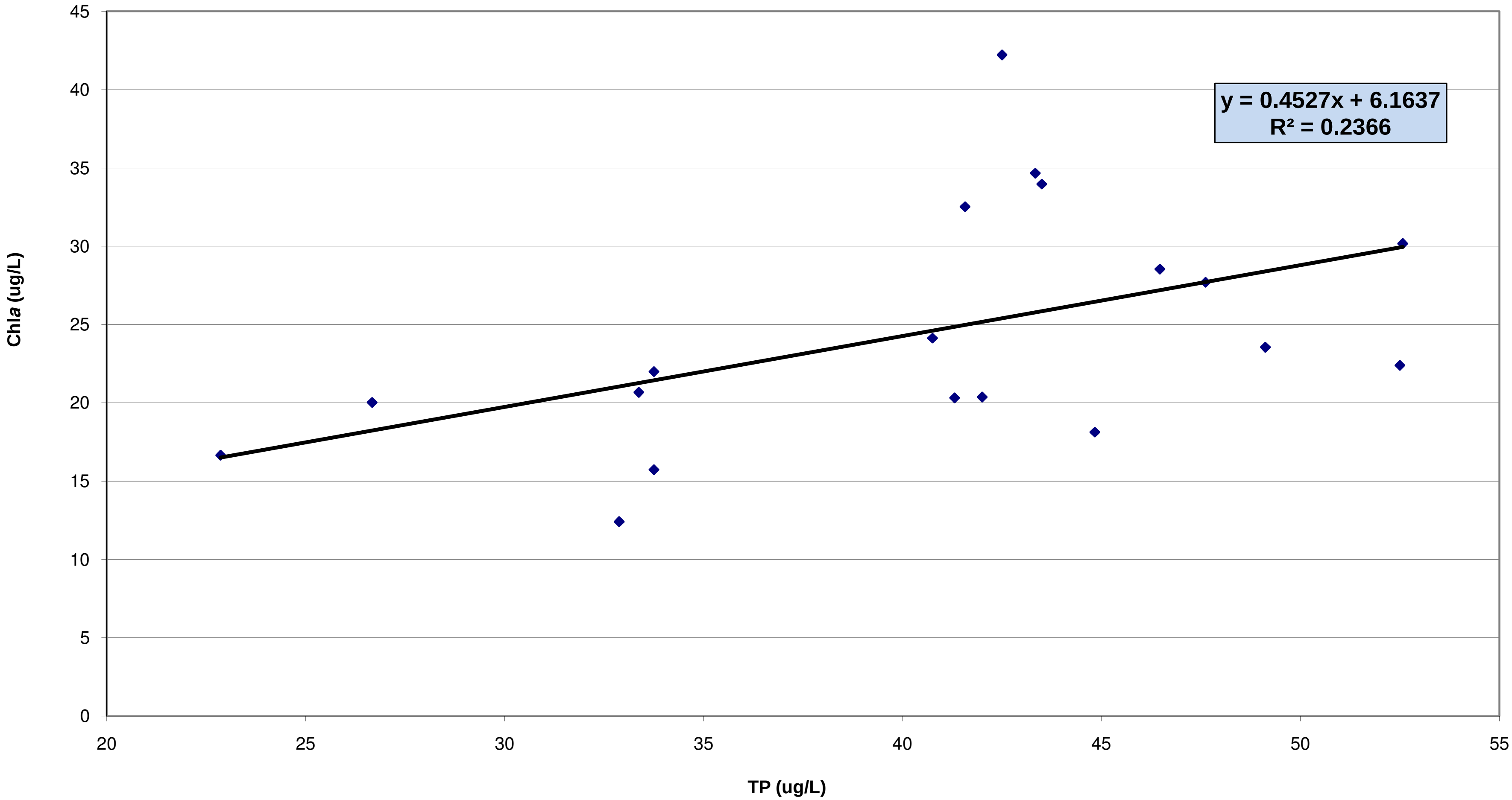

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Figure 3-6a
Crystal Lake 2006 Isopleth Diagram for Total Phosphorus (mg/L)

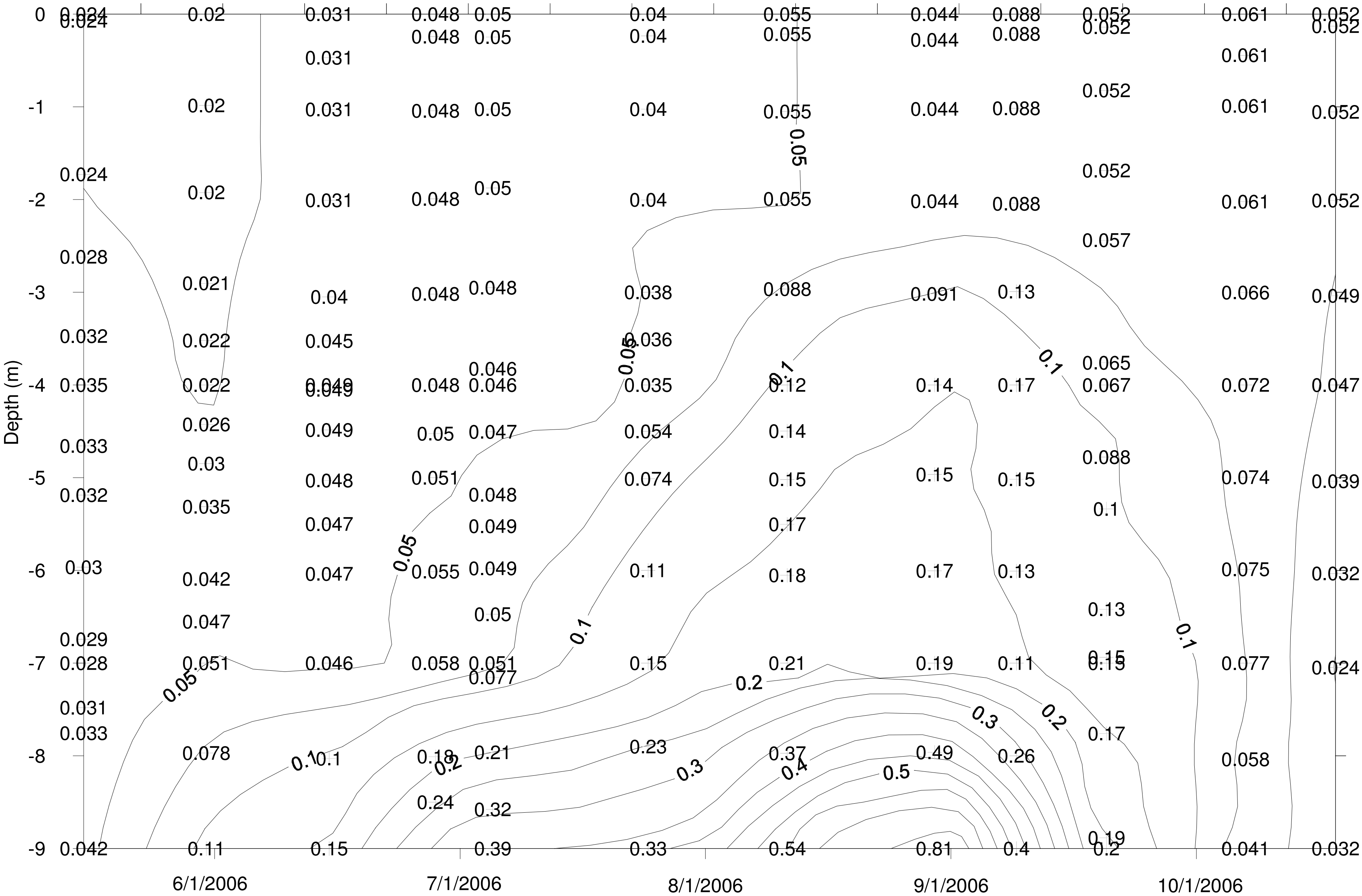
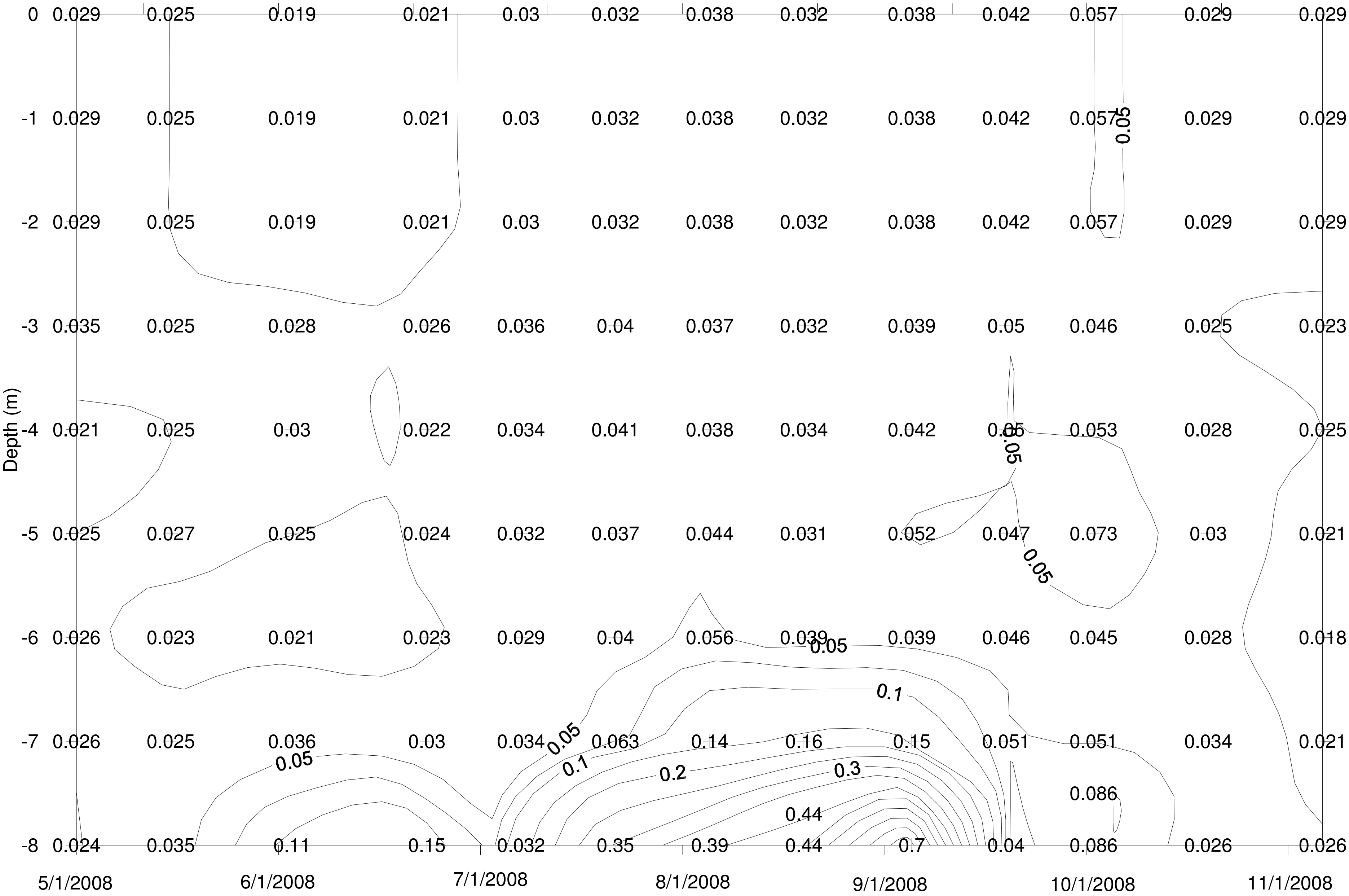


Figure 3-6b
Crystal Lake 2008 Isopleth Diagram for Total Phosphorus (mg/L)



3.2 Historical Water Quality in Keller Lake

Keller Lake's historical (1996-2008) concentrations of TP, Chl *a* and SD are discussed below. Figures 3-7 through 3-9 show Keller Lake's growing season mean TP, Chl *a,* and SD measurements, respectively.

Historic TP data for Keller Lake were available for 1996 – 2008. The growing season mean surface water concentrations of TP in Keller Lake have ranged from 33 µg/L (in 2008) to 131 µg/L (in 2000). These TP concentrations fall within the eutrophic to hypereutrophic range. The growing season mean TP concentration over the last 10 years (1999 to 2008) is 83.9 µg/L.

Historic Chl *a* data for Keller Lake were available for 1996 – 2008. The growing season mean surface water concentrations of Chl *a* in Keller Lake have ranged from 3 µg/L (in 2008) to 96 µg/L (in 1996). These Chl *a* concentrations fall within the mesotrophic to hypereutrophic range. The growing season mean Chl a concentration over the last 10 years (1999 to 2008) is 28.5 µg/L.

Historic SD data for Keller Lake were available for 1996 – 2008. The growing season mean surface water SD depths in Keller Lake have ranged from 0.6 m (in 2000) to 2.0 m (in 2008). These SD depths fall within the eutrophic to hypereutrophic range. The growing season mean SD depth over the last 10 years (1999 to 2008) is 1.2 m.

Figures 3-10 and 3-11 show the relationships between SD and TP measurements and Chl *a* and TP concentrations, respectively, based on the growing season averages in Keller Lake. At lower TP concentrations (less than 60 µg/L), changes in the lake's TP result in significant changes in the lake's transparency. At higher TP concentrations, changes in lake TP result in relatively smaller changes in the lake's transparency.

In 2006 (critical climatic condition) and 2008, more rigorous lake water quality surveys provided enough samples to create isopleth diagrams of Keller Lake's TP concentrations, indicating the dynamic nature of TP in the lake throughout the growing season (Figure 3-12a and Figure 3-12b). In 2006, the isopleths indicate the increase of phosphorus concentrations along the bottom of the lake during August and September indicating the presence of internal sediment loading in Keller Lake. However, in 2008, water quality data suggests that Keller Lake was well mixed and total phosphorus concentrations in the lake were fairly constant throughout the depth profile, indicating the phosphorus loading from the sediments was minimal.

As previously discuss in Section 3.1, the BDWMO operated the ferric chloride treatment system on and off between 1996 and 2008 (see Section 3.1 for further discussion).

Although the ferric chloride treatment system had a minimal impact on the water quality within Crystal Lake, it appears that water quality and clarity in Keller Lake may have improved significantly as the result of operating the system. In addition, the ferric chloride treatment system plays a significant role in maintaining the water levels in Keller Lake.

Table 3-3 summarizes the historical water quality information for Keller Lake compared to the shallow lake listing criteria. Because the causal water quality factor (TP) and one of the response factors (Chl *a*) exceed the Listing Criteria on average over the last 10 years, Keller Lake is listed as "Impaired" on the 303(d) list (Keller Lake was first listed in 2002.)

Table 3-3 Keller Lake Historical Nutrient Related Water Quality Parameters

Water Quality Parameter	MPCA's Shallow Lake Eutrophication Standards (NCHF)	Keller Lake Historical (Entire Record) Growing season Average	Keller Lake 10-Year (1999-2008) Growing season Average
Total Phosphorus (µg/L)	≤ 60	82.3	83.9
Chlorophyll *a* (µg/L)	≤ 20	32.2	28.5
Secchi disc (m)	≥ 1.0	1.3	1.2

3.2.1 Baseline Water Quality Modeling

MnLEAP modeling has been done in the past to identify Minnesota lakes which may be in better or worse condition than they "should be" based on their location, watershed area and lake basin morphometry (Heiskary and Wilson, 1990). Results of MnLEAP modeling done for Keller Lake suggest that Keller Lake could achieve "better" water quality than is currently observed (Heiskary and Lindbloom, 1993). MnLEAP predicts TP concentrations of approximately 74 µg/L (with a standard error of 21 µg/L). The MPCA's eutrophication criteria are at the lower end of this range.

Vighi and Chiaudani (1985) developed a method to determine the phosphorus concentration in lakes that are not affected by anthropogenic (human) inputs. Using the long-term average alkalinity values from the Keller Lake, the predicted TP concentration from natural, background loadings are estimated to be 26 µg/L. The lakes used to develop the relationship between alkalinity and TP concentration were typically deep lakes with surface areas greater than approximately 50 acres. Because Keller Lake is dissimilar to the lakes used to develop the relationship, the TP concentration estimated by the relationship may not accurately reflect the background TP concentration for Keller Lake.

Figure 3-7
KELLER LAKE
Summer Average (June through September)
Mean Total Phosphorus Concentrations
1996-2008

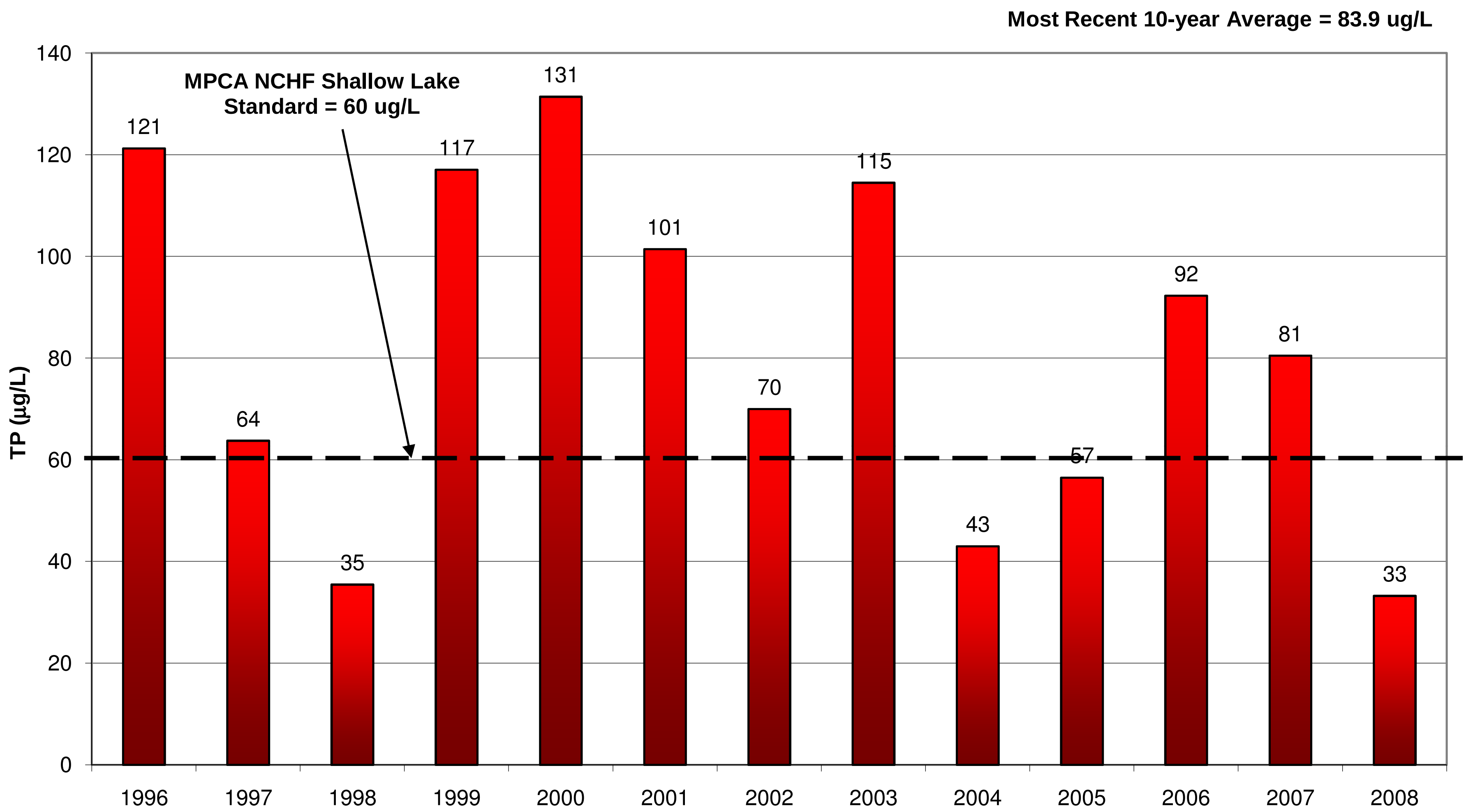


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Figure 3-8
KELLER LAKE
Summer Average (June through September)
Mean Chlorophyll a Concentrations
1996-2008

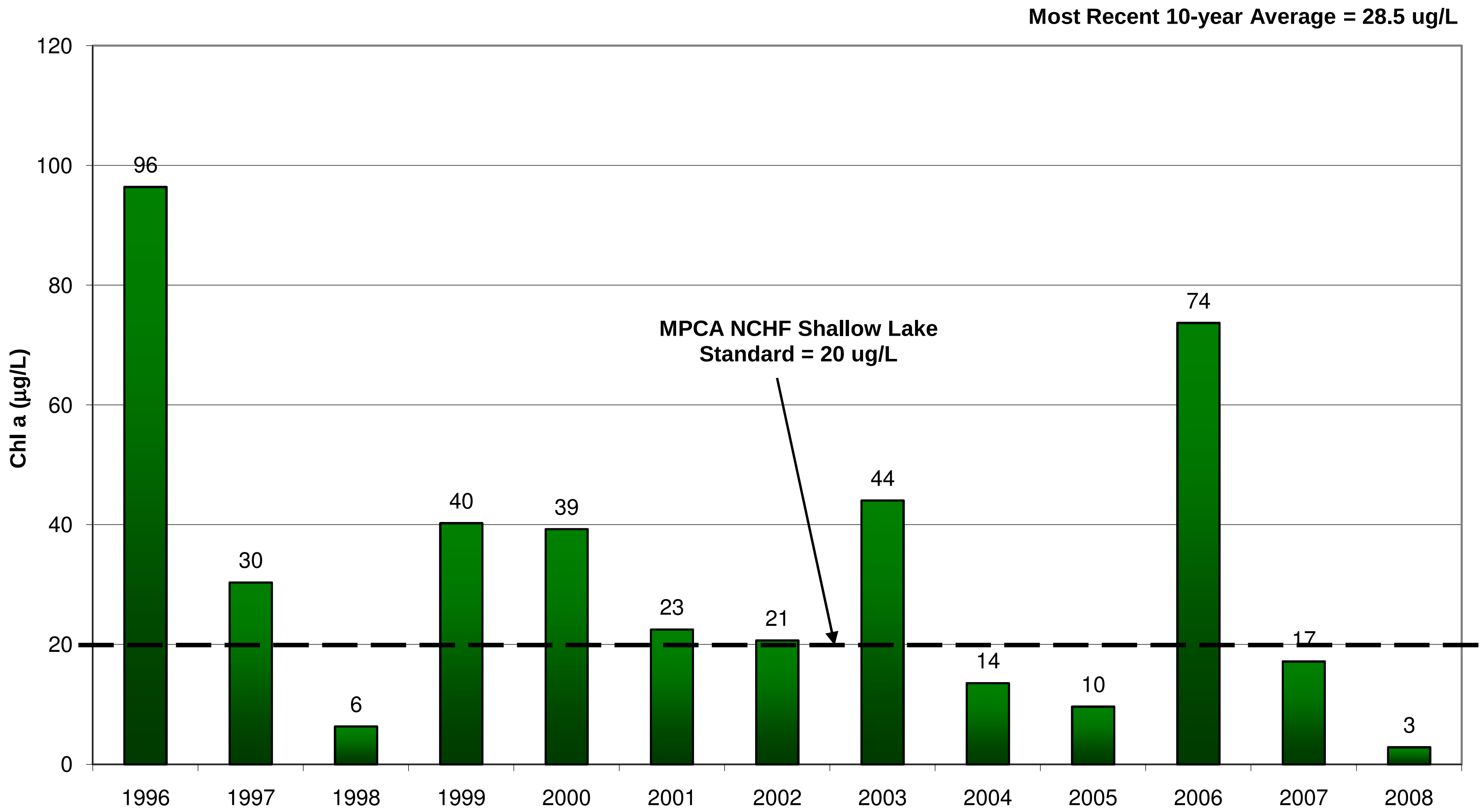

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Figure 3-9
KELLER LAKE
Summer Average (June through September)
Mean Secchi Disc Transparencies
1996-2008

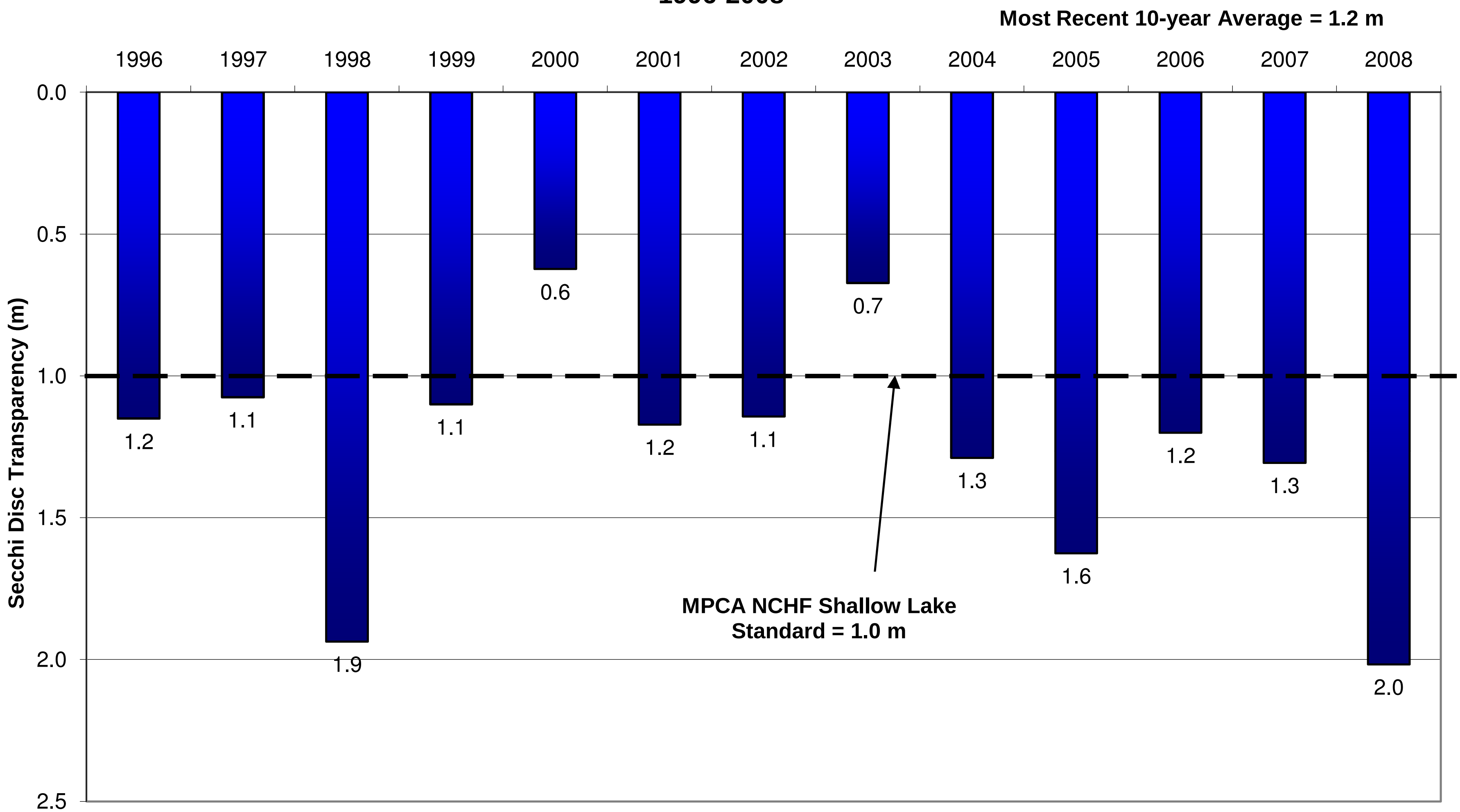

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Figure 3-10
Keller Lake Growing Season Water Quality Relationships
Secchi Disc Transparency-Total Phosphorus

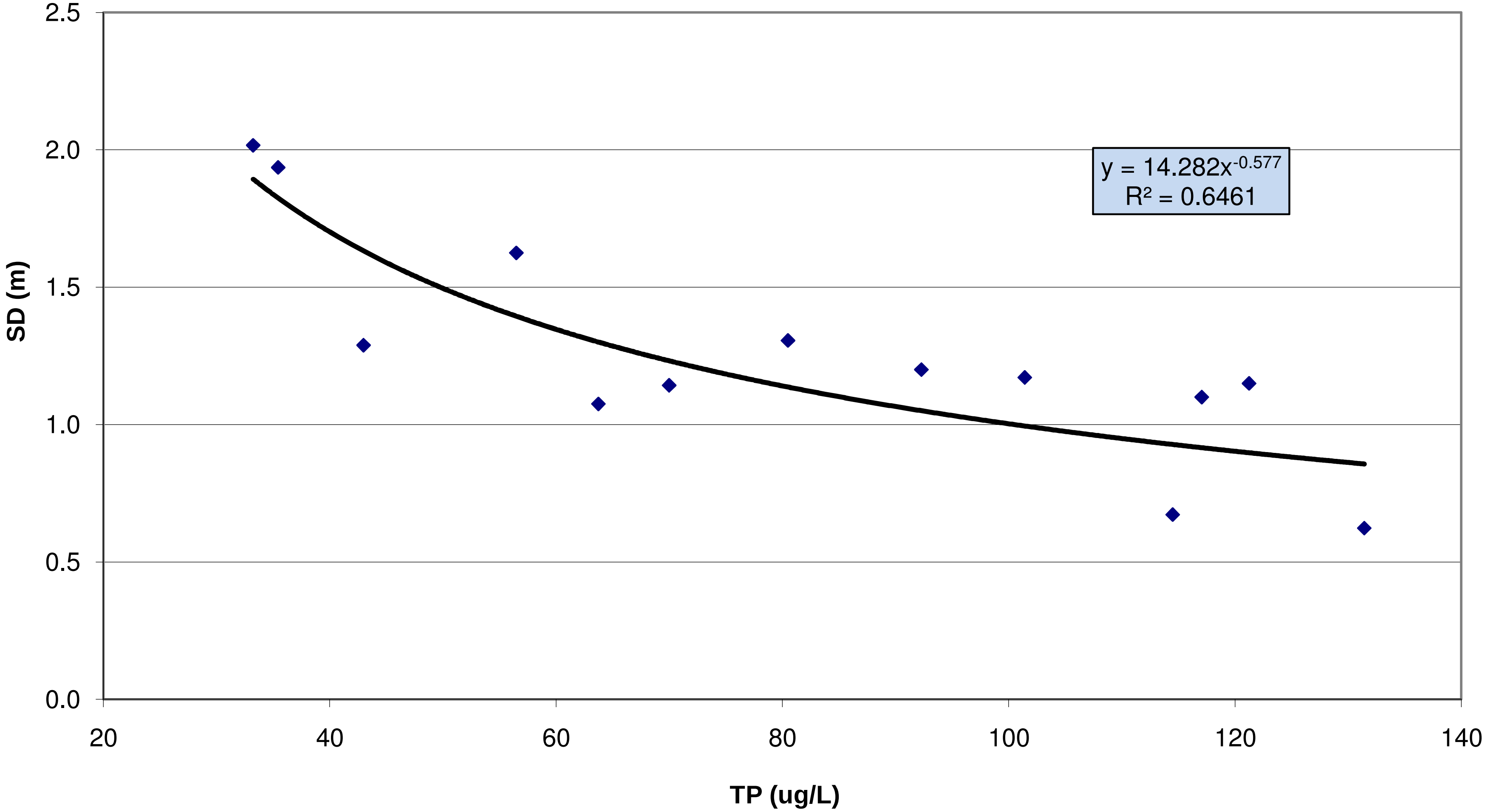

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Figure 3-11
Keller Lake Growing Season Water Quality Relationships
Chlorophyll *a*-Total Phosphorus

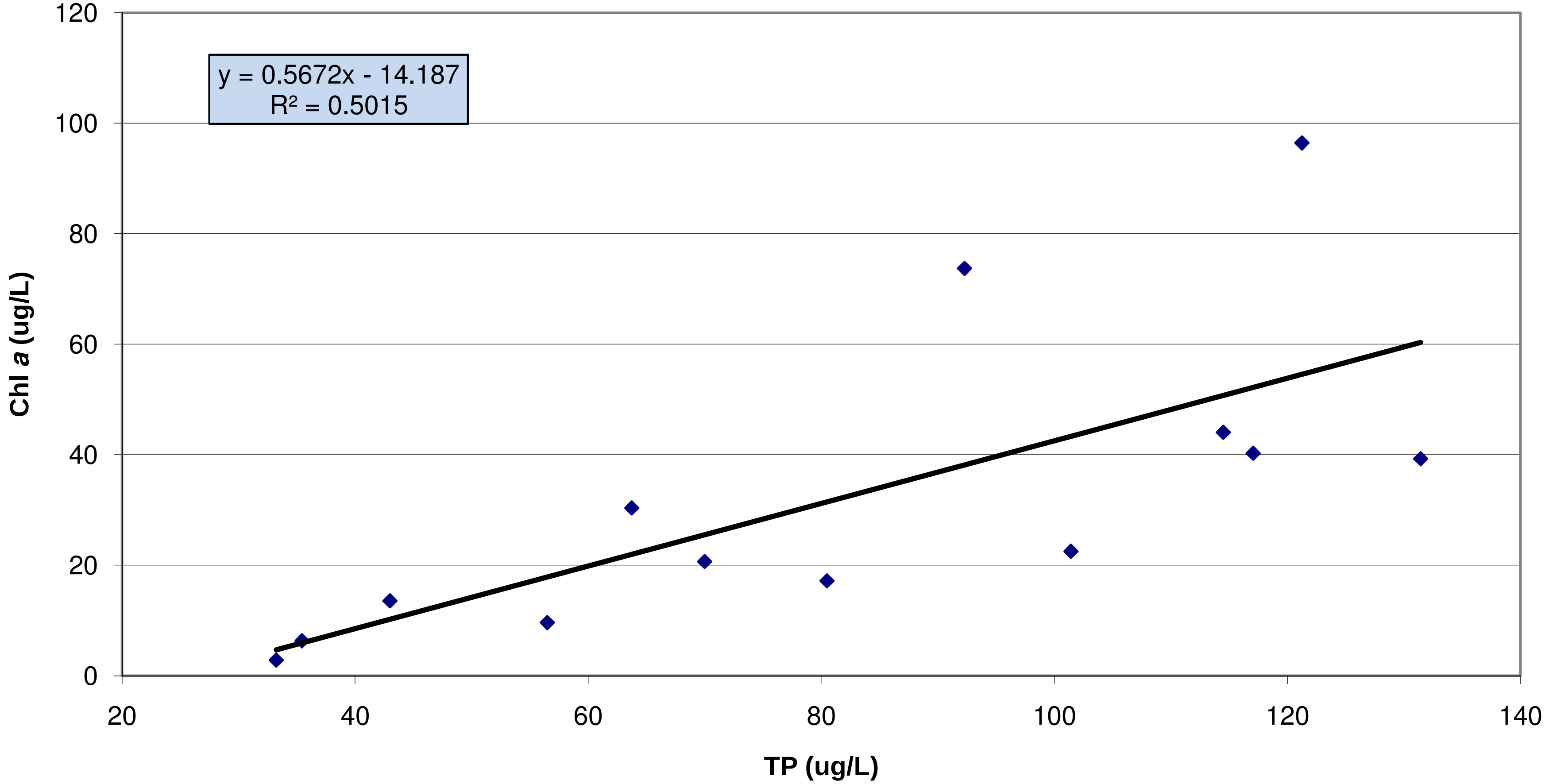

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Figure 3-12a
Keller Lake 2006 Isopleth Diagram for Total Phosphorus (mg/L)

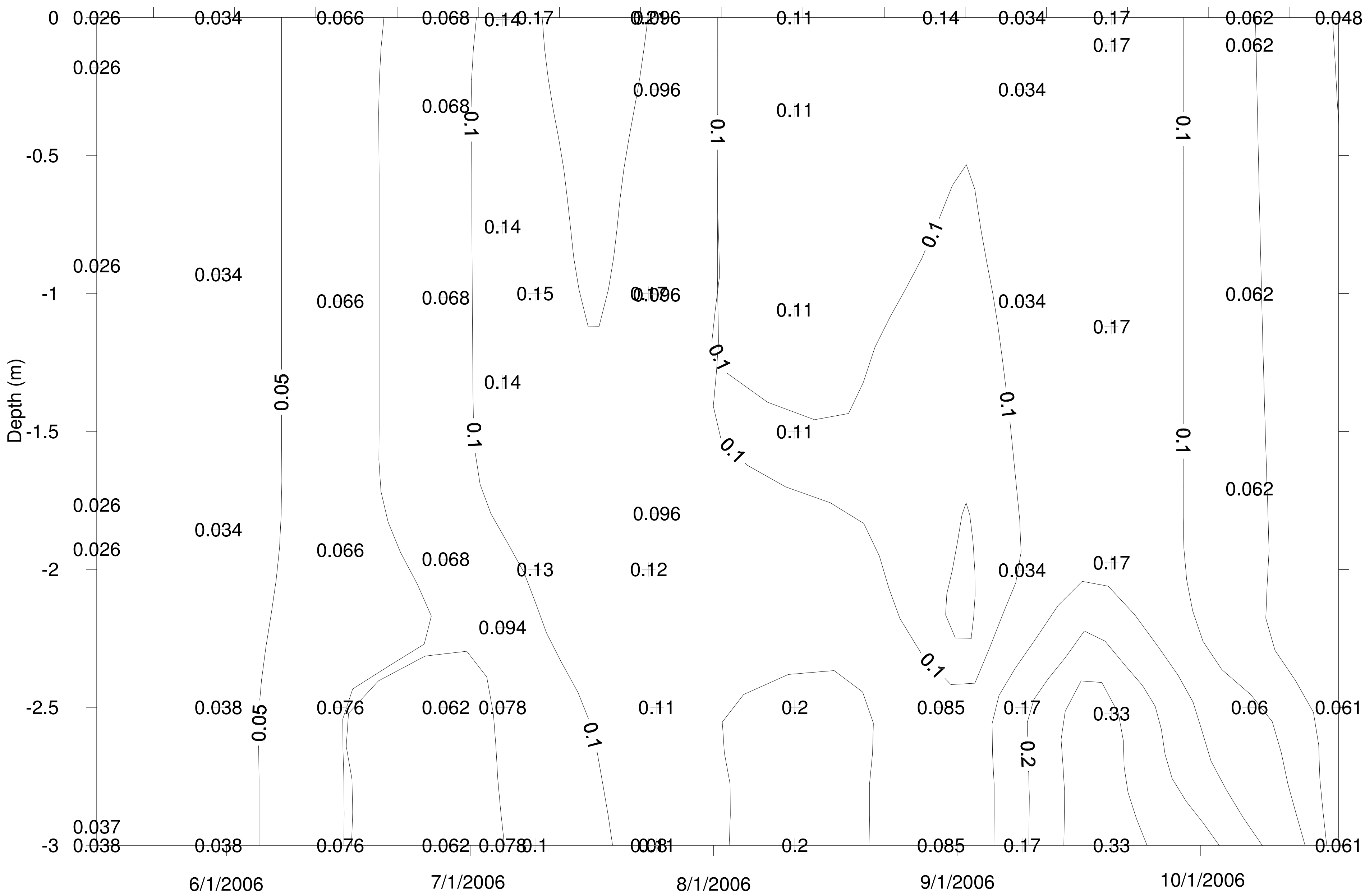
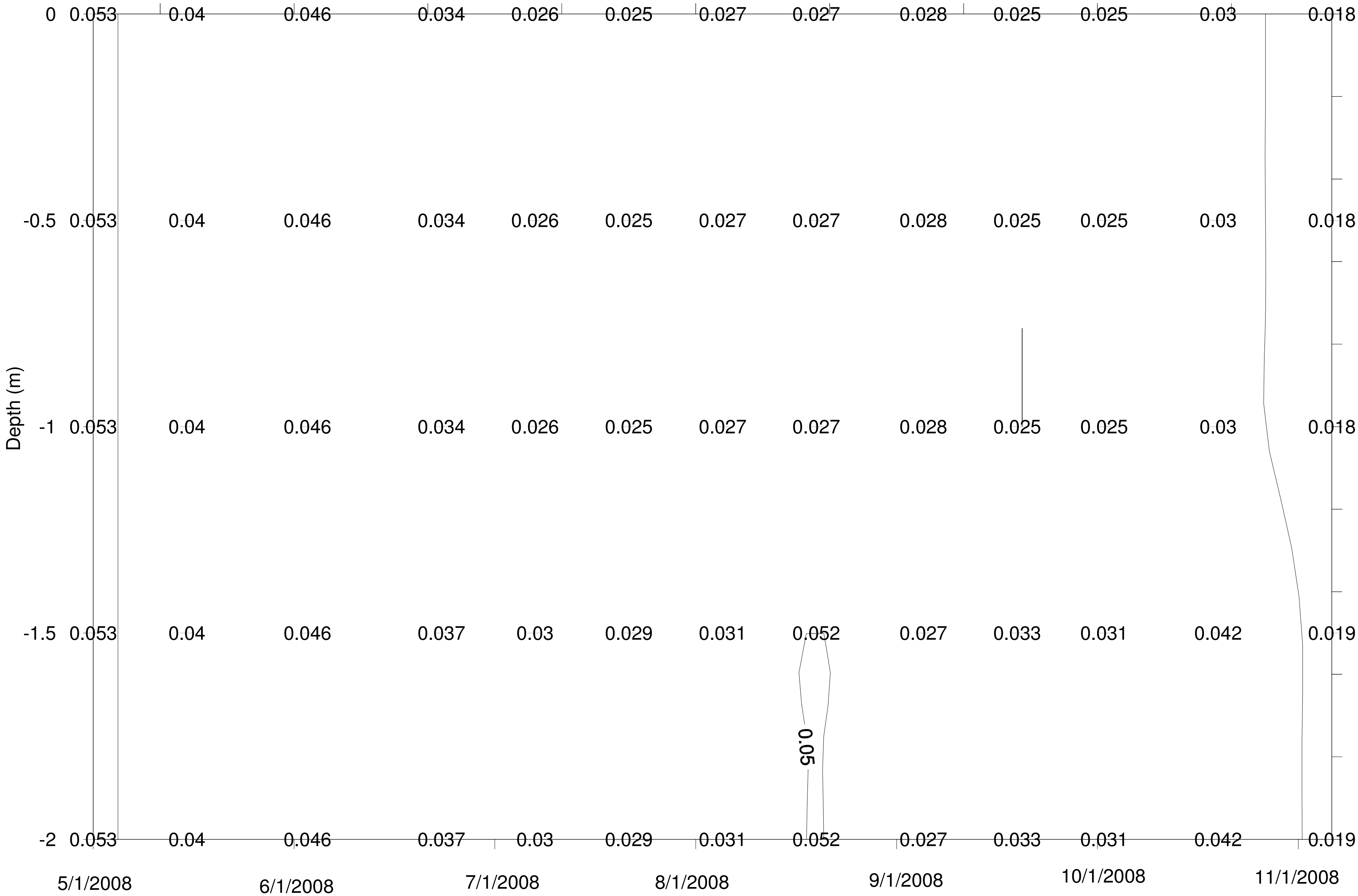


Figure 3-12b
Keller Lake 2008 Isopleth Diagram for Total Phosphorus (mg/L)



3.3 Historical Water Quality in Lee Lake

Lee Lake's historical (1994-2008) concentrations of TP, Chl *a*, and SD are discussed below. Figures 3-13 through 3-15 show the growing season means of Lee Lake's TP, Chl *a*, and SD measurements, respectively.

Historic TP data for Lee Lake were available for 1994 - 1997 and 2000 – 2008. The growing season mean surface water concentrations of TP in Lee Lake have ranged from 43 µg/L (in 1997) to 110 µg/L (in 2000). These TP concentrations fall within the eutrophic to hypereutrophic range. The growing season mean TP concentration over the last 10 years (1999 to 2008) is 66.4 µg/L.

Historic Chl *a* data for Lee Lake were available for 1994 - 1997 and 2000 – 2008. The growing season mean surface water concentrations of Chl *a* in Lee Lake have ranged from 13 µg/L (in 1997) to 49 µg/L (in 2000). These Chl *a* concentrations fall within the eutrophic to hypereutrophic range. The growing season mean Chl *a* concentration over the last 10 years (1999 to 2008) is 24.3 µg/L.

Historic SD data for Lee Lake were available for 1994 - 1997 and 2000 – 2008. The growing season mean surface water SD depths in Lee Lake have ranged from 0.8 m (in 2000) to 2.0 m (in 1997). These SD depths fall within the eutrophic range. The growing season mean SD depth over the last 10 years (1999 to 2008) is 1.3 m.

Figures 3-16 and 3-17 show the relationships between SD and TP measurements and Chl *a* and TP concentrations, respectively, based on growing season averages in Lee Lake. At lower TP concentrations (less than 60 µg/L), changes in the lake's TP result in significant changes in the lake's transparency. At higher TP concentrations, changes in lake TP result in relatively smaller changes in the lake's transparency.

In 2008, a more rigorous lake water quality survey provided enough samples to create an isopleth diagram of Lee Lake's TP concentrations, indicating the dynamic nature of TP in the lake throughout the growing season (Figure 3-18). The isopleth shows that there was an increase of phosphorus concentrations seen during the stratified conditions throughout the summer, indicating the presence of internal sediment loading in Lee Lake.

Table 3-4 summarizes this historical water quality information compared to the recommended shallow lake listing criteria. Because the causal water quality factor (TP) and one of the response factors (chlorophyll *a*) exceed the Listing Criteria on average over the last 10 years, Lee Lake is listed as "Impaired" on the 303(d) list (Lee Lake was first listed in 2002.)

Table 3-4 Lee Lake Historical Nutrient Related Water Quality Parameters

Water Quality Parameter	MPCA's Shallow Lake Eutrophication Standards (NCHF)	Lee Lake Historical (Entire Record) Growing season Average	Lee Lake 10-Year (1999-2008) Growing season Average
Total Phosphorus (µg/L)	≤ 60	61.3	66.4
Chlorophyll *a* (µg/L)	≤ 20	22.9	24.3
Secchi disc (m)	≥ 1.0	1.4	1.3

3.3.1 Baseline Water Quality Modeling

Results of MnLEAP modeling done for Lee Lake suggests that Lee Lake could achieve "better" water quality than is currently observed (Heiskary and Lindbloom, 1993). MnLEAP predicts total phosphorus concentrations of approximately 51 µg/L (with a standard error of 18 µg/L). The MPCA's eutrophication criteria are at the upper end of this range.

Using the 2008 specific conductivity values from the Lee Lake, the predicted phosphorus concentration from natural, background loadings are estimated to be 28 µg/L. Similar to Keller Lake, Lee Lake is outside the bounds of the data set used to develop the relationship between specific conductivity and background TP concentration. Therefore, the TP concentration estimated by the relationship may not accurately reflect the background TP concentration for Lee Lake.

Figure 3-13
LEE LAKE
Summer Average (June through September)
Mean Total Phosphorus Concentrations
1994-1997, 2000-2008

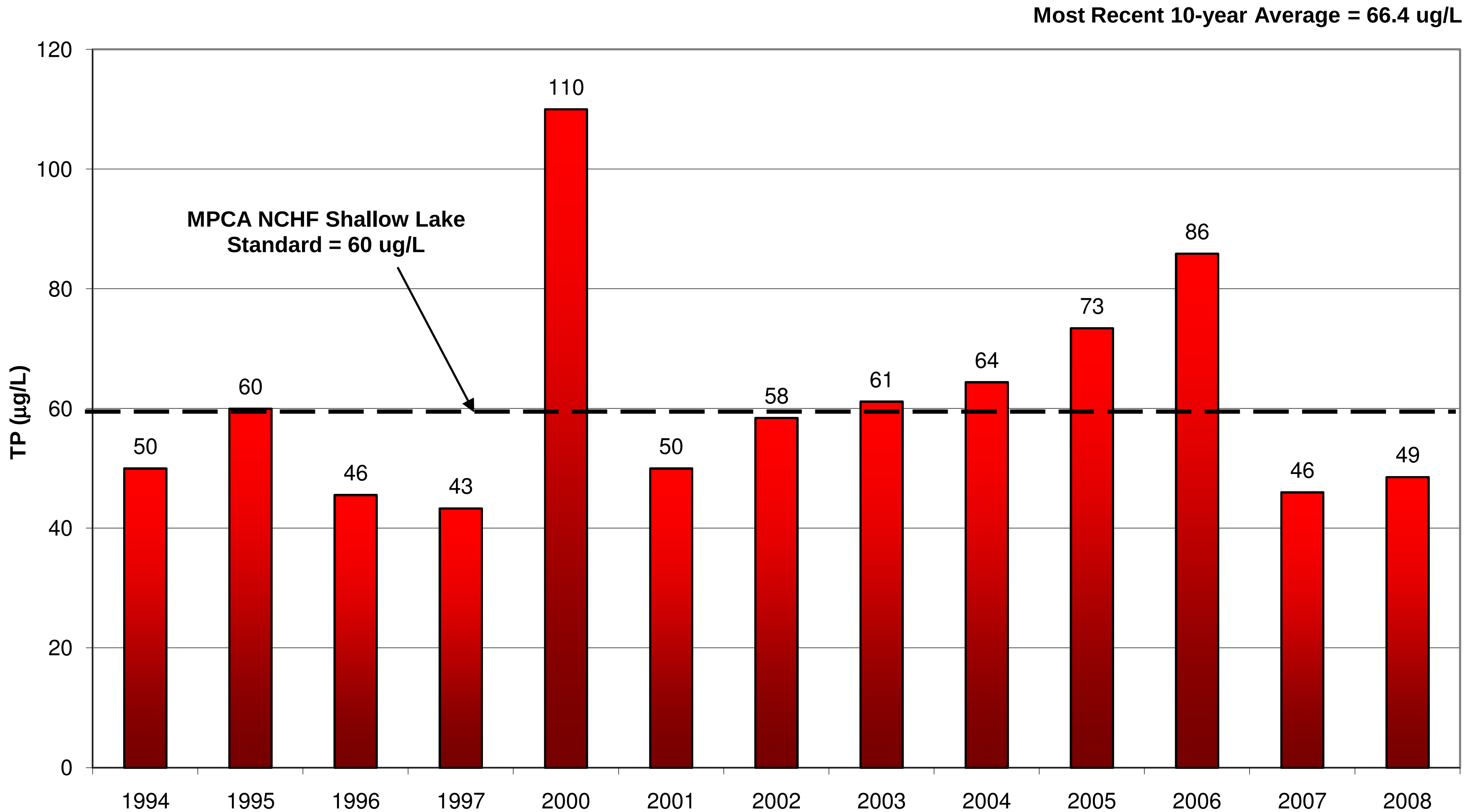


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Figure 3-14
LEE LAKE
Summer Average (June through September)
Mean Chlorophyll a Concentrations
1994-1997, 2000-2008

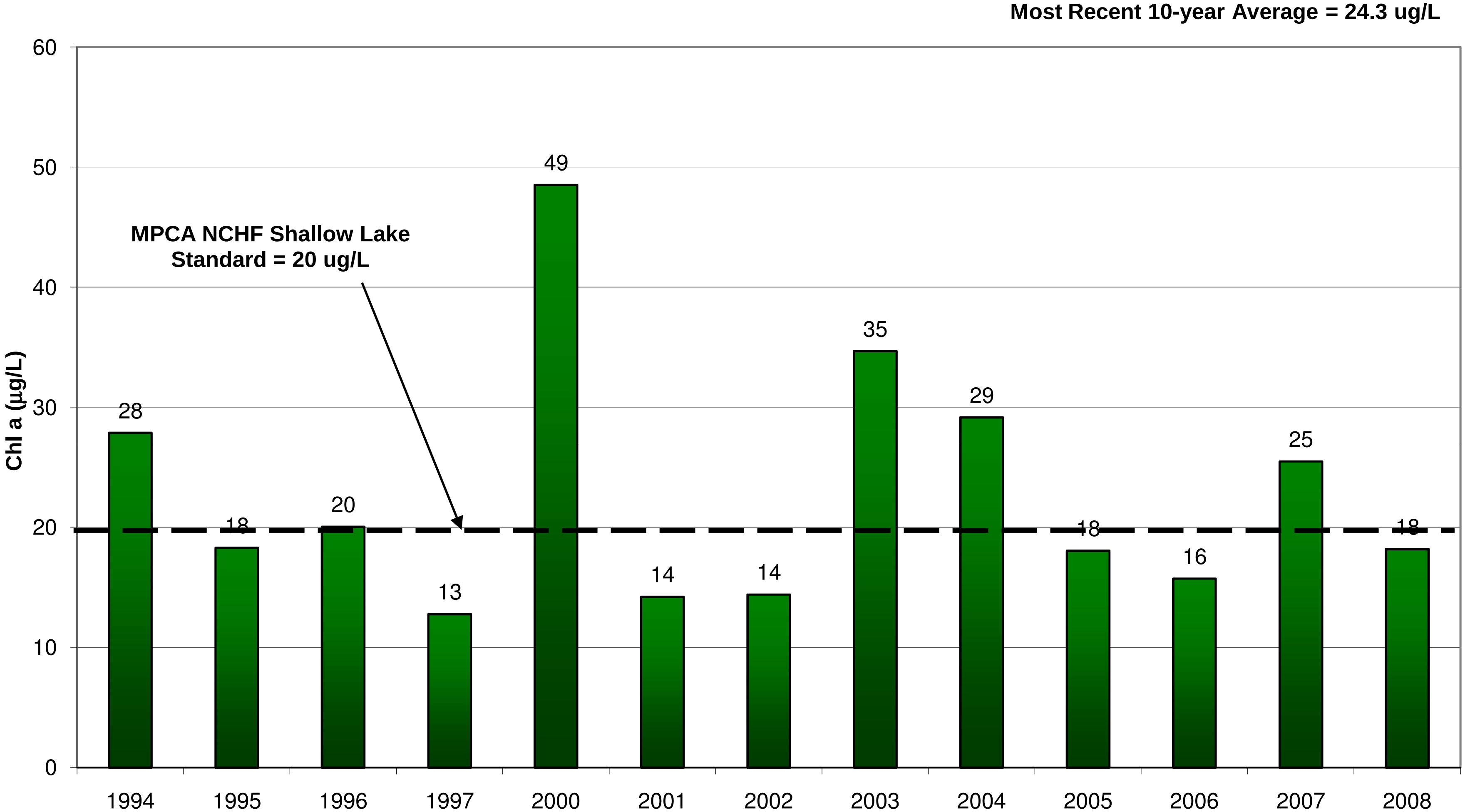

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Figure 3-15
LEE LAKE
Summer Average (June through September)
Mean Secchi Disc Transparencies
1994-1997, 2000-2008

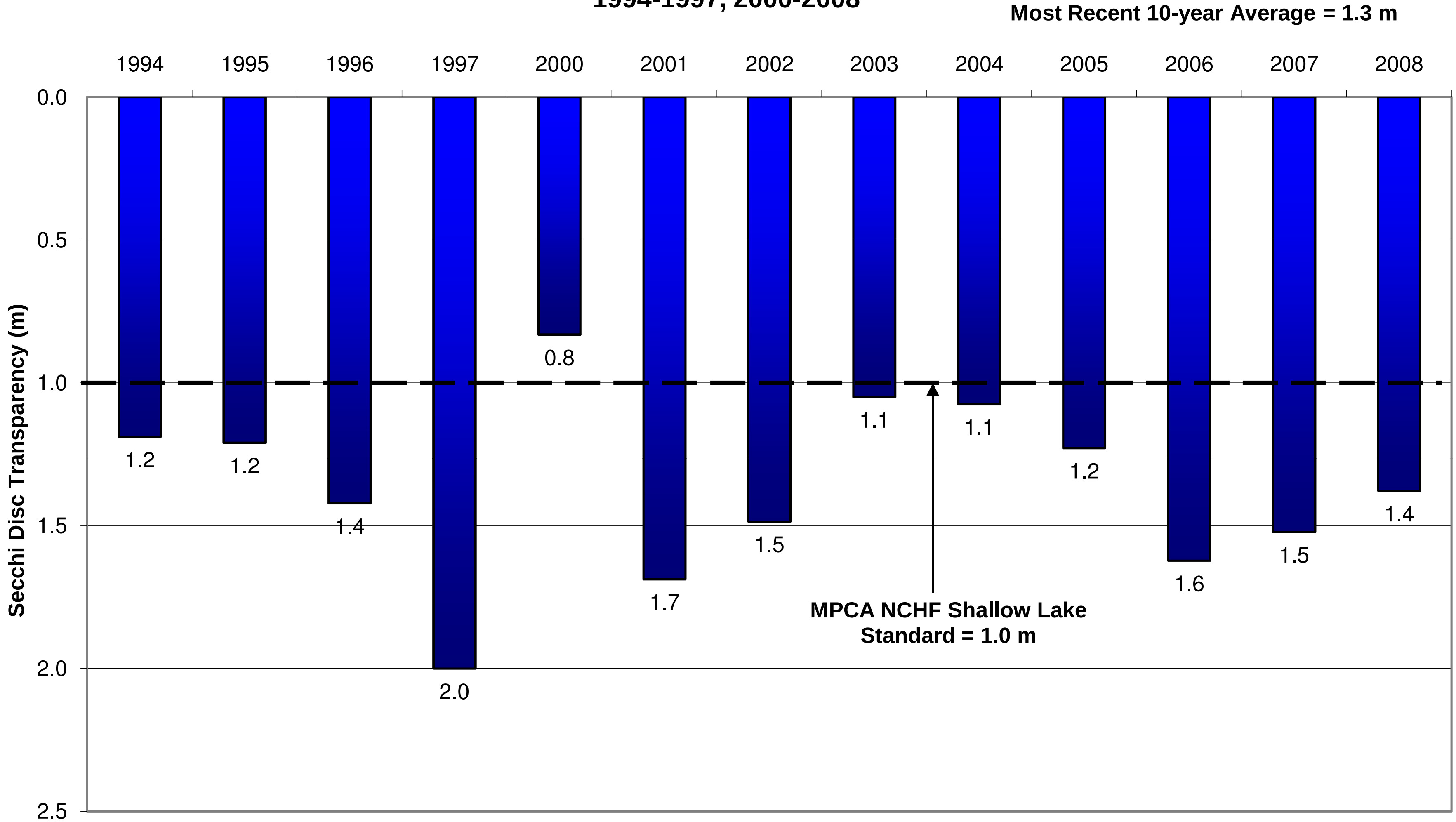

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Figure 3-16
Lee Lake Growing Season Water Quality Relationships
Secchi Disc Transparency-Total Phosphorus Relationship

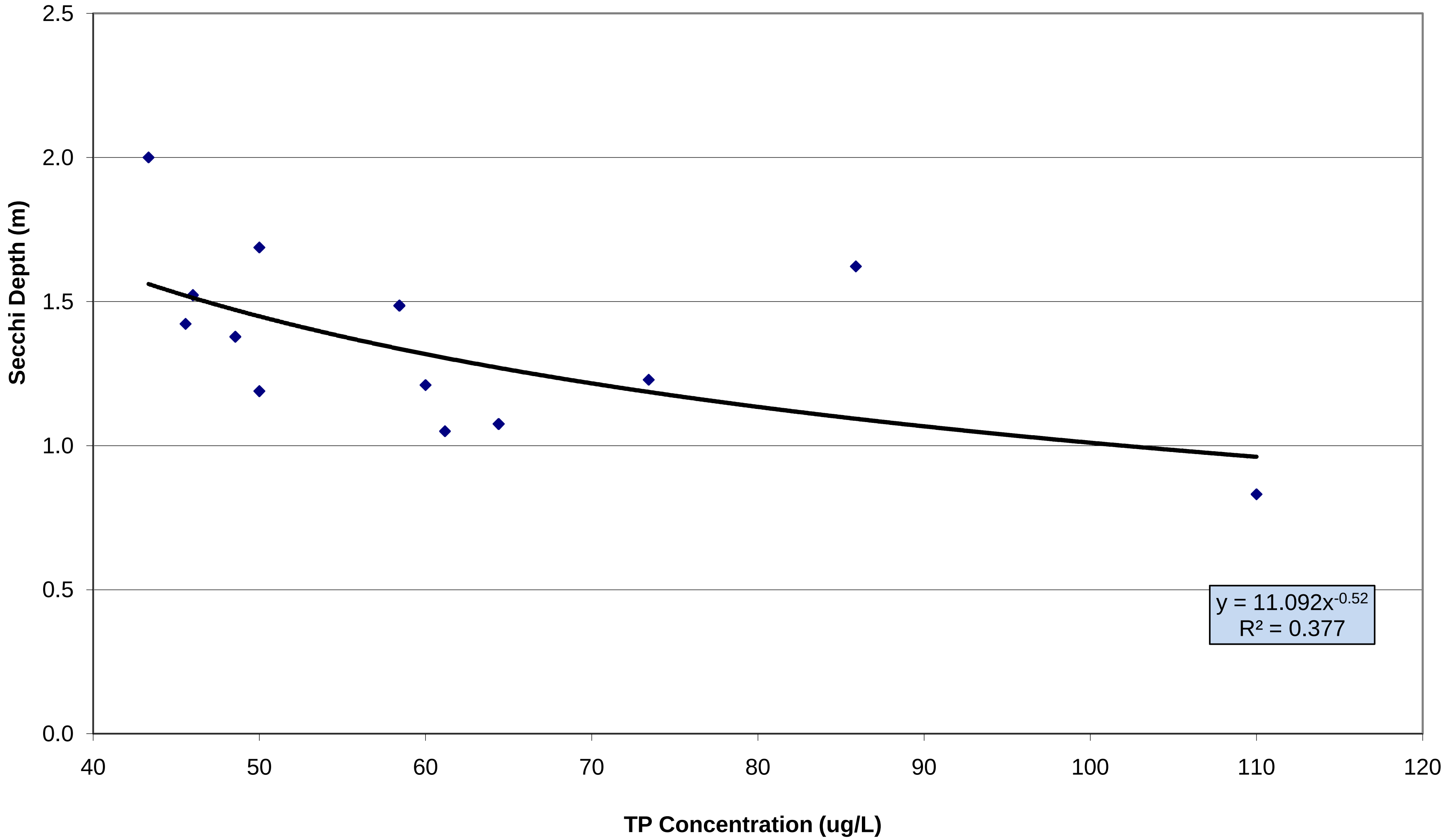

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Figure 3-17
Lee Lake Growing Season Water Quality Relationships
Chlorophyll *a*-Total Phosphorus Relationship

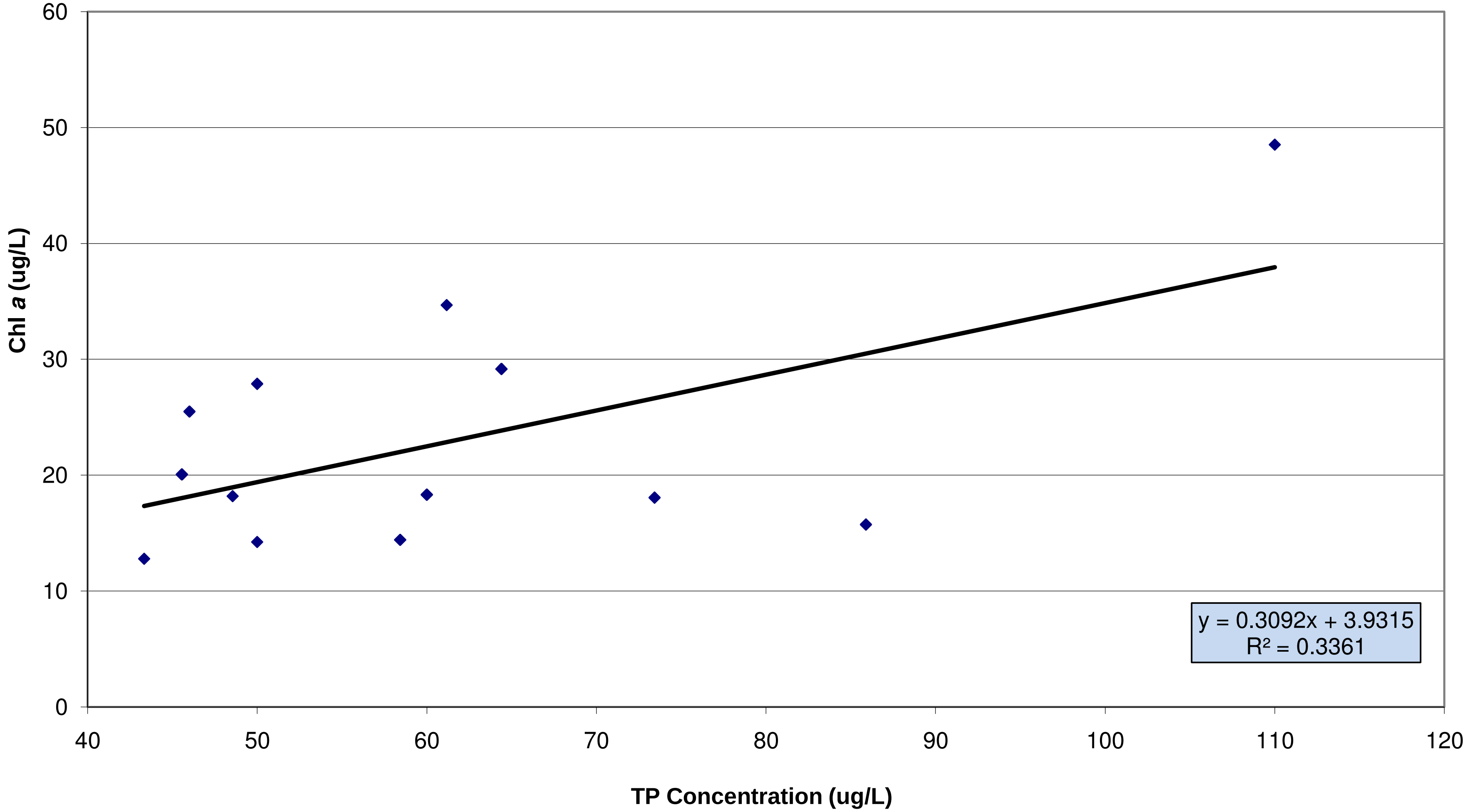

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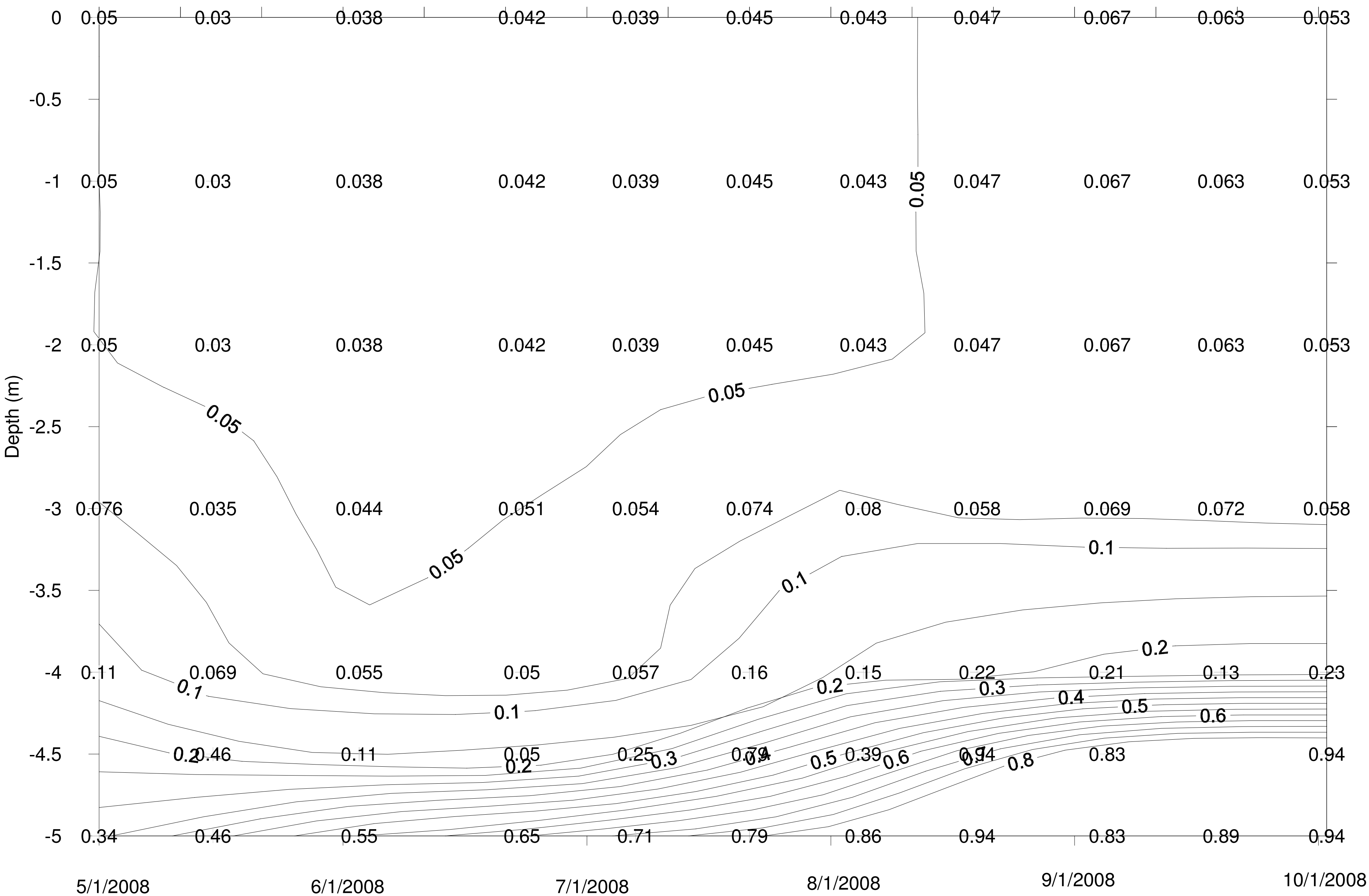
Figure 3-18
Lee Lake 2008 Isopleth Diagram for Total Phosphorus (mg/L)



3.4 Historical Water Quality in Earley Lake

Earley Lake's historical (1994-2008) concentrations of TP, Chl *a*, and SD are discussed below. Figures 3-19 through 3-21 show the growing season means of Earley Lake's total phosphorus (TP), Chl *a*, and SD measurements, respectively.

Historic TP data for Earley Lake were available for 1994 – 2008. The growing season mean surface water concentrations of TP in Earley Lake have ranged from 35 µg/L (in 2008) to 68 µg/L (in 1998). These TP concentrations fall within the eutrophic to hypereutrophic range. The growing season mean TP concentration over the last 10 years (1999 to 2008) is 51.4 µg/L.

Historic Chl *a* data for Earley Lake were available for 1999 – 2008. The growing season mean surface water concentrations of Chl *a* in Earley Lake have ranged from 6 µg/L (in 2008) to 19 µg/L (in 1999). These Chl *a* concentrations fall within the eutrophic range. The growing season mean Chl a concentration over the last 10 years (1999 to 2008) is 12.7 µg/L.

Historic SD data for Earley Lake were available for 1994 – 2008. The growing season mean surface water SD depths in Earley Lake have ranged from 1.1 m (in 1996, 1998, and 1999) to 1.9 m (in 2008). These SD depths fall within the eutrophic range. The growing season mean SD depth over the last 10 years (1999 to 2008) is 1.5 m.

Table 3-5 summarizes this historical water quality information compared to the recommended shallow lake listing criteria. Because Earley Lake meets the shallow lake water quality standards for all parameters, the MPCA is in the process of removing Earley Lake from the 2010 303(d) Impaired Waters List and Earley Lake was not modeled or assigned phosphorus allocations as part of the TMDL study.

Table 3-5 Earley Lake Historical Nutrient Related Water Quality Parameters

Water Quality Parameter	MPCA's Shallow Lake Eutrophication Standards (NCHF)	Earley Lake Historical (Entire Record) Growing season Average	Earley Lake 10-Year (1999-2008) Growing season Average
Total Phosphorus (µg/L)	≤ 60	54.1	51.4
Chlorophyll *a* (µg/L)	≤ 20	12.7	12.7
Secchi disc (m)	≥ 1.0	1.4	1.5

3.4.1 Baseline Water Quality Modeling

Results of MnLEAP modeling done for Earley Lake suggests that Earley Lake is currently achieving better water quality than would typically be expected (Heiskary and Lindbloom, 1993). MnLEAP predicts total phosphorus concentrations of approximately 85 µg/L (with a standard error of 22 µg/L). The MPCA's eutrophication criteria are at the lower end of this range.

Using the 2006 average conductivity values for Earley Lake the predicted natural phosphorus concentration is estimated to be 13-53 µg/L.

Figure 3-19
EARLEY LAKE
Summer Average (June through September)
Mean Total Phosphorus Concentrations
1994 to 2008

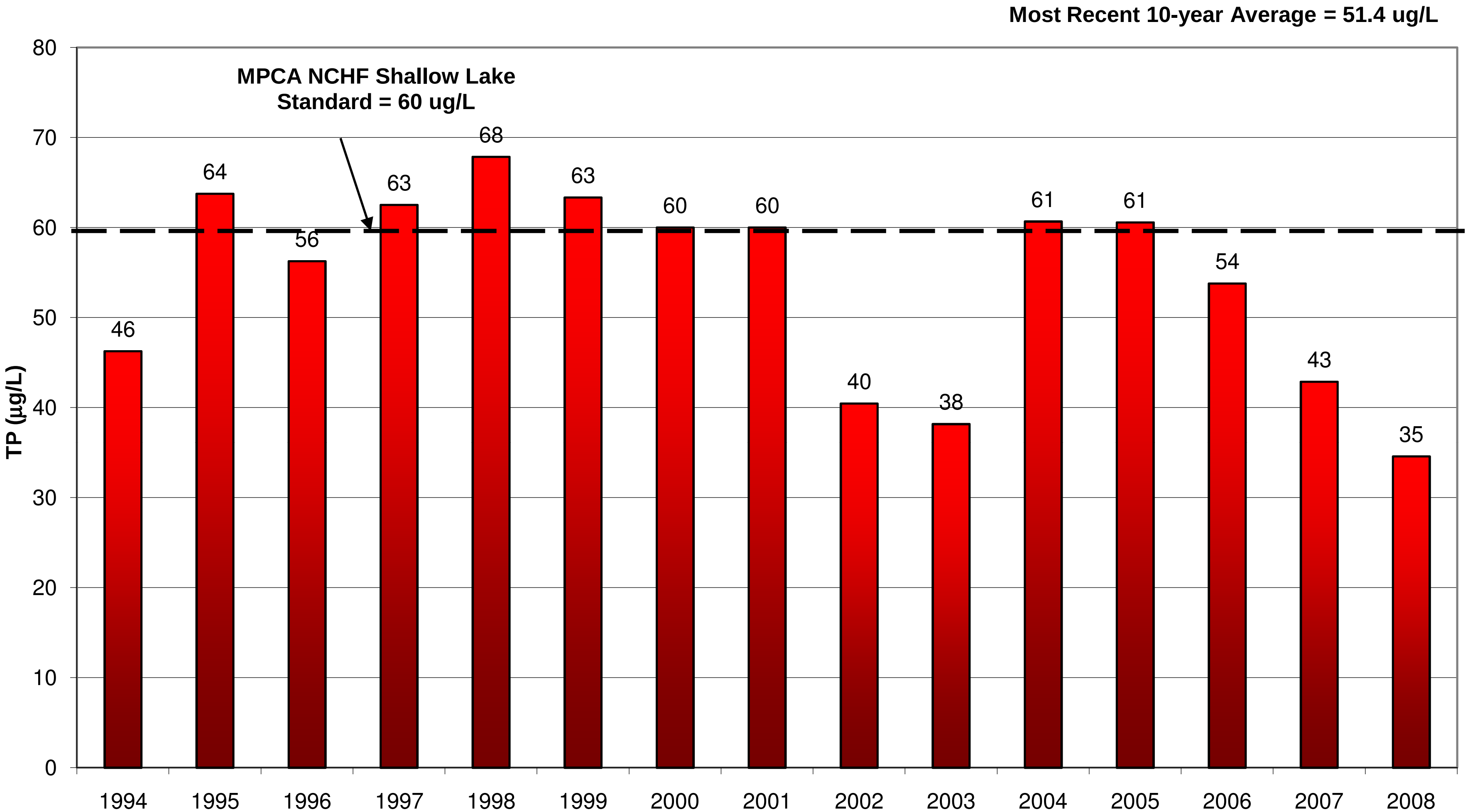


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Figure 3-20
EARLEY LAKE
Summer Average (June through September)
Mean Chlorophyll a Concentrations
1999 to 2008

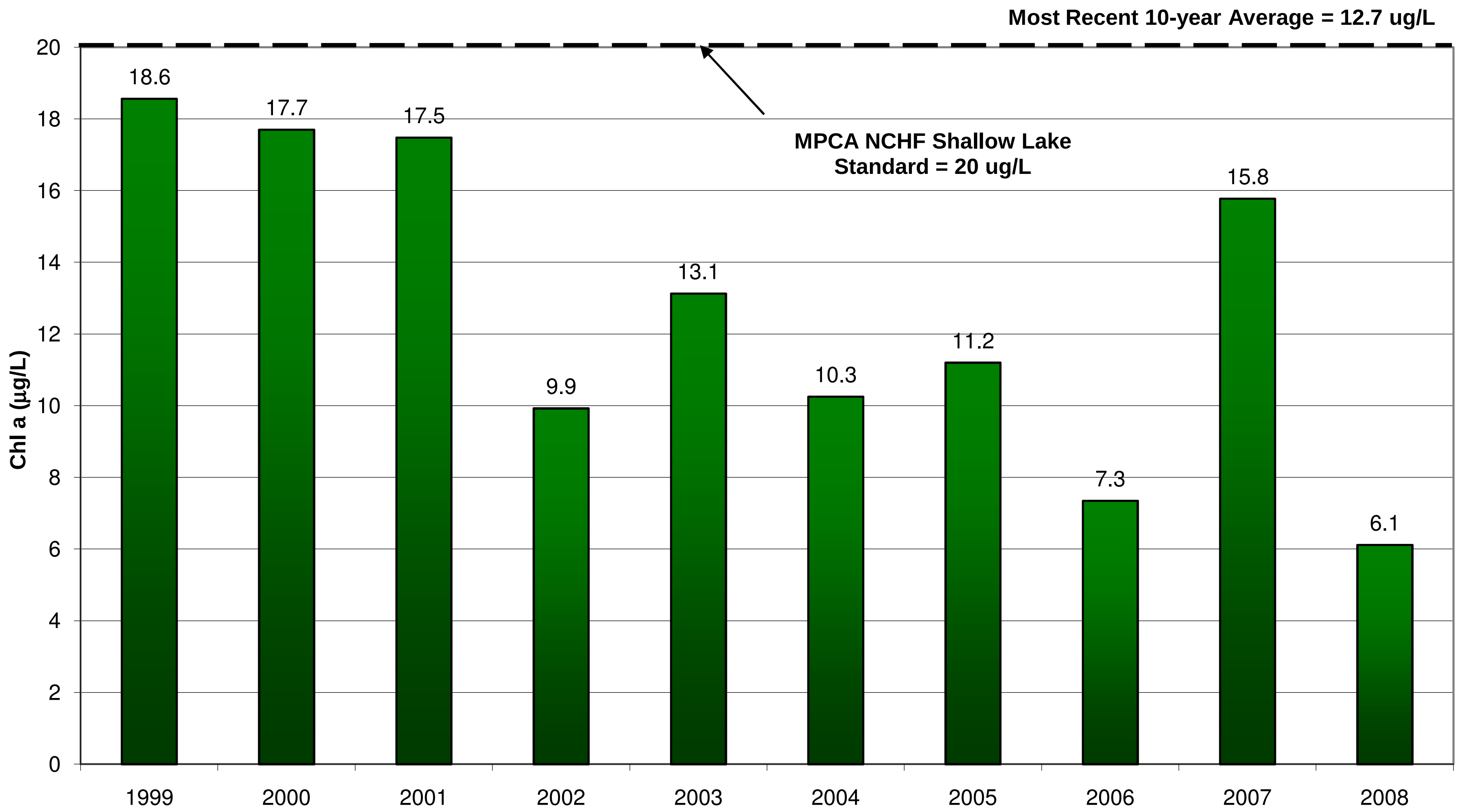

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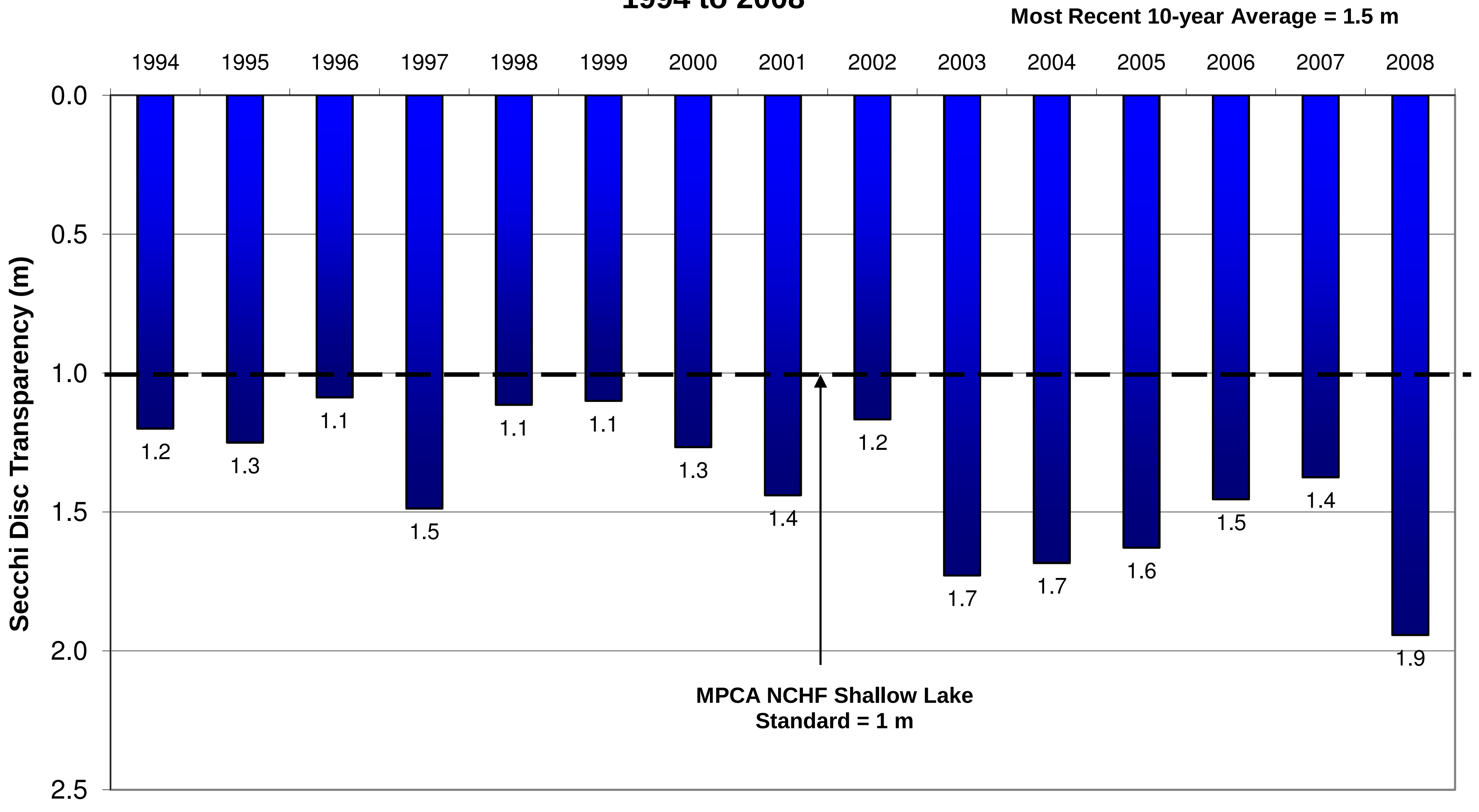
Figure 3-21
EARLEY LAKE
Summer Average (June through September)
Mean Secchi Disc Transparencies
1994 to 2008



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4.0 Source Assessment and Reduction Options

4.1 Water Quality Modeling of Crystal, Keller, and Lee Lakes

Water quality modeling provided the means to estimate the TP sources to Crystal, Keller, and Lee Lakes and estimate their effects on lake water quality. Because the MPCA is in the process of removing Earley Lake from the 303(d) Impaired Waters list, water quality modeling for Earley Lake and its watershed were not performed as part of this TMDL study.

Water quality modeling was two-fold, involving:

- A stormwater runoff model (P8 Urban Catchment Model; IEP, Inc., 1990) that estimated the water and TP loads from each lake's tributary watershed
- An in-lake mass balance model that took the water and TP loads from each lake's watershed and generated the resultant lake TP concentration

The P8 Urban Catchment Model and the in-lake mass balance model are described in more detail below.

4.1.1 P8 Urban Catchment Model

The P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds) Urban Catchment (computer) Model (Version 2.4) was used to estimate watershed runoff and total phosphorus loads from each lake's tributary watershed. The model and its supporting information can be downloaded from the internet at http://wwwalker.net/p8/.

P8 is a useful diagnostic tool for evaluating and designing watershed improvements and BMPs because it can estimate the treatment effect of several different kinds of potential BMPs. P8 tracks stormwater runoff as it carries phosphorus across watersheds and incorporates the treatment effect of detention ponds, infiltration basins, flow splitters, etc. on the TP loads that ultimately reach downstream water bodies. P8 accounts for phosphorus attached to a range of particulate sizes, each with their own settling velocity, tracking their removal accordingly.

The P8 model used in this study was originally developed as part of the *Crystal and Keller Lake Use Attainability Analysis Diagnostic-Feasibility Study: Water Quality Issues and Potential Restorative Measures* (Barr, 2003).

The key inputs to the P8 model are based on the total subwatershed area, the fraction of the watershed that is directly-connected imperviousness, depression storage, as well as the composite pervious area curve number (representing pervious and unconnected impervious areas). Directly connected imperviousness indicates that the runoff generated on these surfaces are hydraulically connected to the drainage systems, while runoff that drains from impervious surfaces to pervious surfaces is not considered directly connected. The P8 model also requires climate data (precipitation and temperature), treatment device configurations information (outlets, storage volumes, seepage rates, etc.) and pollutant loading parameters to estimate pollutants in runoff and removal of pollutants by various BMPs. A detailed discussion about the P8 modeling inputs used for this study is located in Appendix A.

In this study, P8 was used to generate a range of water and phosphorus loadings from each lake's watershed during three different water years (October 1 through September 30) with varying climatic conditions: a wet year (2001-02: 37.2 inches of precipitation); a dry year (2007-08: 25.9 inches of precipitation); and a year with near-average precipitation (2005-06: 31.8 inches of precipitation). The estimated P8 loadings to each lake for each event during the calibration periods can be found in Appendices B, C, and D.

It is not always clear whether a wet, dry or average year will result in the highest in-lake TP concentration. For example, wet years result in larger volumes of runoff to the lakes; if the runoff has high phosphorus concentrations, a wet year may result in a higher lake phosphorus concentration. If the runoff has low phosphorus concentrations, a wet year will likely result in a relatively lower lake phosphorus concentration. The impact of internal phosphorus loads are also affected by climatic conditions. Larger volumes of runoff entering the lake can "flush out" the lake, moving the elevated mass of phosphorus, due to internal loading, out of the system. The converse can be true of dry years; the impact of internal phosphorus loads may be magnified as phosphorus released from the sediment remains in the water column longer. Therefore, by evaluating a range of climatic conditions, a more realistic range of potential lake TP concentration estimates can be made.

The daily water balance model developed for each lake was used in conjunction with the P8 estimated watershed runoff volumes and 2008 lake level data to estimate the groundwater exchange. To validate the runoff volumes and groundwater exchange, P8 was run for the other climatic years (i.e., wet: 2001-2002 and dry: 2005-2006). For each year being evaluated, the P8 model reflected the watershed conditions at the time the lake levels were measured. The water balance was updated with the new runoff and climatic data, and verified against the actual lake level data. Results of the water balance calibration can be found in Appendices B, C, and D for Crystal, Keller, and Lee Lakes, respectively.

4.1.2 In-Lake Mass Balance Modeling

In-lake modeling was accomplished through the creation of a mass balance model that tracked the flow of water and phosphorus through the lake over a range of climatic conditions including wet (2001-2002), dry (2007-2008), and average (2005-2006) conditions. The model considered water and phosphorus loads for a 17-month period. The estimated water and phosphorus loads of the first year (12 months from May through April of the following year) were used to establish the steady-state phosphorus concentration in the lake at the beginning of the calibration period, using published empirical models. The water and phosphorus loads from the remaining five months were used during the calibration of the in-lake mass balance model which was from the beginning of May through the end of September. The in-lake mass balance model included both a water balance as well as a phosphorus balance. Modeling results from June 1 through September 30 were used to estimate the growing season average (as defined by the MPCA).

The key input parameters for the in-lake mass balance model included the unique stage-storage-discharge relationship developed for each lake, direct precipitation and evaporation data, groundwater exchange, the water and total phosphorus loads from the watershed as predicted by the P8 model for wet, dry, and average climatic conditions, and in the cases of Crystal and Keller Lakes the water and phosphorus loads from the upstream lakes (see additional discussion in Sections 4.1.2.1, 4.1.2.2 and 4.1.2.3). These upstream loads were based on the in-lake mass balance models developed for each upstream lake respectively. Additionally, pumping from Crystal Lake to Keller Lake was incorporated during periods when the ferric chloride system was operating. Estimated losses to the groundwater were also included in the modeling.

Prior to conducting the phosphorus mass balance modeling for the individual lake, a water balance model was calibrated to observed lake level data collected during the 17-month time periods representing the various climatic conditions. As part of the water balance calibration, the groundwater exchange was estimated, to provide the best fit between the predicted water levels and the observed water levels.

The phosphorus mass balance modeling comprised two phases. The first step was to predict the steady-state phosphorus concentration in the lake at the beginning of the calibration season. As previously mentioned, the P8 model was used to not only estimate the watershed loads for the calibration period (e.g. May 1, 2006 through Sept. 30, 2006) but also for the year prior (May 1, 2005 through April 30, 2006). These annual loads for the year prior to the calibration period were then used to estimate the steady-state concentration at the beginning of the calibration period. Several published empirical models were evaluated for each lake under the various climatic conditions (wet, dry, and average), and the model that provided the best fit to the observed early season phosphorus data was selected. Table 4-1 summarizes the empirical relationship used to estimate the steady-state phosphorus concentration in each lake. Because the lake dynamics for the three lakes in this TMDL study vary so greatly, an unique steady empirical model that best represented the lake dynamics was selected for each lake rather than applying the same model to all three lakes.

Table 4-1 Steady State Phosphorus Models

Lake	Steady-State Equation
Crystal	Dillon and Rigler (1974) with Nurnberg (1984) phosphorus retention coefficient
Keller	Reckow (1977)
Lee	Vollenweider (1976)

The second step to the calibration of the phosphorus mass balance model was to predict the observed total phosphorus concentrations in the lake during the respective calibration periods (May through September) for each of the climatic conditions. Many of the empirical phosphorus models used to predict total phosphorus concentrations assume the lake to be well-mixed, meaning phosphorus concentrations in the lake are uniform. This assumption is useful in making general predictions of lake conditions, but it does not account for the seasonal changes that can occur with total phosphorus concentrations in a lake.

To calibrate the phosphorus mass balance in-lake water quality model for existing land use conditions, phosphorus loads from the direct watershed for each climatic condition were predicted using the P8 model and were combined with (1) phosphorus loads from upstream lakes (if applicable), (2) atmospheric deposition directly onto the lake surface, and 3) phosphorus release from Curlyleaf pondweed (*Potamogeton crispus*) to estimate the total phosphorus concentration in the lake at each water quality sampling date. Estimated losses due to flushing, the operation of the ferric chloride system, and uptake by Coontail (*Ceratophyllum demersum*) were also accounted for in the phosphorus mass balance model. Coontail is a macrophyte that absorbs its nutrients directly from the water column and its presence could impact the TP concentration observed in the lakes.

To estimate the internal phosphorus loading from other sources or losses (e.g., sediment release, fish, etc.), the predicted phosphorus concentration was compared to the observed in-lake water quality data during that same time period. The magnitude of the internal phosphorus load to the lake's surface waters was deduced by comparing the observed water quality in the lake to the water quality predicted by the in-lake model under existing conditions using the following general mass-balance equation:

P Adjustment = Observed P + Outflow P + Coontail Uptake P –
Runoff P – Upstream P - Atmospheric P – Curlyleaf Pondweed P – P Initial

The key calibration parameter for the in-lake model included the estimation of the internal load that affects the lake's surface waters during the growing season.

Table 4-2 summarizes the results of the in-lake water quality model calibration as well as the in-lake water quality model for existing conditions for Crystal, Keller, and Lee Lakes.

Table 4-2 In-Lake Water Quality Model Calibration for Crystal, Keller, and Lee Lakes

Climatic Condition	Monitoring Data		Calibration Conditions		Existing Conditions	
	Observed Spring TP (ug/L)	Observed Growing Season Average TP (ug/L)	Predicted Spring TP[1] (ug/L)	Predicted Growing Season Average TP[1] (ug/L)	Predicted Spring TP[2] (ug/L)	Predicted Growing Season Average TP[2] (ug/L)
Crystal						
Wet (2002)	21	42	31	42	31	42
Dry (2008)	17	33	28	34	31	36
Average (2006)	27	46	26	50	28	49
Keller						
Wet (2002)	48	70	52	67	51	66
Dry (2008)	53	33	48	31	52	56
Average (2006)	29	92	55	99	62	167
Lee						
Wet (2002)	54	58	33	57	33	57
Dry (2008)	50	49	38	46	38	46
Average (2006)	37	86	42	86	43	87

1 - Calibration conditions assume watershed conditions at time of monitoring and in the cases of Crystal and Keller Lakes, the ferric chloride system is operating in 2006 and 2008; ferric chloride system not operating in 2002.

2 - Existing conditions assumes 2008 watershed conditions and in the cases of Crystal and Keller Lakes, the ferric chloride system is not operating.

See Appendices B, C, and D for tables summarizing the components of the mass balances for Crystal, Keller, and Lee Lakes, respectively, during the calibration period as well as for existing conditions.

Verifying the Internal Load of Phosphorus

The internal load was calculated by deduction, using the in-lake mass balance model and the observed water quality data. To verify that the estimated internal loads predicted by the in-lake mass balance model for each lake were reasonable, the estimated loads were compared to the sediment core analysis performed in the summer of 2008.

The sediment cores collected from Crystal, Keller, and Lee Lakes (twelve, three, and five sediment cores, respectively) were analyzed for mobile phosphorus (mobile P) content. Knowing the mobile P concentration and depth distribution, a regression equation relating mobile P and the maximum possible sediment total phosphorus release rate was used to estimate sediment release rate of total phosphorus during anoxic conditions at the sediment surface. This method is presented in a research article by Pilgrim et al. (2007). This maximum possible release rate was compared to the rate calculated by deduction to confirm that the deduced load was reasonable. A summary of the sediment core analysis for Crystal, Keller, and Lee Lakes can be found in Appendix E.

Macrophyte surveys performed for Crystal, Keller and Lee Lakes indicate the presence of Curlyleaf pondweed, a non-native submerged aquatic macrophyte, in each lake. Because Curlyleaf pondweed dies back in summer it likely contributes to the internal phosphorus loading in each lake, in addition to the release from bottom sediments. The amount of total phosphorus loading from Curlyleaf pondweed was based on the estimated areal coverage and relative density estimates from the early summer surveys (before the die-back of Curlyleaf pondweed in late-June or early-July). If macrophyte survey data were available for the calibration year, these data were used to estimate the coverage and density of Curlyleaf pondweed. In some cases, a macrophyte survey was not available for the calibration period. Then, it was assumed that the macrophyte coverage was similar to that of the other macrophyte survey data available. The estimated biomass phosphorus content was based on data collected as part of a study of Big Lake in Wisconsin (Barr, 2001) and compared to recent biomass measurements made for Medicine Lake (Vlach & Barten, 2006). The phosphorus release rate was based on the Half Moon Lake study (James et al., 2001).

Additionally, coontail is present in all three lakes. Because this macrophyte grows suspended in the water column, rather than in the bottom sediments, it can directly uptake phosphorus from the water column and can impact the observed phosphorus concentrations. Based on the estimated areal coverage and relative density estimates from the early and late summer surveys, the amount of total phosphorus uptake by coontail could be estimated (based on the equations presented by Lombardo and Cooke (2003)) and by coontail density information (Newman, 2004).

4.1.2.1 In-Lake Mass Balance Modeling for Crystal Lake

The following steady-state mass balance equation was used for modeling the total phosphorus concentration of Crystal Lake at the beginning of the open water season:

$$\mathrm{P} = \frac{L(1-R)}{z\rho}$$

where:

P = total phosphorus concentration at the beginning of the open water season (μg/L)

L = areal total phosphorus loading rate (mg/m²/yr)

R = retention coefficient $= \dfrac{15}{(18+q_s)}$, Nurnberg (1984)

q_s = annual areal water outflow load (m/yr)

= Q/A

z = lake mean depth (m)

t_d = hydraulic residence time = (V/Q)

ρ = hydraulic flushing rate (1/yr)

= 1/(t_d)

Q = annual outflow (m³/yr)

V = lake volume (m³)

A = lake surface area (m²)

4.1.2.2 In-Lake Mass Balance Modeling of Keller Lake

The following steady-state mass balance equation was used for modeling the total phosphorus concentration of Keller Lake at the beginning of the open water season:

$$P = \frac{L}{(11.6 + 1.2 * q_s)}$$

where:

P	=	total phosphorus concentration at the beginning of the open water season (µg/L)
L	=	areal total phosphorus loading rate ($mg/m^2/yr$)
q_s	=	annual areal water outflow load (m/yr)
	=	Q/A
Q	=	annual outflow (m^3/yr)
A	=	lake surface area (m^2)

4.1.2.3 In-Lake Mass Balance Modeling of Lee Lake

The following steady-state mass balance equation was used for modeling the total phosphorus concentration of Lee Lake at the beginning of the open water season:

$$P = \frac{L}{(q_s + K_s * \frac{V}{A})}$$

where:

P	=	total phosphorus concentration at the beginning of the open water season (µg/L)
L	=	areal total phosphorus loading rate ($mg/m^2/yr$)
K_s	=	first order settling loss rate per year
	=	v_s/z, with v_s= 10 m/yr
		[typical values for v_s range from 10 m/yr (Vollenweider, 1975) to 16 m/yr (Chapra & Tarapchak, 1976)]
z	=	lake mean depth (m)
q_s	=	annual areal water outflow load (m/yr)
	=	Q/A
Q	=	annual outflow (m^3/yr)
V	=	lake volume (m^3)
A	=	lake surface area (m^2)

4.2 Modeling Results

The calibrated in-lake mass balance models for Crystal, Keller, and Lee Lakes were based on the watershed conditions at the time the water quality sampling was performed (wet (2001- 2002), dry (2007-2008), and average (2005-2006)). For Crystal and Keller Lakes, the ferric chloride system was operating for periods of the summer during dry and average climatic conditions. The ferric chloride system was not operating during wet climatic conditions. The calibration for each of the respective years was used to estimate the internal phosphorus loading from the various sources.

To model existing conditions, the following updates where made to the P8, water balance, and the in-lake water quality modeling:

- The P8 models reflect the current (2008) watershed conditions which were used to develop the water and phosphorus loads inflows to the lakes, for each of the various climatic conditions
- For Crystal and Keller Lakes, it was assumed that the ferric chloride system would no longer be operated by the BDWMO.
- For Crystal and Lee Lakes, the internal loading from the sediments and Curlyleaf pondweed was assumed to be the same as the internal load estimated by the calibrated models.
- For Keller Lake, the internal loading from the sediments was assumed to be the same as the load estimated by the calibrated models. The calibrated loading due to Curlyleaf pondweed was adjusted by a factor of 1.3 to reflect the impact of the ferric chloride system. This factor was based on a comparison of Curlyleaf pondweed survey coverage and densities in Keller Lake during years when the ferric chloride system was and was not operating.

The results summarized in the following sections reflect the existing conditions P8 and in-lake mass balance modeling.

4.2.1 Modeling Results for Crystal Lake

Table 4-3 presents the existing conditions water loads and external and internal total phosphorus loads for Crystal Lake that were calculated using the P8 and in-lake models.

Table 4-3 Water, Total Phosphorus and Internal Load Budgets in Crystal Lake for Average, Dry, and Wet Precipitation Conditions[1]

Precipitation Year	Water Load Over the Water Year (AF)	External Total Phosphorus Load Over the Water Year[3] (lbs)	Internal Total Phosphorus Load Over the Water year (lbs)[2]
Average (2006)	1,946	454	789
Dry (2008)	1,437	336	731
Wet (2002)	2,519	574	1,157

1 – Assumes ferric chloride system no longer operating
2 – Sum of all internal phosphorus loading sources
3 – External sources include all sources of external phosphorus: watershed runoff, atmospheric deposition, and inflow from upstream lakes.

The internal phosphorus loading in Crystal Lake is the result of the senescence of Curlyleaf pondweed, release of phosphorus from lake bottom sediments, and possibly resuspension by spawning and feeding activities of the fishery. The upper layer of lake sediment would contain more recently accumulated phosphorus and the deeper lake sediments contains phosphorus that has historically accumulated prior to the implementation of the existing watershed BMPs.

Macrophyte surveys for Crystal Lake were available for the climatic years considered (2002, 2006, and 2008). In early summer for all three years, Curlyleaf Pondweed was present at approximately 85 to 95 percent of the surveyed sites at a moderate density (within the lakes littoral area). These surveys indicate that Coontail is present throughout the season, covering anywhere from 65 to 92 percent of the surveyed sites by late summer. The invasive macrophyte, Eurasian Watermilfoil, is also present in Crystal Lake, covering 15 to 16 percent of the surveyed sites by late summer at a low density (McComas & Stuckert, 2008).

Using the respective early summer macrophyte surveys for Crystal Lake for each of the various climatic condition years, the loading rates of phosphorus from senescing Curlyleaf pondweed in the lake were estimated. For average climatic conditions, the annual phosphorus load from Curlyleaf pondweed was estimated to be 211 lbs. For dry climatic conditions, the annual load from Curlyleaf pondweed was estimated to be 192 lbs. And for wet climatic conditions, the phosphorus load from Curlyleaf pondweed was estimated to be 245 lbs.

The activity of benthivorous (bottom-feeding) fish (e.g. common carp and bullhead) can resuspend phosphorus into the water column and degrade water quality. Additionally, they can impact the long-term effectiveness of an alum treatment of lake bottom sediments. In addition to benthivorous fish having a negative impact on water quality, significant populations of planktivorous fish (e.g., sunfish, bluegills, and minnows) can also increase turbidity and degrade water quality in a water body (Zimmer et al., 2001). The most recent MDNR fishery survey was completed in 2005 (MDNR, 2005). Bluegills are very abundant in Crystal Lake as were sunfish. Northern pike were sampled in average to low numbers. Largemouth bass were found in abundance. Black and yellow bullhead were found in average numbers as well. Although carp were not sampled, the typical MDNR survey methods often underestimate the number of carp in a system (Sorenson, 2009).

The internal load from Crystal Lake's sediment appears to be fairly constant during the periods of stratification through the summer months. The total phosphorus isopleth diagrams (Figure 3-6a and Figure 3-6b) and monitoring data provided useful information in determining when the lake experienced an internal load of phosphorus and when it did not.

In addition, the magnitude of the lake's internal load value was verified by estimating the potential release rate of total phosphorus from Crystal Lake sediment. The maximum possible loading rate of mobile phosphorus from Crystal Lake sediment was estimated to be 4.37 $mg/m^2/day$. This loading rate was applied to the growing season months (122 days), to come up with an existing internal phosphorus load of 1389 lbs per year from the lake's bottom sediments. The in-lake mass balance model estimated the annual internal phosphorus load was 578 lbs for average climatic conditions (with the likely sources being release from the bottom sediments as well as the activity of benthivorous fish). The annual internal loads for dry and wet conditions were estimated to be 539 lbs and 912 lbs, respectively. All of the estimated internal phosphorus loads estimated by the mass balance modeling were less than the maximum expected loading resulting from the sediment core analysis, indicating that the loads predicted by the model appear reasonable.

Table 4-4 compares the estimated internal sediment total phosphorus load (based on the sediment core analysis) to the internal loads deduced for the three precipitation scenarios in the existing conditions in-lake model. These results are reasonable, given the different degrees of lake mixing in the lake over the three different growing seasons.

Table 4-4 Estimated Internal Phosphorus Load, Not Including Curlyleaf Pondweed Senescence for Crystal Lake[1]

Scenario	Internal Phosphorus Load Over the Water Year (lbs)[3]	Percent of Maximum Estimated Internal Load (%)	Phosphorus Release Rate ($mg/m^2/d$)
Maximum Possible Phosphorus Load based on the Sediment Analysis	1,389	100	4.37
Average[2] (2006)	578	42	1.82
Dry[2] (2008)	539	39	1.70
Wet[2] (2002)	912	65	2.87

1 – Assumes ferric chloride system no longer operating
2 – The variability between the sediment core analysis and the mass balance modeling estimates are likely because of (1) limited number of sediment cores analyzed (2) impacts of fishery activities, (3) phosphorus is being released from deeper sediments, (4) organic material phosphorus release, (5) underestimating the phosphorus release from Curlyleaf pondweed senescence.
3 – Does not include phosphorus load attributed to the senescence of Curlyleaf pondweed.

4.2.2 Modeling Results for Keller Lake

Table 4-5 presents the existing conditions water load and external and internal total phosphorus loads for Keller Lake that were calculated using the P8 and in-lake models.

Table 4-5 Water, Total Phosphorus and Internal Load Budgets in Keller Lake for Average, Dry, and Wet Precipitation Conditions[1]

Precipitation Year	Water Load Over the Water Year (AF)	External Total Phosphorus Load Over the Water Year[3] (lbs)	Internal Total Phosphorus Load Over the Water year (lbs)[2]
Average (2006)	850	434	288
Dry (2008)	619	316	37
Wet (2002)	1,037	522	59

1 – Assumes ferric chloride system no longer operating
2 – Sum of all internal phosphorus loading sources
3 – External sources include all sources of external phosphorus: watershed runoff and atmospheric deposition.

The internal phosphorus loading in Keller Lake is the result of the senescence of Curlyleaf pondweed, the release of phosphorus of lake bottom sediments, and possibly resuspension by spawning and feeding activities of the fishery.

Macrophyte surveys for Keller Lake were available for average and dry climatic conditions (2006 and 2008). Since a survey was not available for the wet climatic conditions (2002), the macrophyte survey results from 2003 were used to estimate the macrophyte coverage and density present in 2002. In early summer for all three years, Curlyleaf Pondweed was present at approximately 68 to 86 percent of the surveyed sites at a moderate density. The macrophyte surveys indicate that Coontail is present throughout the season, covering anywhere from 54 to 97 percent of the surveyed sites by late summer at a moderate density. The invasive macrophyte, Eurasian Watermilfoil, is also present in Keller Lake, covering 46 to 95 percent of the surveyed sites by late summer at a low density (McComas & Stuckert, 2008).

The most recent MDNR fishery survey for Keller Lake was completed in 1985 (MDNR, 1985). Both bluegills and crappies were very abundant. Sunfish were also in the lake. Black bullhead were also present in Keller Lake.

The internal loading rates of phosphorus from senescing Curlyleaf pondweed in Keller Lake were estimated using the respective early summer macrophyte surveys for each of the various climatic condition years. For average climatic conditions, the annual phosphorus load from Curlyleaf pondweed was estimated to be 54 lbs. For dry climatic conditions, the annual load from Curlyleaf pondweed was estimated to be 29 lbs, and for wet climatic conditions, the phosphorus load from Curlyleaf pondweed was estimated to be 28 lbs.

The internal load from Keller Lake's sediments is highly variable throughout the season as well as between the various climatic conditions. The total phosphorus isopleth diagrams (Figure 3-12a and Figure 3-12b) and monitoring data provided useful information in determining when the lake experienced an internal load of phosphorus and when it did not. In addition, the magnitude of the lake's internal load value was verified by estimating the potential release rate of total phosphorus from Keller Lake sediment. The maximum possible loading rate of mobile phosphorus from Keller Lake sediment was estimated to be 2.8 $mg/m^2/day$, based on the sediment core analysis. This loading rate was applied to the growing season months (122 days), to come up with an existing internal phosphorus load of 160 lbs per year from the lake's bottom sediments. The in-lake mass balance model estimated the annual phosphorus load from sediment release and fish activity to be 234 lbs for average climatic conditions. The annual internal loads from the sediments and fish activity for dry and wet conditions were estimated to be 8 lbs and 31 lbs, respectively.

The estimated sediment phosphorus loading during dry and wet climatic conditions are significantly less than the expected loading from the sediment core analysis. Several reasons why the mass balance modeling is likely estimating more internal load than the sediment core analysis for average conditions include (1) limited number of sediment cores (3 cores) analyzed (i.e., high variability of releasable phosphorus over a lake's bottom), (2) significant impacts of fishery activities, (3) phosphorus is being released from deeper sediments (only the top 20-30 centimeters are analyzed for mobile phosphorus), (4) organic material phosphorus release, and (5) underestimating the phosphorus release from Curlyleaf pondweed senescence. Therefore the combined internal loading predicted by the mass-balance model appears reasonable.

Table 4-6 compares the estimated internal sediment total phosphorus load (based on the sediment core analysis) to the internal loads deduced for the three precipitation scenarios in the existing conditions in-lake model. These results are reasonable, given the different degrees of lake mixing in the lake over the three different growing seasons.

Table 4-6 Estimated Internal Phosphorus Load, Not Including Curlyleaf Pondweed Senescence for Keller[1]

Scenario	Internal Phosphorus Load Over the Water Year (lbs)[3]	Percent of Maximum Estimated Internal Load (%)	Phosphorus Release Rate ($mg/m^2/d$)
Maximum Possible Phosphorus Load based on the Sediment Analysis	160	100	2.8
Average[2] (2006)	234	146	4.1
Dry[2] (2008)	8	5	0.1
Wet[2] (2002)	31	19	0.5

1 – Assumes ferric chloride system no longer operating
2 – The variability between the sediment core analysis and the mass balance modeling estimates are likely because of (1) limited number of sediment cores analyzed (2) impacts of fishery activities, (3) phosphorus is being released from deeper sediments, (4) organic material phosphorus release, (5) underestimating the phosphorus release from Curlyleaf pondweed senescence.
3 – Does not include phosphorus load attributed to the senescence of Curlyleaf pondweed.

4.2.3 Modeling Results for Lee Lake

Table 4-7 presents the existing conditions water load and external and internal total phosphorus loads for Lee Lake that were calculated using the P8 and in-lake models.

Table 4-7 Water, Total Phosphorus and Internal Load Budgets in Lee Lake for Average, Dry, and Wet Precipitation Conditions

Precipitation Year	Water Load Over the Water Year (AF)	External Total Phosphorus Load Over the Water Year[2] (lbs)	Internal Total Phosphorus Load Over the Water year (lbs)[1]
Average (2006)	165	70	74
Dry (2008)	123	55	27
Wet (2002)	205	85	37

1 – Sum of all internal phosphorus loading sources
2 – External sources include all sources of external phosphorus: watershed runoff and atmospheric deposition.

The internal phosphorus loading in Lee Lake is the result of the senescence of Curlyleaf pondweed, release of phosphorus from lake bottom sediments, and possibly resuspension by spawning and feeding activities of the fishery.

Macrophyte surveys for Lee Lake were available for dry climatic conditions (2008) only. Since a survey was not available for the wet climatic conditions (2002), the macrophyte survey results from 2003 were used to estimate the macrophyte coverage and density during 2002. For average climatic conditions (2006), the average coverage and density from the 2003 and 2008 surveys was used. In early summer, Curlyleaf Pondweed was present at approximately 80 to 90 percent of the surveyed sites. The macrophyte surveys indicate that Coontail is present throughout the season, covering approximately 85 percent of the surveyed sites by late summer. The invasive macrophyte, Eurasian Watermilfoil, is currently not present in Lee Lake (McComas & Stuckert, 2008).

Using the available early summer macrophyte surveys for Lee Lake, the loading rates of phosphorus from senescing Curlyleaf pondweed in the lake were estimated. For average climatic conditions, the annual phosphorus load from Curlyleaf pondweed was estimated to be 10 lbs. For dry climatic conditions, the annual load from Curlyleaf pondweed was estimated to be 10 lbs, and for wet climatic conditions, the phosphorus load from Curlyleaf pondweed was estimated to be 11 lbs.

The most recent MDNR fishery survey for Lee Lake was completed in 1991 (MDNR, 1991). Bluegills were very abundant along with black bullhead. Although carp were not sampled, the typical MDNR survey methods often underestimate the number of carp in a system (Sorenson, 2009). In recent years, the City of Lakeville removed significant numbers of small planktivorous fish from Lee Lake.

The internal load from Lee Lake's sediments appears to be fairly constant throughout the season. The total phosphorus isopleth diagram (Figure 3-18) and monitoring data provided useful information in determining when the lake experienced an internal load of phosphorus and when it did not. Additionally, the magnitude of the lake's internal load value was verified by estimating the potential release rate of total phosphorus from Lee Lake sediment. The maximum possible loading rate of mobile phosphorus from Lee Lake sediment was estimated to be 13.5 $mg/m^2/day$, based on the sediment core analysis. This loading rate was applied to the growing season months (122 days), to come up with an existing internal phosphorus load of 282 lbs per year from the lake's bottom sediments. The in-lake mass balance model estimated the annual phosphorus load from sediment release and fish activity to be 64 lbs for average climatic conditions. The annual internal loads from the sediments and fish activity for dry and wet conditions were estimated to be 17 lbs and 26 lbs, respectively. All of the estimated internal sediment phosphorus loads were less than the maximum expected loading resulting from the sediment core analysis, indicating that the internal loads predicted by the mass-balance model are reasonable.

Table 4-8 compares the estimated internal sediment total phosphorus load (based on the sediment core analysis) to the internal loads deduced for the three precipitation scenarios in the existing conditions in-lake model. These results are reasonable, given the different degrees of lake mixing over the three different growing seasons.

Table 4-8 Estimated Internal Phosphorus Load, Not Including Curlyleaf Pondweed Senescence for Lee Lake

Scenario	Internal Phosphorus Load Over the Water Year[2] (lbs)	Percent of Maximum Estimated Internal Load (%)	Phosphorus Release Rate ($mg/m^2/d$)
Maximum Possible Phosphorus Load based on the Sediment Analysis	282	100	13.5
Average[1] (2006)	64	23	3.1
Dry[1] (2008)	17	6	0.8
Wet[1] (2002)	26	9	1.3

1 – The variability between the sediment core analysis and the mass balance modeling estimates are likely because of 1) limited number of sediment cores analyzed 2) impacts of fishery activities, 3) phosphorus is being released from deeper sediments, 4) organic material phosphorus release, 5) underestimating the phosphorus release from Curlyleaf pondweed senescence.
2 – Does not include phosphorus load attributed to the senescence of Curlyleaf pondweed.

5.0 TMDL Allocation Analysis

The TMDL is defined by the loading capacity for a given pollutant which is distributed among its components as follows (EPA 1999):

TMDL = WLA + LA + MOS + Reserve Capacity

Where:

WLA	=	Wasteload Allocation to Point (Permitted) Sources
LA	=	Load Allocation to NonPoint (Non-Permitted) Sources
MOS	=	Margin of Safety
Reserve Capacity	=	Load set aside for future allocations from growth or changes

This section will define each of the terms in this equation for Crystal, Keller, and Lee Lakes and will discuss seasonal variation and reasonable assurances that the TMDL for each lake pursued.

5.1 Critical Climatic Conditions

Of the three precipitation scenarios evaluated in this study, the critical year (the one resulting in the worst water quality) for Crystal, Keller, and Lee Lakes was the "average" precipitation scenario (the growing season of 2006). During that year, the watershed phosphorus loads and the lakes' internal loads of phosphorus combined to produce higher concentrations than in the other years modeled for this study (dry – 2008, wet – 2002).

While it is true that the wet year precipitation scenario results in a larger total phosphorus load to the lakes from their watersheds, it does not result in a higher lake total phosphorus concentration. In wet climatic conditions, the total phosphorus is diluted and the lake's flushing rate decreases the overall total phosphorus concentration. During the dry year precipitation scenario, the phosphorus loads from the watersheds are lower, and internally loaded phosphorus from the lakes was typically lower than during average conditions.

For this reason, the average climatic condition was determined to be the critical condition and the wasteload and load allocations presented in this TMDL are based on the reduction required to bring the lakes' growing season average total phosphorus concentrations below the MPCA eutrophication standards for the average climatic condition. Using the critical climatic condition to establish the TMDL for the lakes contributes to the implicit MOS. Also, because it is a year of average precipitation, it serves as a fair baseline to set wasteload allocations for municipalities. It is reasonable to expect that, on average, the MS4s in the watersheds will have existing watershed TP loads on the order of those modeled during the 2006 water year.

5.2 Crystal Lake TMDL Allocation Analysis

5.2.1 Load Capacity Estimation

The existing conditions in-lake mass balance model was used to estimate the total phosphorus load to Crystal Lake that would achieve the MPCA's deep lake eutrophication standard (≤ 40 µg/L) during average climatic conditions. This maximum allowable load is referred to as the lake's loading capacity. When estimating the load capacity, it was assumed that the MPCA standard was 10 percent less (36 µg/L) than the actual standard. Using the water quality relationships summarized in Section 3.1 (see Figures 3-4 and 3-5), it is expected that at a TP concentration of 36 µg/L, the resulting Secchi depth (2.0 meters) will meet the MPCA standard; however, the predicted Chlorophyll-*a* concentration (22.5 µg/L) will still exceed the MPCA standard (see Appendix B-24).

The in-lake water quality model for the average climatic conditions assumed that the watershed was reflective of existing watershed (2008) conditions, that the ferric chloride system was no longer operating, and that the upstream lakes (Lee and Keller) were meeting their respective MPCA total phosphorus goals (60 µg/L for both lakes). Figure 5-1 summarizes the required phosphorus load reductions to achieve the MPCA water quality standards for all climatic conditions.

To estimate the required load reduction (resulting in the load capacity for Crystal Lake), the existing conditions in-lake mass balance model was used to evaluate reductions in the loads to the lake that would result in average growing season phosphorus concentrations that achieve the MPCA standard for Crystal Lake. For the load capacity analysis, it was assumed that the upstream water bodies (Keller and Lee Lakes) were achieving the MPCA shallow lake standard for phosphorus (60 µg/L), that atmospheric deposition would remain the same as for existing conditions, and that the spring phosphorus concentration was also the same as for existing conditions (a conservative assumption since it is likely that if phosphorus loads to the lake are reduced, the springtime concentration will likely also be reduced). Then an equal percent reduction was applied to all other sources of phosphorus to the lake including watershed runoff, Curlyleaf pondweed, and the estimated internal load.

The components of the Crystal Lake TMDL load allocation analysis for average climatic conditions, including the estimated phosphorus loading capacity (i.e., the amount of phosphorus that the lake can receive and still achieve the water quality standard) for the lake are summarized in the following sections. For average climatic conditions, a 30.7 percent reduction in the overall total phosphorus load (internal and external) to Crystal Lake is required to meet the MPCA's deep lake standard, resulting in an annual phosphorus load capacity of 862 lbs.

5.2.2 Wasteload Allocations to Permitted Sources

All of Crystal Lake's allocated watershed loads are expressed as wasteload allocations because the communities and governmental entities in the watershed are all defined as Municipal Separate Storm Sewer Systems (MS4s), requiring National Pollutant Discharge Elimination System (NPDES) permits for discharge of stormwater (Permit Number MNR040000). Figure 5-2 shows the different MS4 entities that make up the Crystal Lake direct tributary watershed, not including those contributing to Keller and Lee Lakes upstream of Crystal Lake (see Sections 5.3 and 5.4 for more information about the TMDL load allocations specific to those water bodies).

The MS4 identification number and tributary watershed area associated with each of the MS4s, including total area, total impervious area, and directly connected impervious area, are listed in Table 5-1.

Table 5-1 MS4 Identification Numbers and Tributary Watershed Area Associated with each MS4 in the Crystal Lake Watershed

MS4	MS4 Identification Number	Watershed Area within MS4 (acres)	Total Impervious Area within MS4 (acres)	Directly Connected Impervious Area within MS4 (acres)
Burnsville	MS400076	472	81	56
Lakeville	MS400099	1091	280	215
Dakota County	MS400132	74	27	27
MnDOT	MS400170	82	33	33
TOTAL[1]		1719	421	331

1 – Does not include Crystal Lake surface area = 292.5 acres (located within Burnsville and Lakeville)

The wasteload allocations for each of the MS4 communities in the Crystal Lake watershed were estimated as part of this study. However, wasteload allocations for new construction, redevelopment and/or all other related land disturbances are considered to be minimal because they are regulated under the cities' permitting programs. Therefore, loads from construction, redevelopment and/or other related land disturbances can be considered to be included in the WLAs for the MS4s. There are no known permitted municipal wastewater or industrial dischargers in the Crystal Lake watershed.

The P8 modeling was done to calculate existing loads with no BMPs (representing watershed runoff with no treatment) as well as to estimate the existing loads accounting for BMPs (e.g., ponds, wetlands, and infiltration) that are currently in place (constructed as of 2008). Because the P8 modeling is performed at the subwatershed scale rather than the MS4 scale (see subwatersheds in Figure 2-3), a method to distribute the existing watershed loads predicted by P8 back to MS4s needed to be developed.

Directly connected impervious surfaces generate the majority of the overall runoff volumes and pollutant loads from a watershed in the P8 model. Because of this, the amount of directly connected impervious area was used to redistribute the estimated subwatershed loads for the existing conditions (with and without BMPs) back to the MS4s within each subwatershed. The benefits of the existing BMPs (TP removals) are distributed to the MS4s located within the same subwatershed as the BMP, again based on the proportion of directly connected impervious area in each MS4 within the subwatershed. This methodology only considers what is happening in the ponds direct watershed and does not allocate the removal benefits back through upstream ponds.

For this TMDL study, the approach to estimating the components of the TMDL equation and to meet the loading capacity for the lake, is to first address the watershed phosphorus loads (wasteload allocations) to Crystal Lake to the maximum extent practicable, followed by addressing the internal phosphorus loads (load allocations). To first address the loads from the watershed runoff, the wasteload allocations for the MS4s within the Crystal Lake watershed were initially estimated applying a runoff total phosphorus concentration of 150 μg/L to the existing condition annual watershed runoff load (919 acre-feet). The total phosphorus concentration of 150 μg/L is a typical concentration of urban stormwater runoff after treatment by a water quality treatment pond (MPCA, 2005), and is a reasonable expectation for watershed runoff total phosphorus loads after treatment. The estimated wasteload allocation was then redistributed back to the MS4s within the Crystal Lake watershed based on the total area of each MS4 within the watershed, resulting in an equal area total phosphorus loading rate applied to each MS4.

In the case of the Crystal Lake watershed, the majority of the existing conditions watershed runoff from the MS4s already receives a significant amount of treatment due to the number of ponds and wetlands throughout the watershed. For some MS4s within the watershed, the estimated wasteload allocation for a given MS4 could be higher than the existing conditions load. This is true for the Cities of Burnsville and Lakeville, as well as Dakota County. Because these regulated MS4s have already reduced their loads beyond the target watershed load for the TMDL, the wasteload allocations for the Burnsville, Lakeville, and Dakota County were assumed to be the same as the existing conditions load to meet anti-degradation requirements. The modeling indicates that a reduction in total phosphorus load is required for MnDOT to meet its wasteload allocation. Table 5-2 compares the existing conditions load with the original estimate of the wasteload allocation.

Table 5-2 Crystal Lake Annual Existing Conditions Load vs. Original Estimated TMDL Wasteload Allocation

MS4	Existing Conditions TP Load (lbs/yr)	Estimated TMDL Wasteload Allocation (lbs/yr)	Estimated Reduction (lbs/yr)
Burnsville	67	102	Anti-degradation[1]
Lakeville	230	239	Anti-degradation[1]
Dakota County	8	16	Anti-degradation[1]
MnDOT	30	18	12

1 – Because the estimated wasteload allocation assuming a watershed runoff concentration of 150 ug/L results in a higher load than for existing conditions, anti-degradation applies and the TMDL wasteload allocation for those MS4s will be set equal to the existing conditions load. See Table 5-3 for the final TMDL wasteload allocation for Crystal Lake.

5.2.3 Load Allocations to Non-Permitted Sources

The load allocations for Crystal Lake are attributable to the atmospheric deposition, upstream lakes (Keller and Lee), and internal loads of phosphorus to Crystal Lake.

5.2.3.1 Atmospheric Deposition

Phosphorus loading from atmospheric deposition onto the lake surface was estimated assuming a 0.2615 kg/ha/yr rate (Barr, 2005). This loading rate was applied to the surface area of the lake resulting in an annual TP load of 68 pounds.

5.2.3.2 Keller Lake Discharge

To estimate the existing conditions total phosphorus load from Keller Lake to Crystal Lake, the in-lake mass balance model (See Sections 4.1.2 and 4.2.2) for existing conditions was used. Again, for this TMDL study, existing conditions assumes that the ferric chloride system is no longer operating.

For Keller Lake, it was assumed that the Keller Lake water quality was at the MPCA's shallow lake standard (60 µg/L). This total phosphorus concentration was applied to the existing conditions annual discharge volume from Keller Lake to Crystal Lake to estimate the TMDL load allocation (40 pounds annually). Water quality improvements are needed for Keller Lake to meet the shallow lake standard throughout the growing season. See Section 5.3 for more information on the Keller Lake TMDL load allocation analysis.

5.2.3.3 Lee Lake Discharge

To estimate the existing conditions total phosphorus load from Lee Lake to Crystal Lake, the in-lake mass balance model (See Sections 4.1.2 and 4.2.3) for existing conditions was used.

For Lee Lake, it was initially assumed that the Lee Lake water quality was at the MPCA's shallow lake standard (60 μg/L). This total phosphorus concentration was applied to the existing conditions annual discharge volume from Lee Lake to Crystal Lake to estimate the TMDL load allocation. However, this method resulted in a higher phosphorus load to Crystal Lake than was estimated for existing conditions as the water quality in Lee Lake during periods of discharge under average climatic conditions (2005-2006) was less than the MPCA's shallow lake standard. Lee Lake typically acts as a land-locked basin and rarely discharges to Crystal Lake. To maintain anti-degradation, the TMDL load allocation for Lee Lake was assumed to be the same as the load estimated for existing conditions (2 pounds annually). Water quality improvements are needed for Lee Lake to meet the shallow lake standard. See Section 5.4 for more information on the Lee Lake TMDL load allocation analysis.

5.2.3.4 Internal Loading

The estimated internal phosphorus loading to Crystal Lake is the likely the result of the senescing of Curlyleaf pondweed, the release from lake-bottom sediments, and resuspension due to benthivorous and planktivorous fish activity. The existing conditions internal load is the sum of the estimated load due to Curlyleaf pondweed as well as the internal load back-calculated as part of the in-lake modeling. The TMDL total load allocation for the internal loading within Crystal Lake was back-calculated based on the difference between the estimated total load capacity for the lake and the other components of the TMDL equation (atmospheric deposition, Keller Lake discharge, Lee Lake discharge, the Wasteload Allocation, Margin of Safety (see Section 5.5) and Reserve Capacity (see Section 5.6). The estimated load allocation for internal phosphorus sources is 429 pounds annually resulting in a required reduction of 46 percent in the internal loads to Crystal Lake to meet the TMDL load capacity. An application of alum to the lake sediments will decrease the internal phosphorus load by 80 percent (Welch and Cook, 1999) and will likely be effective for approximately 10 years, depending on the control of watershed nutrient loads. Whole-lake herbicide treatments for Curlyleaf pondweed are still considered experimental and the long-term effectiveness of a series of herbicide treatments on the reduction in Curlyleaf pondweed is unknown. It is likely even after multi-year, whole-lake treatments, follow-up spot treatments will be needed. However, recent studies have shown an 85 to 98 percent reduction in the coverage of Curlyleaf pondweed during the year of treatment (Barr, 2010; Skogerboe et al., 2008; Jones and Johnson, 2009).

Therefore, the expected reduction by typical in-lake management techniques to control internal phosphorus loads (e.g. alum treatment of the sediments, whole-lake treatment of Curlyleaf pondweed) is estimated to be approximately 80 percent; therefore the internal load allocation (and the associated reduction) is reasonable for Crystal Lake.

Reducing the availability of phosphorus released from the lake sediment (recently and historically deposited sediments), in conjunction with reductions in the watershed load by MnDOT, BMP maintenance by Burnsville, Lakeville and Dakota County, and treatment of Curlyleaf pondweed are expected to lead to long-term restoration of the water quality in Crystal Lake.

Table 5-3 summarizes the existing conditions loads to Crystal Lake, as well as the annual TMDL wasteload and load allocations.

Table 5-3 Crystal Lake Annual[4] Total Phosphorus Load Allocations for Average (Critical) Climatic Conditions

TP Source	Existing Conditions without BMPs[1] (lbs/yr)	Existing Conditions with 2008 BMPs[1] (lbs/yr)	Percent Reduction by Existing BMPs (%)	TMDL Allocation (lbs/yr)	TMDL Allocation (lbs/day)	Required Load Reduction (lbs/yr)	Percent Reduction From Existing Load (%)
Wasteload Allocations (Permitted Sources)							
Burnsville (MS400076)	102	67	34	67	0.183	0	0
Lakeville (MS400099)	502	230	54	230	0.630	0	0
Dakota County (MS400132)	59	8	86	8	0.022	0	0
MnDOT (MS400170)	64	30	53	18	0.049	12	40
Total Wasteload Sources	**727**	**335**	**54**	**323**	**0.884**	**12**	**4**
Load Allocations (Non-Permitted Sources)							
Atmospheric Deposition		68		68	0.186	0	0
Keller Lake		49		40	0.110	9	18
Lee Lake		2		2	0.005	0	0
Internal Sources[5]		789		429	1.175	360	46
Total Load Sources		**908**		**539**	**1.476**	**369**	**41**
Margin of Safety[2]							
--		--		Both Implicit and Explicit MOS		--	--
Reserve Capacity[3]							
--		--		--	--	**--**	--
Overall Source Total		**1,243**		**862**	**2.361**	**381**	**30.7**

1 – Assumes the ferric chloride system is not operating

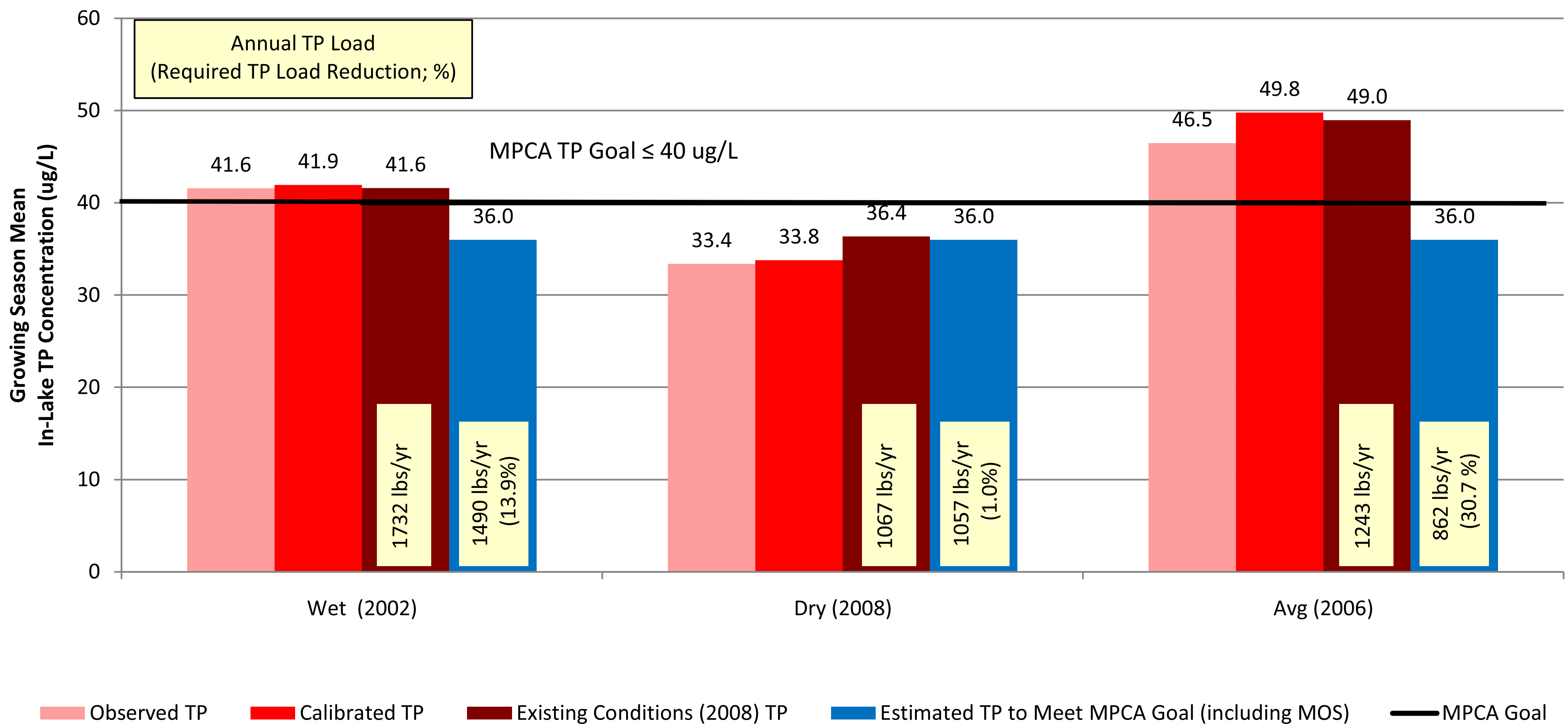
2 – See Section 5.5 for a discussion of the Margin of Safety

3 – See Section 5.6 for a discussion of the Reserve Capacity

4 – Based on 2006 water year (October 1, 2005 – September 30, 2006)

5 – Reflects the sum of all internal sources of phosphorus (e.g. Curlyleaf pondweed, sediment release)

Figure 5-1
Crystal Lake Growing Season Mean TP Concentrations, Annual TP Load, and Required TP Load Reduction to Meet MPCA Water Quality Standards



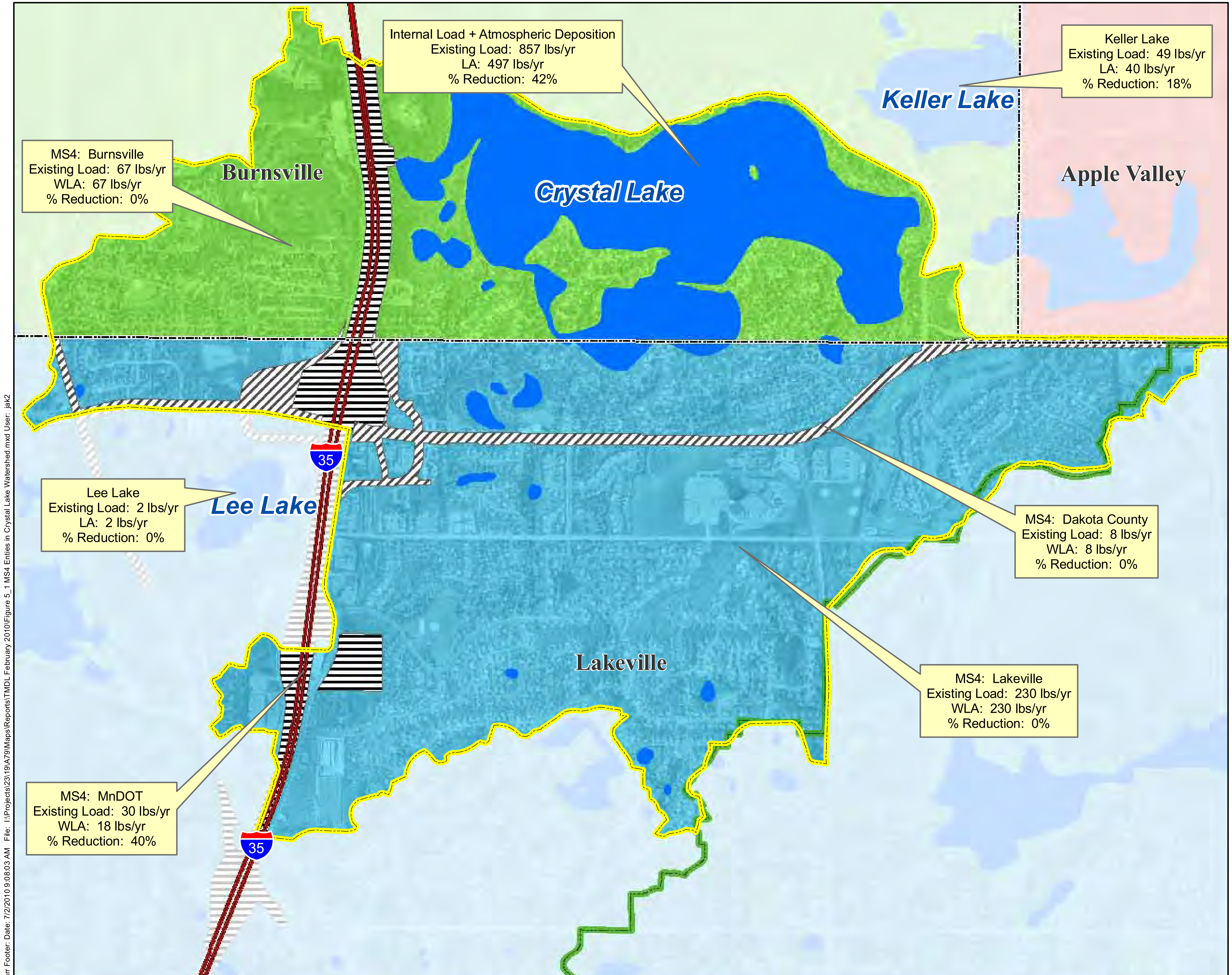


Figure 5-2
Crystal Lake Watershed:
MS4 Entities and TMDL Load
Allocation Summary

Crystal, Keller, and Lee Lakes
Nutrient Impairment TMDL and Earley Lake
Water Quality Assessment Report
BDWMO & MPCA

5.3 Keller Lake TMDL Allocation Analysis

5.3.1 Load Capacity Estimation

The existing conditions in-lake mass balance model was used to estimate the maximum allowable total phosphorus load to Keller Lake that would achieve the MPCA's shallow lake standard (≤ 60 µg/L) during average climatic conditions. When estimating the load capacity, it was assumed that the MPCA standard was 10 percent less (54 µg/L) than the actual standard. Using the water quality relationships summarized in Section 3.2 (see Figures 3-10 and 3-11), it is expected that at a TP concentration of 54 µg/L, the resulting Secchi depth (1.4 meters) will meet the MPCA standard along with the predicted Chlorophyll-*a* concentration (16.4 µg/L) (see Appendix C-26).

The in-lake water quality model for the average climatic conditions assumed that the watershed was reflective of existing watershed (2008) conditions and that the ferric chloride system was no longer operating. Figure 5-3 summarizes the required phosphorus load reductions to achieve the MPCA water quality standards for all climatic conditions.

To estimate the required load reduction (resulting in the load capacity for Keller Lake), the existing conditions in-lake mass balance model was used to evaluate reductions in the loads to the lake that would result in average growing season phosphorus concentrations that achieve the MPCA standard for Keller Lake. For the load capacity analysis, it was assumed that atmospheric deposition would remain the same as for existing conditions and that the spring phosphorus concentration was also the same as for existing conditions (a conservative assumption since it is likely that if phosphorus loads to the lake are reduced, the springtime concentration will likely also be reduced). Then an equal percent reduction was applied to all other sources of phosphorus to the lake including watershed runoff, Curlyleaf pondweed, and the estimated internal load.

The components of the Keller Lake TMDL load allocation analysis for average climatic conditions, including the estimated phosphorus loading capacity (i.e., the amount of phosphorus that the lake can receive and still achieve the water quality standard) for the lake are summarized in the following sections. For average climatic conditions, a 62.2 percent reduction in the overall total phosphorus load (internal and external) to Keller Lake is required to meet the MPCA's shallow lake standard, resulting in an annual phosphorus load capacity of 272 lbs.

5.3.2 Wasteload Allocations to Permitted Sources

All of Keller Lake's allocated watershed loads are expressed as wasteload allocations because the communities and governmental entities in the watershed are all defined as MS4s, requiring NPDES permits for the discharge of stormwater (Permit Number MNR040000). Figure 5-4 shows the different MS4 entities that make up the Keller Lake tributary watershed.

The MS4 identification numbers and tributary watershed area associated with each of the MS4s, including total area, total impervious area, and directly connected impervious area, are listed in Table 5-4.

Table 5-4 MS4 Identification Numbers and Tributary Watershed Areas Associated with Each MS4 in the Keller Lake Watershed

MS4	MS4 Identification Number	Watershed Area within MS4 (acres)	Total Impervious Area within MS4 (acres)	Directly Connected Impervious Area within MS4 (acres)
Apple Valley	MS400074	788	215	160
Burnsville	MS400076	567	138	101
Dakota County	MS400132	41	21	21
TOTAL[1]		***1396***	***374***	***282***

1 – Does not include Keller Lake surface area = 52.58 acres (located within Burnsville)

The wasteload allocations for each of the MS4 communities in the Keller Lake watershed were estimated. However, wasteload allocations for new construction, redevelopment and/or all other related land disturbances are considered to be minimal because they are regulated under the cities' permitting programs. Therefore, loads from construction, redevelopment and/or other related land disturbances can be considered to be included in the WLAs for the MS4s. There are no known permitted municipal wastewater or industrial dischargers in the Keller Lake watershed.

The P8 modeling was done to calculate existing loads with no BMPs as well as to estimate the existing loads accounting for BMPs that are currently in place. The amount of directly connected impervious area was used to redistribute the subwatershed loads for the existing conditions back to the MS4s within each subwatershed. The benefits of the existing BMPs (TP removals) are distributed to the MS4s located within the same subwatershed as the BMP based on the proportion of directly connected impervious area in each MS4 within the subwatershed.

The original approach to estimating the components of the TMDL equation and to meet the loading capacity for Keller Lake, was to first address the watershed phosphorus loads (wasteload allocations) to Keller Lake to the maximum extent practicable, followed by addressing the internal phosphorus loads (load allocations). To estimate the wasteload allocation for Keller Lake, a runoff total phosphorus concentration of 150 μg/L was originally applied to the existing condition annual watershed runoff volume (721 acre-feet). However, for the average (critical) climatic conditions in Keller Lake, using this method would require a reduction in the internal phosphorus load greater than the existing internal load to the lake (see the internal load allocation discussion for Keller Lake in Section 5.3.3.2).

Instead, to determine the TMDL wasteload allocation for Keller Lake, the load allocation for the internal load was first estimated (assuming that the existing internal load is reduced by 80 percent). Then using the existing conditions water load to Keller Lake, the wasteload allocation to meet the TMDL load capacity for the lake was back-calculated. The wasteload allocation for Keller Lake results in a runoff total phosphorus concentration of 102.6 µg/L. The estimated wasteload allocation was then redistributed back to the MS4s within the Keller Lake watershed based on the total area of each MS4 within the watershed. Table 5-5 compares the existing conditions load with the estimated wasteload allocation.

Table 5-5 Keller Lake Annual Existing Conditions Load vs. Estimated TMDL Wasteload Allocation

MS4	Existing Conditions TP Load (lbs/yr)	Estimated TMDL Wasteload Allocation (lbs/yr)[1]	Estimated Reduction (lbs/yr)
Apple Valley	244	114	130
Burnsville	156	82	74
Dakota County	22	6	16

1 - See Table 5-6 for the final TMDL wasteload allocation for Keller Lake.

5.3.3 Load Allocations to Non-Permitted Sources

The load allocations for Keller Lake are attributable to the atmospheric deposition and internal loads of phosphorus to Keller Lake.

5.3.3.1 Atmospheric Deposition

Phosphorus loading from atmospheric deposition onto the lake surface was estimated assuming a 0.2615 kg/ha/yr rate (Barr, 2005). This loading rate was applied to the surface area of the lake resulting in an annual TP load of 12 pounds.

5.3.3.2 Internal Loading

The estimated internal phosphorus loading to Keller Lake is the likely the result of the senescing of Curlyleaf pondweed, release from lake-bottom sediments, and benthivorous and planktivorous fish activity. Also, because Keller Lake is a shallow lake with a large surface area, physical mixing processes (i.e. wind driven mixing events, etc.) may also resuspend phosphorus into the water column. The original approach of first addressing the watershed loads (wasteload allocations) followed by the internal loads (load allocations) to the lake, resulted in an internal load reduction greater than the existing conditions internal load (see Section 5.3.2 for more discussion of the Keller Lake wasteload allocation methods). However, it is not reasonable to assume that all internal loads to a lake can be controlled. Therefore, to estimate the load allocation for internal loads, an 80 percent reduction in the internal loads to Keller Lake was assumed. The estimated load allocation for internal phosphorus sources is 58 pounds annually resulting in a required reduction in the internal loads to Keller Lake to meet the TMDL load capacity of 80 percent.

The expected reduction by typical in-lake management techniques to control internal phosphorus loads (e.g. alum treatment of the sediments, whole-lake treatment of Curlyleaf pondweed) is estimated to be approximately 80 percent; as a result, the internal load allocation is reasonable for Keller Lake.

Table 5-6 summarizes the existing conditions loads to Keller Lake, as well as the annual TMDL wasteload and load allocations.

Table 5-6 Keller Lake Annual[4] Total Phosphorus Load Allocations for Average (Critical) Climatic Conditions

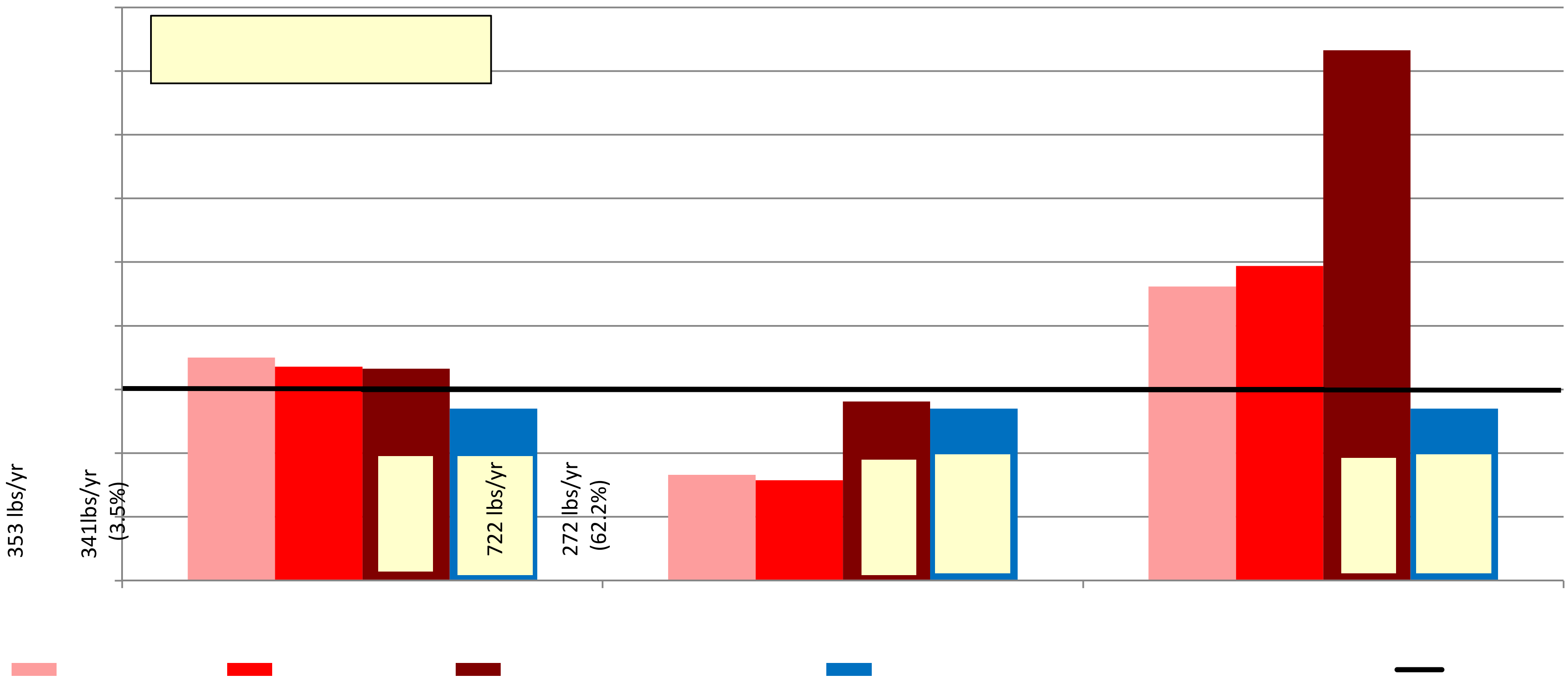
TP Source	Existing Conditions without BMPs[1] (lbs/yr)	Existing Conditions with 2008 BMPs[1] (lbs/yr)	Percent Reduction by Existing BMPs (%)	TMDL Allocation (lbs/yr)	TMDL Allocation (lbs/day)	Required Load Reduction (lbs/yr)	Percent Reduction of Existing Load (%)
Wasteload Allocations (Permitted Sources)							
Apple Valley (MS400074)	303	244	20	114	0.312	130	53
Burnsville (MS400076)	242	156	36	82	0.225	74	47
Dakota County (MS400132)	33	22	33	6	0.016	16	73
Total Wasteload Sources	**578**	**422**	**27**	**202**	**0.553**	**220**	**52**
Load Allocations (Non-Permitted Sources)							
Atmospheric Deposition		12		12	0.033	0	0
Internal Sources		288		58	0.159	230	80
Total Load Sources		**300**		**70**	**0.192**	**230**	**77**
Margin of Safety[2]							
--		--		Both Implicit and Explicit MOS		--	--
Reserve Capacity[3]							
--		--		--	--	**--**	--
Overall Source Total		**722**		**272**	**0.745**	**450**	**62.2**

1 – Assumes the ferric chloride system is not operating

2 – See Section 5.5 for a discussion of the Margin of Safety

3 – See Section 5.6 for a discussion of the Reserve Capacity

4 – Based on 2006 water year (October 1, 2005 – September 30, 2006)


40
33.2
31.5
20
0
Wet (2002)
Dry (2008)
Avg (2006)
Observed TP
Calibration TP
Existing Conditions (2008) TP
Estimated TP to Meet MPCA Goal (including MOS)
MPCA Goal
353 lbs/yr
341lbs/yr
(3.5%)
722 lbs/yr
272 lbs/yr
(62.2%)

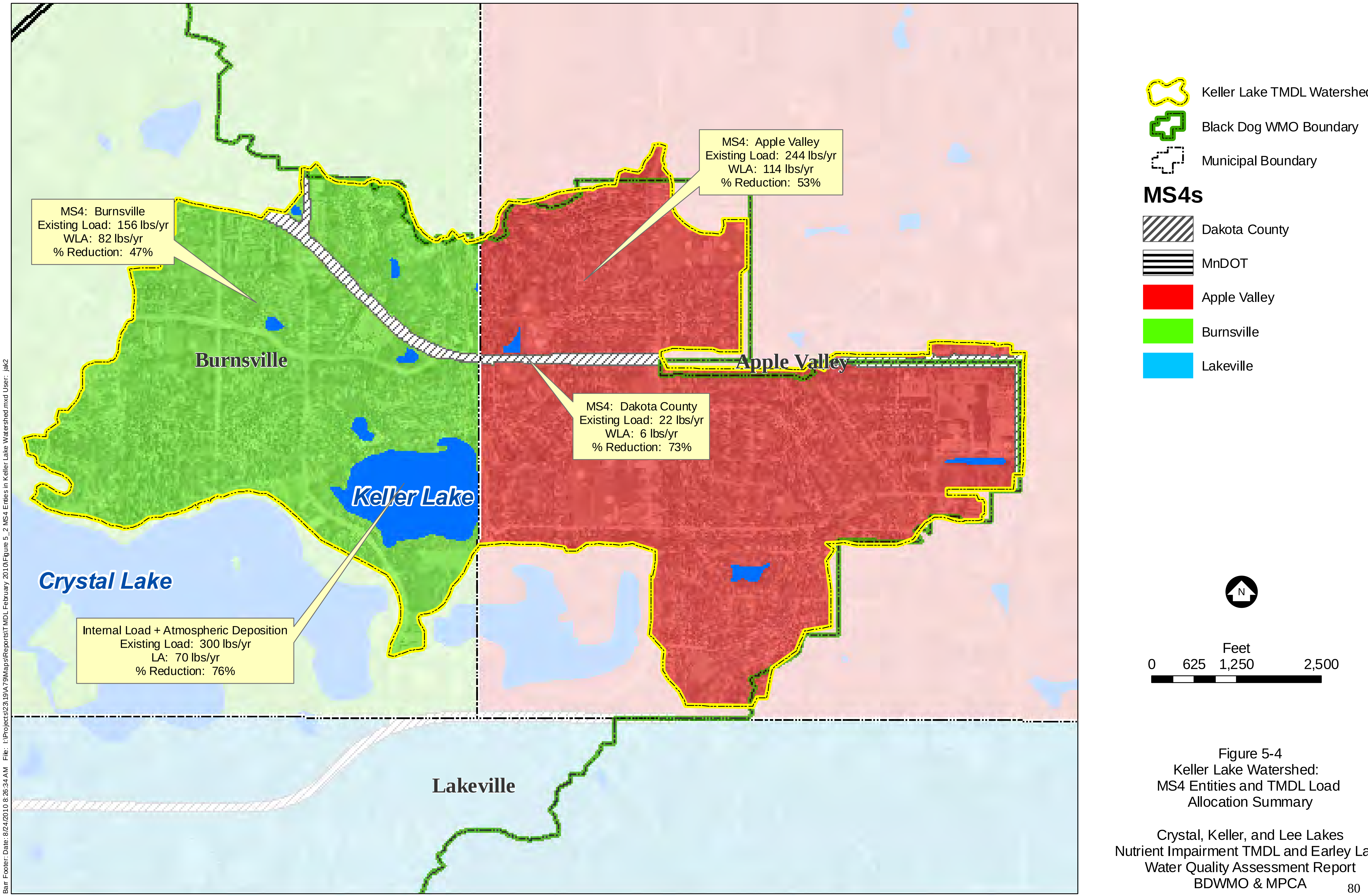


Figure 5-4
Keller Lake Watershed:
MS4 Entities and TMDL Load
Allocation Summary

5.4 Lee Lake TMDL Allocation Analysis

5.4.1 Load Capacity Estimation

The existing conditions in-lake mass balance model was used to estimate the maximum allowable total phosphorus load to Lee Lake that would achieve the MPCA's shallow lake standard (≤ 60 µg/L) during average climatic conditions. When estimating the load capacity, it was assumed that the MPCA standard was 10 percent less (54 µg/L) than the actual standard. Using the water quality relationships summarized in Section 3.2 (see Figures 3-16 and 3-17), it is expected that at a TP concentration of 54 µg/L, the resulting Secchi depth (1.4 meters) will meet the MPCA standard; however, the predicted Chlorophyll-*a* concentration (20.6 µg/L) will still exceed the MPCA standard (see Appendix D-24).

The in-lake water quality model for the average climatic conditions assumed that the watershed was reflective of existing watershed (2008) conditions. Figure 5-5 summarizes the required phosphorus load reductions to achieve the MPCA water quality standards for all climatic conditions.

To estimate the required load reduction (resulting in the load capacity for Lee Lake), the existing conditions in-lake mass balance model was used to evaluate reductions in the loads to the lake that would result in average growing season phosphorus concentrations that achieve the MPCA standard for Lee Lake. For the load capacity analysis, it was assumed that atmospheric deposition would remain the same as for existing conditions and that the spring phosphorus concentration was also the same as for existing conditions (a conservative assumption since it is likely that if phosphorus loads to the lake are reduced, the springtime concentration will likely also be reduced). Then an equal percent reduction was applied to all other sources of phosphorus to the lake including watershed runoff, Curlyleaf pondweed, and the estimated internal load.

The components of the Lee Lake TMDL load allocation analysis for average climatic conditions, including the estimated phosphorus loading capacity (i.e., the amount of phosphorus that the lake can receive and still achieve the water quality standard) for the lake are summarized in the following sections. For average climatic conditions, a 42 percent reduction in the overall total phosphorus load to Lee Lake would be required to meet the MPCA shallow lake standard, resulting in an annual phosphorus load capacity of 84 lbs.

5.4.2 Wasteload Allocations to Permitted Sources

All of Lee Lake's allocated watershed loads are expressed as wasteload allocations because the communities and governmental entities in the watershed are all defined as MS4s, requiring NPDES permits for the discharge of stormwater (Permit Number MNR040000). Figure 5-6 shows the different MS4 entities that make up the Lee Lake tributary watershed.

The MS4 identification numbers and tributary watershed area associated with each of the MS4s, including total area, total impervious area, and directly connected impervious area, are listed in Table 5-7.

Table 5-7 MS4 Identification Numbers and Tributary Watershed Area Associated with Each MS4 in the Lee Lake Watershed

MS4	MS4 Identification Number	Watershed Area within MS4 (acres)	Total Impervious Area within MS4 (acres)	Directly Connected Impervious Area within MS4 (acres)
Lakeville	MS400099	154	41	36
Dakota County	MS400132	9	4	4
MnDOT	MS400170	24	13	13
TOTAL[1]		***187***	***58***	***53***

1 – Does not include Lee Lake surface area = 19.2 acres (located within Lakeville)

The wasteload allocations for each of the MS4 communities in the Lee Lake watershed were estimated. However, wasteload allocations for new construction, redevelopment and/or all other related land disturbances are considered to be minimal because they are regulated under the cities' permitting programs. Therefore, loads from construction, redevelopment and/or other related land disturbances can be considered to be included in the WLAs for the MS4s. There are no known permitted municipal wastewater or industrial dischargers in the Lee Lake watershed.

The P8 modeling was done to calculate existing loads with no BMPs as well as to estimate the existing loads accounting for BMPs that are currently in place. The amount of directly connected impervious area was used to redistribute the subwatershed loads for the existing conditions back to the MS4s within each subwatershed. The benefits of the existing BMPs (TP removals) are distributed to the MS4s located within the same subwatershed as the BMP based on the proportion of directly connected impervious area in each MS4 within the subwatershed.

For this TMDL study, the approach to estimating the components of the TMDL equation and to meet the loading capacity for the lake, is to first address the watershed phosphorus loads (wasteload allocations) to Lee Lake to the maximum extent practicable, followed by addressing the internal phosphorus loads (load allocations). The wasteload allocations for the MS4s within the Lee Lake watershed were initially estimated applying a runoff total phosphorus concentration of 150 µg/L to the existing condition annual watershed runoff volume (111 acre-feet). The estimated wasteload allocation was then redistributed back to the MS4s within the Lee Lake watershed based on the total area of each MS4 within the watershed. Table 5-8 compares the existing conditions load with the estimated wasteload allocation.

Table 5-8 Lee Lake Annual Existing Conditions Load vs. Original Estimated TMDL Wasteload Allocation

MS4	Existing Conditions TP Load (lbs/yr)	Estimated TMDL Wasteload Allocation (lbs/yr)[1]	Estimated Reduction (lbs/yr)
Lakeville	43	37	6
Dakota County	4	2	2
MnDOT	18	6	12

1 - See Table 5-9 for the final TMDL wasteload allocation for Lee Lake.

5.4.3 Load Allocations to Non-Permitted Sources

The load allocations for Lee Lake are attributable to the atmospheric deposition and internal loads of phosphorus to Lee Lake.

5.4.3.1 Atmospheric Deposition

Phosphorus loading from atmospheric deposition onto the lake surface was estimated assuming a 0.2615 kg/ha/yr rate (Barr, 2005). This loading rate was applied to the surface area of the lake resulting in an annual TP load of 5 pounds.

5.4.3.2 Internal Loading

The estimated internal loading to Lee Lake is the likely the result of the senescing of Curlyleaf pondweed, fish activity and the release from lake-bottom sediments. The TMDL load allocation for the internal loading within Lee Lake was back-calculated based on the difference between the estimated load capacity for the lake and the other components of the TMDL equation (atmospheric deposition, the Wasteload Allocation, Margin of Safety (see Section 5.5), and Reserve Capacity (see Section 5.6)). The estimated load allocation for internal phosphorus sources is 34 pounds annually resulting in a required reduction in the internal loads to Lee Lake to meet the TMDL load capacity of 54 percent.

The expected reduction by typical in-lake management techniques to control internal phosphorus loads (e.g. alum treatment of the sediments, whole-lake treatment of Curlyleaf pondweed) is estimated to be approximately 80 percent; therefore the internal load allocation (and the associated reduction) is reasonable for Lee Lake.

Table 5-9 summarizes the existing conditions loads to Lee Lake, as well as the annual TMDL wasteload and load allocations.

Table 5-9 Lee Lake Annual[3] Total Phosphorus Load Allocations for Average (Critical) Climatic Conditions

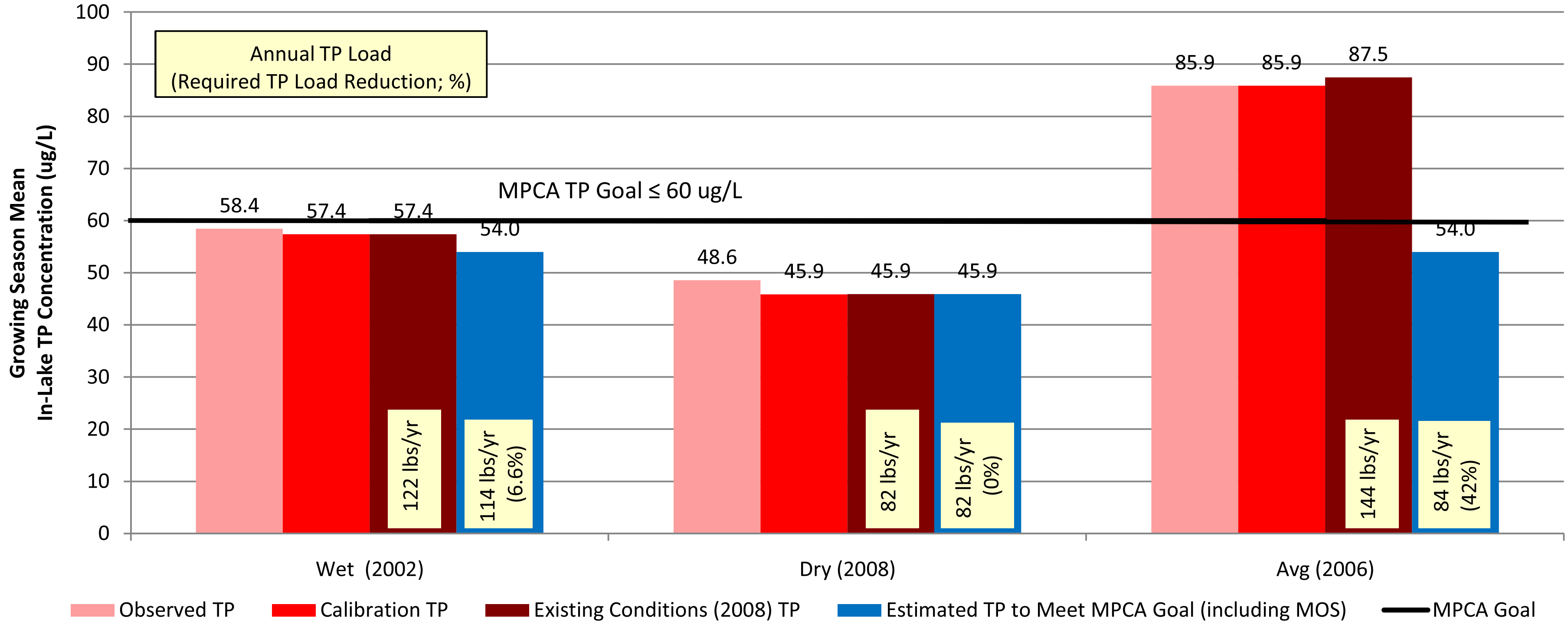
TP Source	Existing Conditions without BMPs (lbs/yr)	Existing Conditions with 2008 BMPs (lbs/yr)	Percent Reduction by Existing BMPs (%)	TMDL Allocation (lbs/yr)	TMDL Allocation (lbs/day)	Required Load Reduction (lbs/yr)	Percent Reduction of Existing Load (%)
Wasteload Allocations (Point Sources)							
Lakeville (MS400099)	75	43	43	37	0.101	6	14
Dakota County (MS400132)	9	4	56	2	0.005	2	50
MnDOT (MS400170)	20	18	10	6	0.016	12	67
Total Wasteload Sources	**104**	**65**	**37**	**45**	**0.122**	**20**	**31**
Load Allocations (NonPoint Sources)							
Atmospheric Deposition		5		5	0.014	0	0
Internal Sources		74		34	0.093	40	54
Total Load Sources		**79**		**39**	**0.107**	**40**	**51**
Margin of Safety[1]							
--		--	--	Both Implicit and Explicit MOS		--	--
Reserve Capacity[2]							
--		--	**--**	--	--	**--**	--
Overall Source Total		**144**		**84**	**0.229**	**60**	**42**

1 – See Section 5.5 for a discussion of the Margin of Safety

2 – See Section 5.6 for a discussion of the Reserve Capacity

3 – Based on 2006 water year (October 1, 2005 – September 30, 2006)

Figure 5-5
Lee Lake Growing Season Mean TP Concentrations, Annual TP Load, and Required TP Load Reduction to Meet MPCA Water Quality Standards



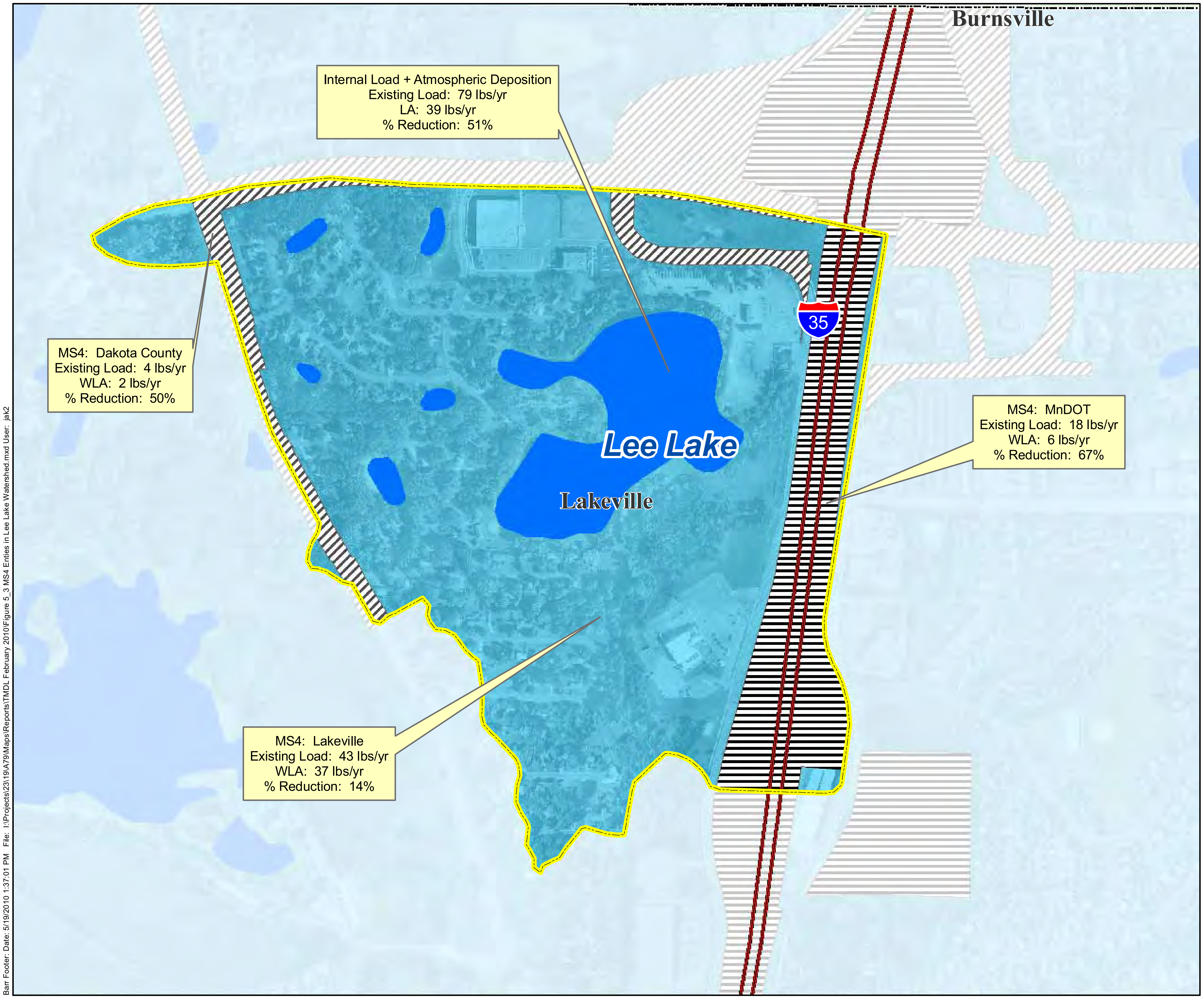


Figure 5-6
Lee Lake Watershed:
MS4 Entities and TMDL Load
Allocation Summary

Crystal, Keller, and Lee Lakes
Nutrient Impairment TMDL and Earley Lake
Water Quality Assessment Report
BDWMO & MPCA

5.5 Margin of Safety

When modeling a natural system, such as the lakes in this TMDL, there can be some uncertainty associated with how the system will respond to changes. Therefore, a margin of safety is included to account for some of the unknowns associated with the behavior of the natural lake system. The margin of safety for this TMDL study is both explicit and implicit through use of conservative modeling assumptions in the development of allocations.

Examples of conservative modeling assumptions used in this TMDL study are described below.

- When the load reduction was estimated, it was assumed that the steady-state concentration in the lake at the beginning of the growing season was not impacted by the estimated reduction in total phosphorus loads (same as existing conditions). In reality, a reduction in the annual phosphorus load to each lake will likely result in lower spring steady-state phosphorus concentrations and ultimately lower concentrations in the lake through the growing season as well.

The following explicit margin of safety was also used during the loading capacity determination.

- When estimating the load reduction required to meet the MPCA standard, the target growing season water quality goal for Crystal Lake was estimated to be 10 percent less than the MPCA deep lake total phosphorus criterion (36 μg/L instead of 40 μg/L).

- When estimating the load reduction required to meet the MPCA standard, the target growing season water quality goals for Keller and Lee Lakes were estimated to be 10 percent less than the MPCA shallow lake total phosphorus criterion (54 μg/L instead of 60 μg/L).

5.6 Reserve Capacity

For Crystal, Keller, and Lee Lakes, the watershed loads are expressed as wasteload allocations because the communities and governmental entities in the watershed are all under the jurisdiction of permitted MS4s. Therefore, the reserve capacity for each of the lakes was assumed to be zero in this TMDL study.

5.7 Seasonal Variation

TP concentrations in each of the lakes can vary significantly during the growing season, typically peaking in late summer. The TMDL guideline for TP is defined as the growing season (June through September) mean concentration (MPCA, 2009). The critical period (growing season) was used to estimate the required reduction of watershed and internal sources of phosphorus so that the predicted growing season average met the MPCA lake standard (see discussion in Section 5.1).

5.8 Reasonable Assurance

When establishing a TMDL, reasonable assurances must be provided, demonstrating the ability to reach and maintain the established water quality goals. Reasonable assurances typically include both regulatory and nonregulatory efforts at the state and local levels that will result in phosphorus load reductions that will help the MS4s achieve their wasteload allocations or reduce internal loads. There are several items in place that will help assure that Crystal, Keller, and Lee Lakes reach their desired water quality.

- Currently, the Cities of Apple Valley, Burnsville, and Lakeville within the Crystal, Keller, and Lee Lake watersheds have NPDES Phase II permits in place, as do both Dakota County and MnDOT. Under the stormwater program, permit holders are required to develop and implement a Stormwater Pollution Prevention Program (SWPPP) which requires MS4s to implement minimum control measures including: 1) public education and outreach, 2) public participation/involvement, 3) illicit discharge detection and elimination, 4) construction site runoff control, 5) post-construction site runoff control, and 6) pollution prevention and good housekeeping.

- The MS4s are required, by permit, to review the adequacy of their SWPPPs to meet the TMDL's wasteload allocation for stormwater sources. If the SWPPP is not meeting the applicable requirements, schedules, and objectives of the TMDL, the SWPPP must be modified, as appropriate, to meet the WLA.

- Construction stormwater permittees are considered in compliance with the TMDL's WLA if they implement all the requirements of the NPDES construction activity general permit, including the provisions for TMDL waters.

- All significant development, redevelopment, industrial, and construction projects need to be designed to maintain or improve existing developed hydrology and pollutant loadings to fully comply with the local watershed and government authorities, NPDES, and anti-degradation requirements.

- The BDWMO was established in June of 1985 in response to the Metropolitan Surface Water Management Act, which required the preparation of watershed management plans in the

Twin Cities metropolitan area. The first BDWMO *Watershed Management Plan* was approved in 1989, and the most recent version of the plan was approved in 2002. The BDWMO *Watershed Management Plan* outlines the pertinent information related to the management of water resources within the watershed including the inventorying of technical and physical data, discussing the regulatory framework for water resource management, assessing current problems and issues as they relate to water resources, outlining the goals and policies of the BDWMO, and laying out the implementation program to begin addressing the identified problems and issues.

- The regulated MS4 cities (Apple Valley, Burnsville, and Lakeville) have developed local watershed management plans that outline their water resource management strategies, specific to their city and in compliance with the requirements outlined in the BDWMO *Watershed Management Plan.* Additionally, each of the MS4s have stormwater management standards and rules to regulate and help manage water quality and runoff volumes from both new and redevelopment. Because the Crystal Lake watersheds (including Keller and Lee Lakes) is fully-developed, most changes in land use will be the result of redevelopment. The general redevelopment standards for the cities of Apple Valley, Burnsville, and Lakeville are summarized in Table 5-10 below. The application of the redevelopment rules will result in anti-degradation (no increase in pollutant loading) or improvement in water quality from existing conditions.

- The Crystal, Keller, and Lee Lake implementation strategies (Section 7.0) are multifaceted, with a phased implementation approach, putting various projects into place over the course of many years, allowing for adaptive management of the treatment strategy (monitoring and reflection on project successes and the chance to change course if progress is exceeding expectations or is unsatisfactory). Individual SWPPPs will be modified accordingly following the recommendations of the separate TMDL *Implementation Plan*.

- Additionally, the BDWMO and member communities plan to continue their lake water quality monitoring programs. This includes monitoring water quality in Crystal, Keller, and Lee Lakes (see Section 6.0 for a discussion of the monitoring plan).

Table 5-10 Redevelopment Standards by MS4

MS4	Redevelopment Standards
Apple Valley	- Redevelopment creating over 0.2 acres of new impervious surface shall be required to achieve no net increase in average annual TSS and TP loading compared to predevelopment conditions of the site or meet the post-construction runoff treatment section of the MPCA NPDES General Construction Permit, whichever is more restrictive. - Redevelopment creating over 0.2 acres of new impervious surface shall be required to achieve no net increase in average annual runoff volume compared to the 1990 nondegradation baseline loading condition.

Burnsville	- Any project resulting in 0.5 acre or more of disturbed area or 5,000 square feet or more of new impervious area:
	  - For all new impervious surfaces, a runoff volume of 1 inch must be treated in infiltration practices
	  - For all redevelopment impervious surfaces, a runoff volume of 0.5 inches must be treated in infiltration practices
	  - For new development portions of a site, provide treatment to remove 90% TSS and 60% TP on an annual basis
	  - For redevelopment portions of a site, provide treatment to remove 70% TSS and 30% TP on an annual basis

Lakeville	- Redevelopment which creates less than 1 acre of new impervious surface and disturbs, replaces, or alters more than 1 acre of existing impervious surface is required to incorporate water quality BMPs to the extent practical.
	  - Meet the post-construction runoff treatment section of the MPCA NPDES General Construction Permit.
	  - Infiltration of 0.5 inches of over the surface of all newly created impervious areas (where possible).
	- Development and redevelopment of commercial areas along the I-35 corridor are limited to less than 70 percent impervious coverage.

TSS = Total Suspended Solids, TP = Total Phosphorus

Sources: Apple Valley *Surface Water Management Plan* (2007), Burnsville *Water Resources Management Plan* (2008), Lakeville *Water Resources Management Plan* (2008)

6.0 Monitoring Plan to Track TMDL Effectiveness

6.1 Lake Water Quality Monitoring

The water quality in Crystal Lake has been monitored for approximately 22 years, in Keller and Lee Lakes for approximately 13 years, and in Earley Lake for approximately 15 years, and will continue to be monitored for the foreseeable future, allowing the BDWMO and the member cities the ability to track changes in the lakes' water quality and assess the impact of the implementation of the various BMPs outlined in the Section 7.0 of this report and the separate TMDL *Implementation Plan*.

According to the BDWMO *Watershed Management Plan* (Barr, 2002), the BDWMO is responsible for the monitoring of all the water bodies within the watershed that were classified (according to the BDWMO classification system) as strategic water bodies (which includes Crystal and Keller Lakes). Member cities are responsible for the monitoring of non-strategic water bodies (including Lee Lake). At a minimum, survey level water quality monitoring is required for these lakes at least once every three years. This program is equivalent to the Metropolitan Council's Citizen Assisted Lake Monitoring Program (CAMP). The monitoring typically includes the collection of basic surface water quality parameters (total phosphorus, total Kjeldahl nitrogen, chlorophyll-*a,* Secchi depth, and water temperature) on a biweekly basis from April through October.

For some of the more regionally important water bodies, such as Crystal Lake, the BDWMO monitoring program involves more detailed monitoring efforts, which includes collection of total phosphorus concentration data along the profile of the water column.

Intensive water quality monitoring can be performed, as needed. The program involves more sample collection dates and analyzing other water quality parameters besides total phosphorus along the profile of the water column. This monitoring method typically includes monitoring of the following parameters: total phosphorus, total dissolved phosphorus, orthophosphate, pH, chlorophyll-*a,* Secchi depth, turbidity, dissolved oxygen, water temperature, specific conductivity, and alkalinity.

Each year the BDWMO compiles an annual watershed report which includes a summary of the water quality of the strategic waterbodies monitored by the BDWMO in that year. This includes a trend analysis of the historic water quality in each water body, which evaluates statistically significant changes (improvement or degradation) in water quality.

6.2 BMP Monitoring

Although most projects implemented in the Crystal, Keller, and Lee Lakes' watersheds will be modeled to estimate the expected reduction in phosphorus loads, it will also be important to monitor the long-term effectiveness the different BMPs that have been and will be implemented in the watersheds to determine if the BMPs are performing as was predicted and designed.

6.3 Monitoring Major Inflows to Keller Lake

Because the TMDL WLA for Keller Lake requires a phosphorus load reduction from the watershed that may be difficult to attain using typical stormwater management practices, monitoring of the major surface inflows to Keller Lake may provide the information needed to verify the modeled watershed loads to the lake, as there is currently no stormwater runoff water quality data available within the Keller Lake watershed.

7.0 TMDL Implementation Strategies (Summary)

The following section will summarize the general implementation strategies developed for Crystal, Keller, and Lee Lakes. The separate *Crystal, Keller, and Lee Lakes Nutrient Impairment Total Maximum Daily Load Implementation Plan and Earley Lake Protection Plan* (*Implementation Plan)* will provide more detail about these restorative measures (Barr, 2010 (draft)).

This section will outline the general projects and approaches that are expected to reduce both external and internal phosphorus loads and improve water quality in each of the lakes. Additionally, this section will outline the approximate timeline for implementation, estimated costs, and expected phosphorus reductions, if available.

The separate *Implementation Plan* will typically follow the adaptive management approach. Proposed projects will be implemented in a phased manner, selecting specific projects for construction/implementation followed by a period of monitoring to evaluate the impact of the projects on the water quality in the respective lake. Depending on the resulting water quality, additional projects may be evaluated and selected for implementation, or it may be determined that the water quality in the lake meets the MPCA standards and the management approach may change from improvement to anti-degradation/protection. The phasing for the implementation plan can be described as follows:

- Ongoing: Refers to activities that are either ongoing practices that will be continued as the result of the implementation of the MS4s' SWPPPs or the implementation of projects and activities as opportunities (e.g. retrofits, redevelopment, road reconstruction, etc.) arise, but the specific implementation projects have not yet been identified.

- Phase I: Refers to projects and activities that have been identified as "first priority" projects with the goal of being implemented in the next permit cycle depending on the availability of funding and permits.

- Phase II: Refers to projects and activities that have been identified as "second priority" projects. These projects will be reconsidered after implementation of those projects in Phase I and monitoring has been done to evaluate the impact of the Phase I projects on the water quality in the lakes.

- Reserve: Refers to projects and activities that may be considered if after the implementation of Phase I and Phase II tasks and sufficient monitoring has been performed, the lakes still do not meet the MPCA water quality goals.

Significant phosphorus reductions will be required for Crystal, Keller, and Lee Lakes. To achieve the TMDL wasteload allocation, structural, nonstructural, and in-lake BMPs were considered to address both external and internal sources of phosphorus. The phasing of projects would emphasize first focusing on implementing projects that address the watershed loads to the maximum extent practicable followed by addressing the internal phosphorus loads to the lakes.

The actual BMPs that will be implemented as the result of this TMDL study may vary from those listed in this section and discussed in more detail in the TMDL *Implementation Plan*. Ultimately the MS4s will select the various BMPs to be implemented to achieve their TMDL wasteload allocations.

Load reductions for construction stormwater activities are not specifically targeted in this TMDL. It should be noted that construction stormwater activities are considered in compliance with provisions of this TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install, and maintain all BMPs required under the permit, including any applicable additional BMPs required in the Construction General Permit for discharges to impaired waters; 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 or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install, and maintain all BMPs required under the permit.

7.1 Restoration Activities

Most of the Crystal, Keller, and Lee Lakes' watershed areas are fully developed. As a result there is limited space to retrofit BMPs and implementing watershed BMPs will be costly. Implementing BMPs in the watershed should first focus on those areas that currently receive little or no water quality treatment. Additionally, BMPs sites that create a series of BMPs, or a "stormwater treatment train" should be considered. Phosphorus load reduction project(s) will be implemented in a stepwise manner, with implementation first of nonstructural practices that are either ongoing or have already occurred prior to the completion of this report. Maintenance of existing structural practices in the watersheds has been ongoing and will continue to be documented in the MS4 SWPPPs. The implementation strategies for each lake will be further developed in the *Implementation Plan.* It is anticipated that it will take at least 20 years to implement all of the projects required to achieve the annual load reductions outlined in this study. Table 7-1 lists potential management strategies needed to improve the water quality in Crystal, Keller, and Lee Lakes to achieve the MPCA's standards. The estimated total cost to achieve the water quality standards for Crystal, Keller, and Lee Lakes ranges from $7,296,000 to $38,645,000.

7.1.1 Restoration Activities for Crystal Lake

Much of the runoff from the Crystal Lake watershed currently receives some form of water quality treatment (i.e., passes through a lake, pond, wetland, or infiltration basin), and as a result, the expected phosphorus reductions from the external sources of phosphorus to the lake are relatively small, including reductions in watershed runoff as well as improving water quality in upstream lakes (Keller and Lee Lakes). The areas within the Crystal Lake watershed that currently do not receive water quality treatment are shown on Figure 7-1. The majority of the phosphorus reduction needed to achieve the water quality standards for Crystal Lake would need to come from controlling the internal sources of phosphorus loading (e.g., sediment phosphorus release, Curlyleaf pondweed, etc.). Table 7-1 outlines the general restorative management strategies for Crystal, Keller, and Lee Lakes. The estimated total cost, including both external and internal measures, to achieve the water quality standards for Crystal Lake is expected to range from $1,775,000 to $5,215,000.

7.1.2 Restoration Activities for Keller Lake

Approximately half of the runoff from the Keller Lake watershed currently receives some form of water quality treatment (i.e., passes through a pond, wetland, or infiltration basin). However the remaining portion of the watershed was developed prior to current treatment requirements and therefore currently discharges to the lake without any treatment. As a result, the expected reduction from the external sources of phosphorus to the lake is relatively significant. The areas within the Keller Lake watershed that currently do not receive water quality treatment are shown on Figure 7-1. Significantly reducing the internal sources of phosphorus are also needed to achieve the water quality standards for Keller Lake. Table 7-1 outlines the general restorative management strategies for Crystal, Keller, and Lee Lakes. The estimated total cost, including both external and internal measures, to achieve the water quality standards for Keller Lake is expected to range from $4,676,000 to $30,631,000.

7.1.3 Restoration Activities for Lee Lake

Approximately half of the runoff from the Lee Lake watershed currently receives some form of water quality treatment (i.e., passes through a pond, wetland, or infiltration basin). However, the remaining portion of the watershed currently discharges to the lake without any treatment. As a result, the expected reduction from the external sources of phosphorus to the lake is required. The areas within the Lee Lake watershed that currently do not receive water quality treatment are shown on Figure 7-1. Significantly reducing the internal source of phosphorus is also needed to achieve the water quality standards for Lee Lake. Table 7-1 outlines the general restorative management strategies for Crystal, Keller, and Lee Lakes. The estimated total cost, including both external and internal measures, to achieve the water quality standards for Lee Lake is expected to range from $845,000 to $2,799,000.

Table 7-1 Crystal, Keller, and Lee Lake Restorative Management Strategies

Management Strategy	Description	Timeline/ Frequency	Estimated Cost
Street Sweeping	The Cities of Apple Valley, Burnsville, and Lakeville's street sweeping programs will continue and as new technology and new techniques are developed they will be evaluated to determine if they would provide a water quality benefit to the lakes and implemented if found to be reasonable and practicable.	Ongoing	Annual[1]
Public Education and Outreach	The Cities of Apple Valley, Burnsville, and Lakeville's water quality education programs will continue to work with watershed residents to increase their understanding of practices that would reduce the pollutant load entering the lakes (e.g., proper fertilizer use, low-impact lawn care practices, installation of native shoreline buffers for lakeshore residents, etc.).	Ongoing	Annual[1]
Retrofit BMPs	The Crystal, Keller, and Lee Lakes' watersheds are almost fully developed so opportunities to implement BMPs within the watershed are limited to retrofits within the existing stormwater management system as well as redevelopment. Efforts to retrofit BMPs should first focus on the areas of the watershed that are currently untreated. Additionally, development of "stormwater treatment trains" (BMPs located in series) should also be considered when selecting sites to retrofit BMPs. A variety of BMPs can be incorporated into the existing stormwater system such as wet detention, infiltration practices, filtration practices, hydrodynamic devices, and underground treatment systems. As new BMPs and water quality improvement technologies are developed they will be evaluated to determine if they can provide a water quality benefit to the Lake and they will be implemented if determined to be reasonable and practicable.	Ongoing	Crystal Lake $110,000 to $TBD[2] Keller Lake $1,286,000 to $TBD[2] Lee Lake $210,000 to $TBD[2]
Infiltration/ Filtration	There are significant areas in the watershed that receive no or inadequate treatment before discharging to the lake. As an extension of retrofitting BMPs, implementation of an aggressive infiltration/filtration program within these	Ongoing	Crystal Lake $450,000 to $2,900,000 Keller Lake $2,000,000 to

Management Strategy	Description	Timeline/ Frequency	Estimated Cost
	areas (treating anywhere from 0.25 to 1.0 inches of runoff from the impervious surfaces) could have a significant impact on load reductions to the lakes. The estimated cost of promoting infiltration/filtration is highly variable due to soil conditions, space availability, and topography. Because the water levels in Keller Lake were significantly influenced by the operation of the ferric chloride treatment system in recent years, there is concern that increasing infiltration of stormwater within the Keller Lake watershed will further reduce the water load to the lake, thus further reducing Keller Lake water levels. Additional investigations may be necessary to better understand the impact of infiltration on the dynamics in Keller Lake.		$25,800,000 Lee Lake $230,000 to $1,700,000
Redevelopment	The Crystal, Keller, and Lee Lakes' watersheds are almost fully developed so opportunities to implement BMPs within the watershed are limited to redevelopment as well as retrofits within the existing stormwater management system. Redevelopment provides an opportunity to incorporate regional treatment, Low Impact Development (LID) design techniques and better site design, as well as other BMPs to manage runoff and improve water quality.	Ongoing	Crystal Lake $TBD[2] Keller Lake $TBD[2] Lee Lake $TBD[2]
Upstream Lake Management	Crystal Lake is influenced by the water quality in Lee and Keller Lakes. Improving the water quality (i.e., reducing the phosphorus concentration) in those lakes would reduce the phosphorus load discharged to Crystal Lake. Both Keller and Lee Lakes are part of this TMDL and implementation tasks have been outlined for each of these lakes to improve their water quality.	Ongoing/ Phase 1/ Phase 2	See Total Estimated Costs for Keller and Lee Lakes (See Sections 7.1.2 and 7.1.3)

Management Strategy	Description	Timeline/ Frequency	Estimated Cost
Macrophyte Management	Curlyleaf pondweed, a non-native submerged aquatic macrophyte, is present in Crystal, Keller, and Lee Lakes. Because Curlyleaf pondweed dies back in summer it contributes to the internal phosphorus loading in each lake. Therefore conducting a multi-year (typically five years) herbicide treatment to limit the growth of Curlyleaf pondweed will limit internal phosphorus loading from Curlyleaf pondweed, and prepare the lake for the inactivation of sediment phosphorus. The MDNR requires special permitting and monitoring to conduct a whole lake herbicide treatment. Prior to this type of a treatment a lake vegetation management plan must also be completed. Eurasian watermilfoil, another non-native macrophyte, is also present in Crystal and Keller Lakes and should be managed concurrently with the Curlyleaf pondweed.	Phase 1	Crystal Lake $660,000 to $990,000 Keller Lake $330,000 to $500,000 Lee Lake $250,000 to $380,000
Inactivation of Sediment Phosphorus	The release of phosphorus from the lake bottom sediment is a significant internal nutrient source in Crystal, Keller, and Lee Lakes. Conducting a whole lake alum treatment would significantly reduce this nutrient source by binding the phosphorus to the sediment. However the alum treatment should be conducted following the reduction of the external phosphorus sources and controlling the growth of Curlyleaf pondweed in order to increase the treatment's longevity.	Phase 2	Crystal Lake $500,000 to $700,000 Keller Lake $150,000 to $250,000 Lee Lake $100,000 to $150,000
Aquatic Communities Studies	The type of fishery and the feeding and spawning activities can impact the water quality in a lake system. Additionally, imbalances in the phytoplankton and zooplankton communities can also impact water quality. If it appears that the fisheries or an imbalance in the plankton communities are negatively affecting the water quality in Crystal, Keller, and Lee Lakes, additional studies and development of management plans may be needed.	Reserve	Crystal Lake $55,000 to $205,000 Keller Lake $55,000 to $205,000 Lee Lake $55,000 to $205,000

1 - Annual cost reflects ongoing activities included in the MS4s SWPPPs and will continue into the future
2 - TBD - Actual costs to be determined at the time of retrofit or redevelopment.

7.1.4 Earley Lake Protection Plan

Because Earley Lake currently is meeting the MPCA eutrophication standards, a TMDL load capacity was not developed for the lake. However, in 2007, the City of Burnsville completed a study that resulted in the development of a UAA[1] for Twin and Earley Lakes. The UAA[1] was entitled *Twin and Earley Lake Use Attainability Analysis: Diagnostic-Feasibility Study: Water Quality Issues and Potential Restorative Measures* (Barr, 2007).

As part of this study, the sources of phosphorus to Earley Lake were quantified. The majority of phosphorus to Earley Lake is from runoff from its tributary watershed and from the outflow from North Twin Lake (located upstream from Earley Lake). Additionally, internal loading from Curlyleaf pondweed and release from sediments contributes a small portion of the phosphorus load to Earley Lake. The UAA[1] identified several restorative measures for Earley Lake and its contributing watershed.

7.2 MS4 Responsibilities

Funds for many of these projects will come from the MS4s, but other sources of funding such as the State Clean Water Partnership Funds, State Revolving Funds, Section 319 grants, Board of Water and Soil Resources Challenge Grants, and other relevant federal and state funds may be able to assist the MS4s in their efforts.

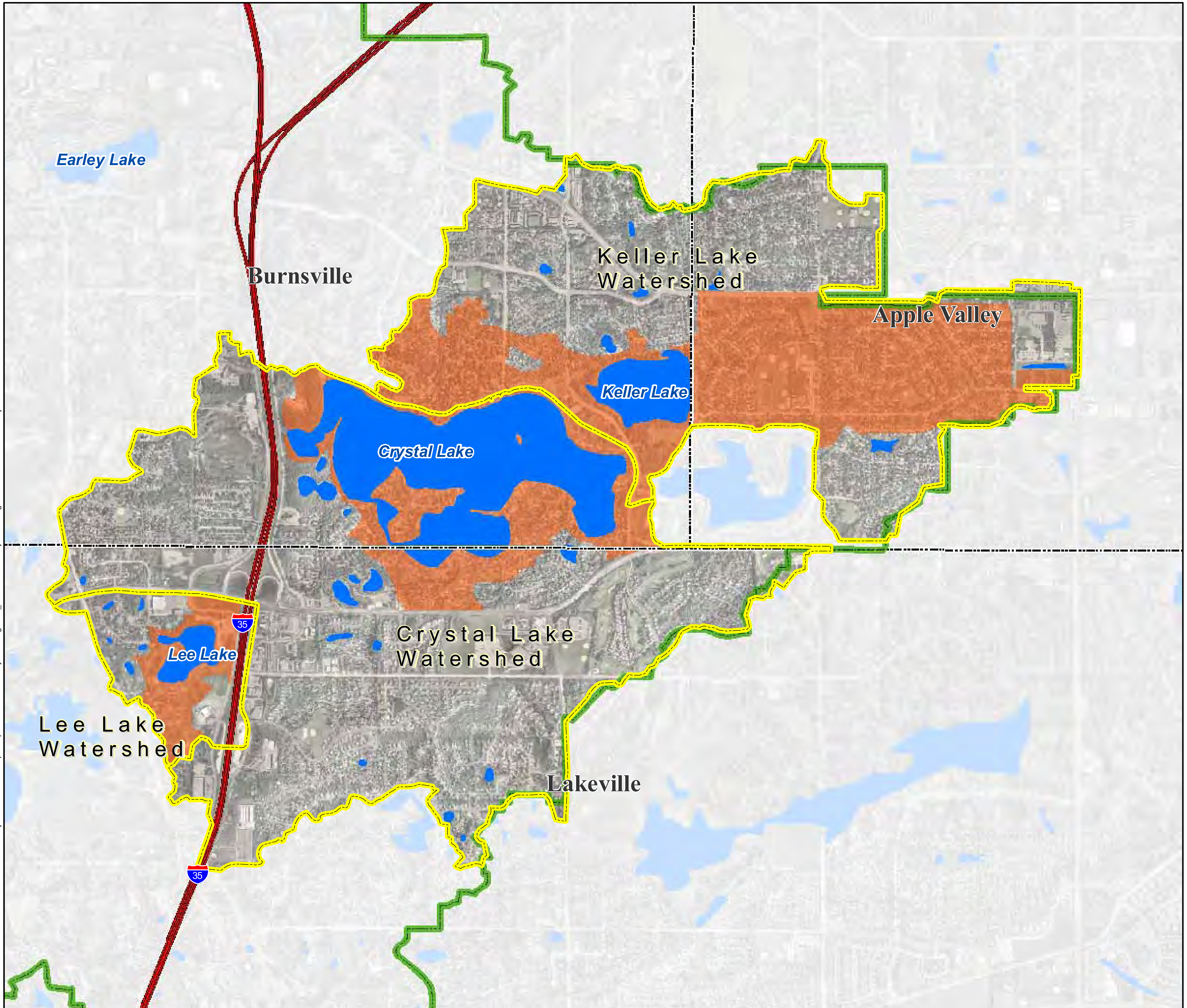
The BDWMO is willing to take the lead role in coordinating the implementation projects to address the internal phosphorus loading, assuming the MS4s are willing to fund the projects. The cities and other MS4s in the Crystal, Keller, and Lee Lake watersheds are expected to fulfill their existing responsibilities in stormwater management to help meet the goals of this TMDL. Specifically, cities and other MS4s in the watershed will:

- Implement select projects that address external phosphorus loads. These projects may require some MS4s to collaborate, to share costs and distribute the phosphorus load reduction to the respective MS4s.

- Continue to implement stormwater management requirements on all development and redevelopment projects to comply with the established rules and NPDES construction permit requirements.

- Look for opportunities to implement additional voluntary projects (other than those specifically outlined in the Implementation Plan) to reduce runoff and phosphorus loads wherever possible.

- Continue to implement their Stormwater Pollution Prevention Plans (SWPPPs) and to improve their public works maintenance practices wherever possible.



Crystal, Keller, and Lee Lakes TMDL Watersheds

Black Dog WMO Boundary

Municipal Boundary

Untreated Subwatersheds

Feet

0 1,000 2,000 4,000

Figure 7-1
Areas Currently Receiving No Treatment
in the Crystal, Keller, and Lee Lake Watersheds

Crystal, Keller, and Lee Lakes
Nutrient Impairment TMDL and Earley Lake
Water Quality Assessment Report
BDWMO & MPCA

8.0 Public Participation

The BDWMO and members of Apple Valley, Burnsville, and Lakeville city staff were intimately involved in the creation of the UAA and its management recommendations for Crystal and Keller Lakes. In addition several public meetings were held before finalizing the UAA to allow public input. More than eight (8) staff and public meetings were conducted during the UAA development (from mid-2002 through the end of 2003). The City of Apple Valley has also conducted public meetings to discuss the recommended implementation of Whitney pond upstream of Keller Lake.

As part of this TMDL study a public meeting was held on February 10, 2010 to present the draft TMDL report. Additionally, several stakeholder and technical advisory meetings (see member list below) have been conducted since this TMDL project was started. This included meetings on:

- March 12, 2008
- February 2, 2009
- October 12, 2009
- November 16, 2009
- December 16, 2009
- March 1, 2010
- March 31, 2010
- April 22, 2010
- May 10, 2010

The December 2009 stakeholder meeting was conducted between BDWMO staff and representatives from the various MS4s that are responsible for loads within the Crystal, Keller, and Lee Lake watershed. At the meeting, the BDWMO's discussed the TMDL load and wasteload allocations as well as the approach to meeting the required reductions as well as MS4 responsibilities. Members from the following entities were in attendance:

- Minnesota Pollution Control Agency
- Minnesota Department of Transportation
- Metropolitan Council
- Dakota County
- Black Dog Watershed Management Organization
- City of Apple Valley

- City of Burnsville
- City of Lakeville

Additional public comments were taken as part of the official TMDL public notice period from March 14, 2011 through April 13, 2011. Fourteen comments were received during the public notice period and minor clarifications were made to the TMDL in response to these comments. The public comments addressed a variety of topics including:

- Evaluation of the implementation of rain gardens in a residential community in the City of Burnsville,
- Effectiveness of alum treatment in the presence of benthivorous fish communities,
- The relationship between water clarity and macrophyte (aquatic plant) growth,
- The P8 pollutant load modeling and the incorporation of directly-connected imperviousness into the modeling,
- Redevelopment standards for the cities of Apple Valley, Burnsville, and Lakeville,
- The BMP implementation strategy of focusing the retrofit of BMPs in areas of the watershed that currently receive no treatment,
- The establishment of the waste load allocations (WLA) and load allocations (LA) for the lakes,
- The implementation of BMPs to address the load allocations (LA) (internal phosphorus loads),
- Application of the shallow lake criteria to Lee Lake,
- The adequacy of the margin of safety, the monitoring program, and the reasonable assurances,
- The inclusion of public comments in the TMDL report, and
- Potential delisting of Lee Lake from the 303(d) impaired waters list based on more recent monitoring data.

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Appendices

Appendix A

TMDL Modeling Process Summary

A-1: TMDL Modeling Process

The modeling performed for the *Crystal, Keller and Lee Lakes Nutrient Impairment Total Maximum Daily Load Report and Earley Lake Water Quality Assessment* included three different models to estimate the TMDL phosphorus load capacity required to meet the MPCA water quality standards including the P8 pollutant loading model, a daily water balance model, and a phosphorus mass balance model that included empirical steady-state phosphorus equations and growing season phosphorus balance model. Appendix A-2 shows a schematic of the TMDL modeling approach.

P8 Pollutant Loading Model

The P8 pollutant loading model was used to estimate the water and phosphorus loads to each lake. The runoff volumes predicted by the P8 model were verified using a water balance model and observed lake level data (see Water Balance Model discussion). The P8 event load file was used to extract the watershed runoff volume (acre-ft) and the predicted phosphorus associated with the different particle classes in P8 (i.e., TP loads in lbs) for each event that was modeled. Both the water and the TP loads were used in the steady state phosphorus model and the phosphorus mass balance model.

Water Balance Model

A daily water balance spreadsheet model was used to verify the runoff volumes predicted by the P8 model as well as observed lake level data (when available) to estimate the lake's volume, and discharge. A stage-area-storage-discharge curve was developed for the lake based on available bathymetry data as well as outlet geometry. The water balance was estimated using the following equation:

$$\Delta \text{ in Lake Storage} = WR + DP + US - EV - GW - D - OL$$

Where:

WR = Watershed Runoff

DP = Direct Precipitation on the surface area of the lake

US = Flows from Upstream Lakes/Sources (when applicable; based on water balance models for upstream lakes)

EV = Evaporation for lake surface based on adjusted pan evaporation data from the University of Minnesota St. Paul Campus Climatological Observatory

GW = Average groundwater exchange fit to lake level monitoring data

D = Estimated average daily discharge based on outlet geometry

OL = Other losses (applicable to the pumping from Crystal Lake to Keller Lake when ferric chloride system was operating)

Phosphorus Mass Balance Model

Once the P8 and water balance models were developed, a phosphorus mass balance model was calibrated to observed water quality data using a differencing methodology. This differencing method allowed the model to be used to estimate phosphorus loading sources and losses not explicitly accounted for in the mass balance modeling during the growing season of interest. The mass balance model was comprised of two phases, evaluating a period of 17 months (beginning on May 1 of a given year through September 30 of the following year). The first phase uses an empirical steady-state phosphorus equation to estimate the steady-state water quality at the beginning of the growing season. Water and phosphorus loads for the first 12 months of the period (May 1 through April 30 of the following year) are used as the inputs to the empirical steady-state phosphorus equation to predict the in-lake phosphorus concentration at the beginning of the calibration period. The steady-state equations used to establish the late-spring phosphorus concentration are discussed in more detail in Section 4.1.2.

The second phase of the water quality modeling considers the 5 month period from May 1 through September 30 to calibrate the mass balance model to observed water quality data and estimate phosphorus sources and losses to the lakes required to match the water quality monitoring data. The phosphorus mass balance model time step is variable, based on the period of time between each of the monitoring events.

The mass balance equation used to estimate the internal load and calibrate the model to observed water quality data for each time step is as follows (also discussed in Section 4.1.2):

P Adjusted = Observed P + Outflow P + Coontail Uptake P –
Runoff P – Upstream P - Atmospheric P – Curlyleaf Pondweed P – P Initial

The following discusses each of the components of the mass balance equation and where these numbers come from based on the data available for this study as well as the P8 and water balance modeling that was performed.

Observed P

The water quality data collected for each water body was used for the calibration of the mass balance model (estimation of the internal loading/losses). Surface total phosphorus (TP) is the primary parameter used for calibration. The observed P is the amount of phosphorus in the epilimnion based on the TP concentration and the estimated epilimnion volume at the time of the monitoring event (the end of the current timestep).

Other water quality parameters typically used to verify the water quality model include water temperature and dissolved oxygen data. Some of the water quality sampling dates have monitoring data available along the depth profile of the lake. The temperature profiles help identify the depth to the thermocline and when used in conjunction with the water balance, can estimate the epilimnetic volume during each period. Additionally, dissolved oxygen profile data can help verify if there is internal loading from the sediments due to anoxia below the thermocline and along the bottom sediments. Some of the water quality sampling dates may have only included surface water quality measurements and therefore, parameters such as depth to the thermocline, was estimated based on interpolation between known data.

Outflow P

Outflow P typically includes losses of phosphorus through surface discharge as well as through losses to the groundwater. The volumes of discharge during each time step were based on the daily water balance model. The TP concentration of the discharge is assumed to be the observed surface TP data from the prior time step. For the calibration of the Crystal Lake model, the discharges also included the pumping from Crystal to Keller Lake as part of the operation of the ferric chloride system.

Coontail Uptake P

Macrophyte surveys were available for most calibration years for Crystal, Keller, and Lee Lakes. These surveys included areal coverage estimates as well as relative densities for a variety of macrophyte species including Coontail. Typically, surveys were also available in early and late summer, so changes in coverage and density could be estimated throughout the growing season. The uptake of TP by Coontail was estimated based on average uptake rates presented by Lombardo and Cook (2003) which are dependent on the density and coverage of the macrophyte (See Section 4.1.2 & Appendices B, C, and D).

Runoff P

The P8 model results were used to estimate the phosphorus associated with watershed runoff. To estimate pollutant loading, the P8 model tracks the build-up, wash-off, and settling of particles and a mass of phosphorus is associated with each particle size (see more discussion in Appendix A-3). The phosphorus mass balance model tracks the various particle sizes estimated by the P8 model and assumes particles will settle out of the epilimnion based on their settling velocity. As a result, the surface runoff TP used by the mass balance model is less than the TP load directly estimated by the P8 model due to particle settling (see the tables in Appendices B, C, and D that compare the P8 TP load and the TP load after particle settling for each time step of the mass balance model).

Upstream P

The in-lake mass balance model accounts for loads from upstream lakes and water bodies. In the case of Crystal Lake, both Keller Lake and Lee Lake are located upstream. For the Keller Lake calibration period, the upstream source of TP included the pumping from Crystal Lake as part of the operation of the ferric chloride system. The volumes from upstream sources during each timestep were based on the daily water balance model. In the case of Crystal Lake, the inflows from the upstream lakes in the water balance were linked to the discharges from the water balances developed specifically for the upstream lakes. The TP concentration associated with upstream sources was based on the phosphorus mass balance models developed as well.

Atmospheric P

Atmospheric phosphorus was applied at a constant loading rate of 0.2615 kg/ha/yr (Barr, 2005). This was applied to the estimated surface area of the lake at each time step.

Curlyleaf P

Macrophyte surveys were available for most calibration years for Crystal, Keller, and Lee Lakes. These surveys included areal coverage estimates as well as relative densities for a variety of macrophyte species including Curlyleaf pondweed. Using the late-spring or early-summer surveys, the coverage and density of the Curlyleaf pondweed could be estimated. The estimated biomass phosphorus content was based on data collected as part of a study of Big Lake in Wisconsin (Barr, 2001) and compared to recent biomass measurements made for Medicine Lake (Vlach & Barten, 2006). The phosphorus release rate was based on the Half Moon Lake study (James et al., 2001) (See Section 4.1.2 & Appendices B, C, and D).

P Initial

This parameter represents the amount of phosphorus that currently exists in the epilimnion at the start of the timestep. It is equivalent to the amount of phosphorus in the epilimnion at the end of the previous time step.

P Adjusted

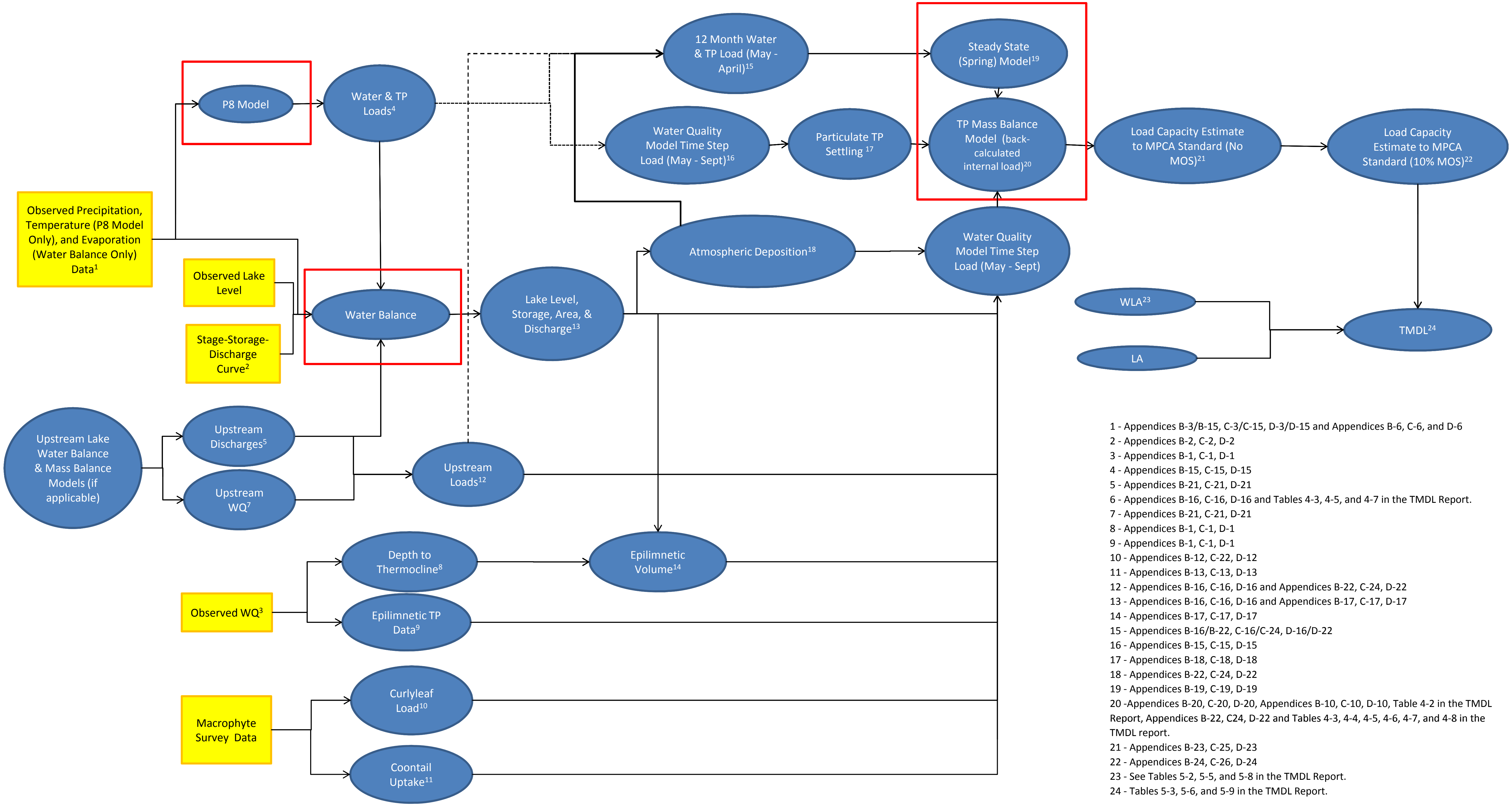
Once the known sources and losses of phosphorus were quantified, the required TP loading adjustment could be back calibrated so that the predicted phosphorus concentration in the epilimnion matches the observed TP data. The estimated TP loading adjustment was verified by checking against the results of the sediment core analysis (See Sections 4.2.1, 4.2.2, and 4.2.3 and Appendix E).

Using the Calibrated Mass Balance Model

Once the in-lake mass balance model was calibrated for each lake, the models were used in a predictive manner to evaluate the impact of changes in water and phosphorus loading on the lake water quality. Additionally, the mass balance was used to estimate the required phosphorus load reduction that would result in the expected in-lake water quality that would meet the MPCA water quality standards during the growing season period.

Appendix A-2 TMDL Modeling Process Flow Chart

Existing Conditions Summary



1 - Appendices B-3/B-15, C-3/C-15, D-3/D-15 and Appendices B-6, C-6, and D-6
2 - Appendices B-2, C-2, D-2
3 - Appendices B-1, C-1, D-1
4 - Appendices B-15, C-15, D-15
5 - Appendices B-21, C-21, D-21
6 - Appendices B-16, C-16, D-16 and Tables 4-3, 4-5, and 4-7 in the TMDL Report.
7 - Appendices B-21, C-21, D-21
8 - Appendices B-1, C-1, D-1
9 - Appendices B-1, C-1, D-1
10 - Appendices B-12, C-22, D-12
11 - Appendices B-13, C-13, D-13
12 - Appendices B-16, C-16, D-16 and Appendices B-22, C-24, D-22
13 - Appendices B-16, C-16, D-16 and Appendices B-17, C-17, D-17
14 - Appendices B-17, C-17, D-17
15 - Appendices B-16/B-22, C-16/C-24, D-16/D-22
16 - Appendices B-15, C-15, D-15
17 - Appendices B-18, C-18, D-18
18 - Appendices B-22, C-24, D-22
19 - Appendices B-19, C-19, D-19
20 -Appendices B-20, C-20, D-20, Appendices B-10, C-10, D-10, Table 4-2 in the TMDL Report, Appendices B-22, C24, D-22 and Tables 4-3, 4-4, 4-5, 4-6, 4-7, and 4-8 in the TMDL report.
21 - Appendices B-23, C-25, D-23
22 - Appendices B-24, C-26, D-24
23 - See Tables 5-2, 5-5, and 5-8 in the TMDL Report.
24 - Tables 5-3, 5-6, and 5-9 in the TMDL Report.

A-3: P8 Model Parameter Selection

The P8 models originally developed for the UAA (Barr, 2003) were modified as part of this TMDL study based on new development within the watershed, changes to the existing system, as well as additional impervious coverage information. This appendix discusses the selected P8 model parameters for the TMDL study. P8 parameters not discussed in the following paragraphs were left at the default setting. P8 version 2.4 was used for the modeling.

Time Step, Snowmelt, & Runoff Parameters (Case-Edit-Other)

1. Time Steps Per Hour (Integer)— 6. Selection was based upon the number of time steps required to minimize continuity errors.

2. Minimum Inter-Event Time (Hours)— 10. The selection of this parameter was based upon an evaluation of storm hydrographs to determine which storms should be combined and which storms should be separated to accurately depict runoff from the lake's watershed. It should be noted that the average minimum inter-event time for the Minneapolis area is 6.

3. Snowmelt Factors—Melt Coef (Inches/Day-Deg-F)—0.03. The P8 model predicts snowmelt runoff beginning and ending earlier than observed snowmelt. The lowest coefficient of the recommended range was selected to minimize the disparity between observed and predicted snowmelt (i.e., the coefficient minimizes the number of inches of snow melted per day and maximizes the number of snowmelt runoff days).

4. Snowmelt Factors— Scale Factor For Max Abstraction—1. This factor controls the quantity of snowmelt runoff (i.e., controls losses due to infiltration). Selection was based upon the factor that resulted in the closest fit between modeled and observed runoff volumes.

5. Growing Season AMC—II = .05 and AMC—III = 100. Because the amount of precipitation and soil moisture can impact the rate of infiltration that occurs within pervious surfaces, the P8 model includes thresholds that defines which antecedent moisture condition the watershed is in based on the precipitation record. The growing season antecedent moisture condition thresholds were set as: AMC-II = 0.05, AMC-III 100. The selected parameters tell the model to only use Antecedent Moisture Condition I when less than 0.05 inches of rainfall occur during the five days prior to a rainfall event and to only use Antecedent Moisture Condition III if more than 100 inches of rainfall occur within five days prior to a rainfall event. Although the model typically assumes

antecedent moisture condition II for most storms, a good fit between modeled and observed water volumes was obtained.

Particle Scale Factor (Case-Edit-Components)

6. Particle Scale Factor—TP—1.0. The particle scale factor determines the total phosphorus load generated by the particles predicted by the model in watershed runoff.

Particle File Selection (Case—Read—Particles)

7. LAKEVNUR.PAR: The particle file reflects the values typically associated with the NURP50 particle file. To estimate pollutant loading, P8 tracks the build-up, washoff, and settling of particles of varying size classes and settling velocities (5 sizes classes, with the smallest particle size class representing non-settleable particles). A mass of pollutant (e.g. phosphorus) is associated with a given mass of the particle size classes. The model uses pollutant loading values consistent with the National Urban Runoff program (NURP50 particle file). Table A-1 summarizes the particle class settling velocities as well as the mass of phosphorus associated with a given mass of each particle class.

Table A-1 P8 Particle Classes and Associated Phosphorus

P8 Particle Class	Description	% of TSS	Settling Velocity (ft/hr)	TP (mg TP/kg Particle)
P0%	Non-Settleable/ Dissolved	0	0	99,000
P10%	10th Percentile	20	0.03	3,850
P30%	30th Percentile	20	0.3	3,850
P50%	50th Percentile	20	1.5	3,850
P80%	80th Percentile	40	15	0

Precipitation File Selection (Case—Edit—First—Prec. Data File)

8. MSPL0008.PCP: The P8 model uses long-term climatic data so that watershed runoff and BMPs can be evaluated for varying hydrologic conditions. Hourly precipitation, obtained from the City of Lakeville precipitation gage LL-35 which is located within the Crystal Lake watershed near 16179 Kenrick Ave (at Lakeville Liquors in Lakeville, MN) when available, and hourly data

from the Minneapolis-St. Paul airport, adjusted by the daily rainfall depths observed at more local gages, was used to augment the precipitation record where needed.

Air Temperature File Selection (Case—Edit—First—Air Temp. File)

9. MSP4908a.tmp: Average daily temperature data was obtained from the Minneapolis-St. Paul airport for the period from 1949 through 2008.

Devices Parameter Selection (Case—Edit—Devices—Data—Select Device)

Additionally, the P8 model for each lake was updated to include all existing watershed BMPs (devices) through 2008. Information for the various BMPs includes the bathymetry of ponds and wetlands within the watersheds as well as information about the outlet structures.

10. Detention Pond— Permanent Pool— Area and Volume— The surface area and dead storage volume of each detention pond was determined and entered here.

11. Detention Pond— Flood Pool— Area and Volume— The surface area and storage volume under flood conditions (i.e., the storage volume between the normal level and flood elevation) was determined and entered here.

12. Detention Pond— Infiltration Rate (in/hr)— Infiltration from the wet detention ponds was assumed to be negligible in Crystal and Keller Lake as it resulted in a close match between the predicted and actual lake levels in the water balance. For Lee Lake, an infiltration rate of 0.018 in/hr was applied to ponds in the watershed to best match the actual lake level data.

13. Detention Pond— Orifice Diameter and Weir Length— The orifice diameter or weir length was determined from field surveys or development plans of the area for each detention pond and entered here.

14. Detention Pond or Generalized Device— Particle Removal Scale Factor— Particle Removal Scale Factor— 0.3 for ponds less than two feet deep and 1.0 for all ponds three feet deep or greater. For ponds with normal water depths between two and three feet, a particle removal factor of 0.6 was selected. The particle removal factor for watershed devised determines the particle removal by device.

15. Detention Pond or Generalized Device— Outflow Device Nos.— The number of the downstream device receiving water from the detention pond outflow was entered.

16. Generalized Device— Infiltration Outflow Rates (cfs)— Although the infiltration rates listed under the detention pond category are the same, the outflow rates at each pond depth were calculated in cfs and entered.

17. Pipe/Manhole— Time of Concentration— The time of concentration for each pipe/manhole device was determined and entered here. Time of concentration was determined in accordance with *TR-55 Urban Hydrology for Small Watershed* for watersheds without ponding areas. A "dummy" pipe/manhole was installed in the network to represent Crystal Lake. This forced the model to total all loads (i.e., water, nutrients, etc.) entering the lake. Failure to enter the "dummy" pipe requires the modeler to manually tabulate the loads entering the lake.

Watersheds Parameter Selection (Case—Edit—Watersheds—Data—Select Watershed)

18. Outflow Device Number— The Device Number of the device receiving runoff from the watershed.

19. Pervious Curve Number— This parameter was assumed to be the same as was originally estimated during the P8 model development as part of the UAA (Barr, 2003). The curve number used the county soil survey data along with land use data. A weighted curve number was estimated based on the amount of pervious area as well as the amount of indirectly connected impervious area (assuming a curve number of 98 those surfaces). For more detailed information, see the UAA.

20. Swept/Not Swept—An "Unswept" assumption was made for the entire impervious watershed area. A Sweeping Frequency of 0 was selected. Selected parameters were placed in the "Unswept" column since a sweeping frequency of 0 was selected.

21. Impervious Fraction— The impervious fraction entered in the P8 model is reflective of the amount of directly-connected impervious area. This value was updated in the P8 model since the original P8 models were developed for UAA. To estimate the amount of directly-connected imperviousness within the Crystal, Keller, and Lee Lake watersheds, a GIS land cover layer originally developed for the Vermillion River Watershed JPO (VRWJPO) was used as the starting point (VRWJPO, 2005). This layer delineated impervious surfaces (such as concrete, asphalt, commercial roof, and residential roofs) as well as pervious land covers (such as lawn, forest, and tall grass). Representative sampling was done to estimate how much of the impervious area was actually directly connected to the stormwater system (e.g., for residential

roofs, it was estimated that about 1/3 of residential roof impervious area was considered directly connected) (Barr, 2009). Additionally, the amount of asphalt area was reduced based on a comparison of the original VRWJPO GIS land cover layer with aerial photographs at random locations throughout the Crystal, Keller, and Lee Lake watersheds. These comparisons lead to a 47 percent reduction in asphalt impervious coverage within municipalities and a 17 percent reduction of the asphalt areas within MnDOT subwatersheds. The impervious and directly connected impervious assumptions related to the VRWJPO land cover layer are summarized in Table A-2.

Table A-2 Land Cover Factors Used to Develop Updated P8 Subwatershed Inputs[3]

Land Cover	Asphalt	Bare Soil	Commercial Roof	Concrete	Corn	Forest	Lawn	Pond	Reservoir	Residential Roof	Tall Grass	Vegetated Pond
Total Area Adjustment[1]	0.53	1	1	1	1	1	1*Lawn + 0.47*Asphalt	1	1	1	1	1
Total Area Adjustment In MnDOT subwatersheds[4]	0.833	1	1	1	1	1	1*Lawn + 0.167*Asphalt	1	1	1	1	1
Total % Impervious[2]	100	0	100	100	0	0	0	0	0	100	0	0
Directly Connected % Impervious[2]	100	0	86	100	0	0	0	0	0	33	0	0

1 - Based on comparison of VRWJPO land cover layer (width of asphalt) with aerial photos. Determined that VRWJPO land cover layer overestimated the width of the right of way in residential areas throughout the watersheds and the asphalt area was reduced by 47%. The area removed from Asphalt was then added to the Lawn area in these watersheds.

2 - Assumptions about the percent impervious and percent directly-connected impervious was based on the VRWJPO Hydrologic and Hydraulic modeling.

3 - The P8 watershed inputs were developed on a subwatershed basis, not by MS4 within a subwatershed.

4 - Based on comparison of VRWJPO land cover layer (width of asphalt) with aerial photos, specifically focusing on the MnDOT right of way. Determined that VRWJPO land cover layer overestimated the width of the MnDOT right of way and the asphalt area was reduced by 16.7%. The area removed from Asphalt was then added to the Lawn area in these watersheds.

22. Pollutant Load Scale Factor: The pollutant load scale factors were adjusted for the MnDOT subwatersheds along I-35. These parameters were reduced from the default of 1.0 to 0.8 to better reflect literature published TP concentrations in runoff from freeway surfaces (about 250 to 260 ug/L) (Pitt, 2003).

23. Depression Storage— 0.02

24. Impervious Runoff Coefficient— 1.0

Passes Through the Storm File (Case—Edit—First—Passes Through Storm File)

25. Passes Through Storm File—10. The number of passes through the storm file was determined after the model had been set up and a preliminary run completed. The selection of the number of passes through the storm file was based upon the number required to achieve model stability. Multiple passes through the storm file were required because the model assumes that dead storage waters contain no phosphorus. Consequently, the first pass through the storm file results in lower phosphorus loading than occurs with subsequent passes. Stability occurs when subsequent passes do not result in a change in phosphorus concentration in the pond waters. To determine the number of passes to select, the model was run with three passes, five passes, and ten passes. A comparison of phosphorus predictions for all devices was evaluated to determine whether changes occurred between the three scenarios. If there was no difference between three and five passes, three passes were sufficient to achieve model stability. If differences were noted between three and five passes and no differences were noted between five and ten passes, then five passes were considered sufficient to achieve model stability. Therefore, it was determined that ten passes through the storm file resulted in model stability.

A-4: Existing Conditions and WLA Estimates

The P8 model was used to estimate the watershed phosphorus loads as well as the phosphorus removal by the existing BMPs and other water bodies within the watershed. The results of this analysis have been included as part of Tables 5-3, 5-6, and 5-9 in the TMDL report, for Crystal, Keller, and Lee Lakes, respectively. Several scenarios were evaluated as part of the development of the TMDL using the P8 model output: Existing Conditions without BMPs and Existing Conditions with BMPs. Additionally, the TMDL Wasteload Allocations were based on the Existing Conditions water loads.

Existing Conditions without BMPs

The existing conditions without BMPs is reflective of watershed loading only (See Column 2 of Tables 5-3, 5-6, and 5-9 and Appendices A-5 through A-7). This assumes existing (2008) land use without treatment by any of the BMPs in place, therefore reflecting the maximum phosphorus loading scenario from the watershed.

The existing conditions load without BMPs is equal to the sum of the all the watershed loads predicted by P8. The total phosphorus load for the watershed was then redistributed back to the various MS4s within the watershed based on the amount of directly-connected impervious area (determined using a GIS analysis and summarized in Tables 5-1, 5-4, and 5-7). The following general equations were used to estimate the existing conditions loads without BMPs by MS4:

$$\mathrm{TPLoad}_{\mathrm{MS4xSWSy}} = P8Load_{SWSy} * \frac{DCIA_{MS4xSWSy}}{DCIA_{TSWSy}}$$

Where:	$\mathrm{TPLoad}_{\mathrm{MS4xSWSy}}$	=	TP load associated with MS4 "x" in subwatershed 'y"
	$\mathrm{P8Load}_{\mathrm{SWSy}}$	=	Subwatershed Load predicted by P8 for subwatershed "y"
	$\mathrm{DCIA}_{\mathrm{TSWSy}}$	=	Total Directly Connected Impervious Area within subwatershed "y"
	$\mathrm{DCIA}_{\mathrm{MS4xSWSy}}$	=	Directly Connected Impervious Area associated with MS4 "x" within subwatershed "y"

$$TPLoad_{MS4x} = \sum_{SWS1}^{SWSi} \mathrm{TPLoad}_{\mathrm{MS4xSWSy}}$$

Where:	$\mathrm{TPLoad}_{\mathrm{MS4x}}$	=	Total TP load associated with MS4 "x" without existing BMPs

Existing Conditions with 2008 BMPs (BMP Crediting)

The existing conditions with 2008 BMPs is reflective of the current phosphorus loading from the watershed after treatment by all the BMPs and water bodies that are in place (See Column 3 of Tables 5-3, 5-6, and 5-9 and Appendices A-5 through A-7). This assumes existing (2008) land use as well as any BMPs in place through 2008. The estimated load reflects the existing conditions load.

The P8 modeling was performed on a subwatershed basis; therefore the existing conditions load with 2008 BMPs was tabulated on a subwatershed basis. The phosphorus load to be distributed among the various MS4s within each subwatershed is equal to the difference between the subwatershed loads (watershed only) predicted by P8 and the amount of phosphorus "removed" by the respective BMP. The P8 model was used to estimate the amount of TP removed by the existing BMPs. The TP removal benefits (or load reductions) associated with a given BMP were distributed to the MS4s within the same subwatershed as the BMP, again, based on the proportion of directly-connected impervious area in each MS4 within the subwatershed using the following equation:

$$TPLoadReduction_{MS4xSWSy} = P8Rem_{BMPy} * \frac{DCIA_{MS4xSWSy}}{DCIA_{TSWSy}}$$

Where: $TPLoadReduction_{MS4xSWSy}$ = TP load reduction associated with MS4 "x" in subwatershed 'y"

$P8Rem_{BMPy}$ = Phosphorus removed by BMP "y" (located in subwatershed "y") as predicted by P8

The computed TP load reduction associated with each MS4 in each subwatershed was subtracted from the computed MS4 TP load within each subwatershed assuming no BMPs to determine the TP load associated with each MS4 after water quality treatment occurs in the existing BMPs using the following equations:

$$TPLoad_{MS4xBMPy} = TPLoad_{MS4xSWSy} - TPLoadReduction_{MS4xSWSy}$$

Where: $TPLoad_{MS4xBMPy}$ = TP load associated with MS4 "x" in subwatershed "y" following TP removal by BMP "y"

$$TPLoad_{MS4xBMP} = \sum_{SWS1}^{SWSYi} TPLoad_{MS4xBMPy}$$

Where: $TPLoad_{MS4xBMP}$ = Total TP load associated with MS4 "x" with existing BMPs

By using this methodology, the MS4s that are located within the direct subwatershed to a BMP receive the benefits of the phosphorus removal by the BMP. In general, the phosphorus load from a subwatershed with no water quality treatment would be equal to the total subwatershed runoff load. However, in watersheds that do have treatment incorporated into the storm water system (which is the case for many of the subwatersheds within the Crystal, Keller, and Lee Lake watersheds), the subwatershed loads after treatment were based on the difference between the watershed runoff load and the phosphorus removal by the BMP, in each individual subwatershed. In some cases, the annual removal in the BMP is actually greater than the estimated subwatershed runoff load, resulting in an apparent negative load. These apparent negative loads are the result of the phosphorus load accounting process (and are not actual negative loads) and happen in cases where there are upstream flows into the BMP that are also being treated within the subwatershed, potentially removing more phosphorus than its directly tributary subwatershed generates (also removing phosphorus loads from upstream water bodies). By having a "negative" load, it indicates that the given BMP is highly functional.

TMDL Wasteload Allocations

The TMDL Wasteload Allocations (WLA) is the phosphorus load assigned to each MS4 that they are allowed to discharge as stormwater runoff so that the downstream water body (in this case, Crystal, Keller, or Lee Lakes) will meet its estimated TMDL load capacity and as a result, meet the MPCA water quality standards (See Column 5 of Tables 5-3, 5-6, and 5-9). A load capacity was established for each lake (See Sections 5.2.1, 5.3.1, and 5.4.1). The existing conditions annual water load (based on output from the P8 model) was multiplied by a phosphorus concentration that is typical of treated stormwater runoff (See Sections 5.2.2, 5.3.2, and 5.4.2) to determine the total WLA from the entire watershed. The total WLA was then redistributed back to each MS4 based on the total area of the MS4 within the watershed. By redistributing the load back to the MS4s based on total area, the resulting areal loading rate is equal for all MS4s. The following general equations were used to estimate the WLA for the various MS4s within a watershed:

$$WLA_T = P8Water_T * TPConc$$

Where: WLA_T = Total Wasteload Allocation

$P8Water_T$ = Existing Conditions Water Load from P8 model

$TPConc$ = Typical TP concentration in treated stormwater runoff

$$Area_T = \sum_{MS41}^{MS4i} Area_{MS4x}$$

Where:	$Area_T$	=	Total Watershed Area
	$Area_{MS4x}$	=	Area of MS4 "x"

$$WLA_{MS4x} = WLA_T * \frac{Area_{MS4x}}{Area_T}$$

Where:	WLA_{MS4X}	=	Wasteload Allocation for MS4 "x"
	WLA_T	=	Total Wasteload Allocation
	$Area_{MS4X}$	=	Area of MS4 "x"
	$Area_T$	=	Total area of the watershed

A-5: Crystal Lake TP Load Analysis and Credit - Average Conditions

	Directly Connected Impervious Area by Subwatershed and MS4 from GIS						P8 Model Output		Distribution of Subwatershed TP Load (Existing Conditions without BMPs)					Distribution of TP Load Reduction					Distribution of TP Load Accounting for 2008 BMPs[3] (Existing Conditions with BMPs)				
P8 Device Name	P8 Subwatershed Tributary to Device	Burnsville (acres)	County (acres)	Lakeville (acres)	MnDOT (acres)	Total Directly Connected Impervious Area by Subwatershed (acres)	P8 Total Subwatershed TP Load (lbs/yr)[1]	P8 TP Load Removed (lbs/yr)[2]	Burnsville (lbs/yr)	County (lbs/yr)	Lakeville (lbs/yr)	MnDOT (lbs/yr)	Total TP Load by Subwatershed without 2008 BMPs (lbs/yr)	Burnsville (lbs/yr)	County (lbs/yr)	Lakeville (lbs/yr)	MnDOT (lbs/yr)	Total TP Load Reduction by Subwatershed (lbs/yr)	Burnsville (lbs/yr)	County (lbs/yr)	Lakeville (lbs/yr)	MnDOT (lbs/yr)	Total TP Load by Subwatershed with 2008 BMPs (lbs/yr)
A12a	A12a	0.3	1.4	3.5	0.0	5.2	11.63	4.36	0.7	3.1	7.8	0.0	11.6	0.3	1.2	2.9	0.0	4.4	0.4	2.0	4.9	0.0	7.3
A13a	A13a	17.9	4.9	2.6	1.1	26.5	56.74	35.12	38.4	10.5	5.6	2.3	56.7	23.7	6.5	3.5	1.4	35.1	14.6	4.0	2.1	0.9	21.6
A13a-1	A13a-1	2.5	0.0	0.0	0.0	2.5	1.43	1.42	1.4	0.0	0.0	0.0	1.4	1.4	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0
A13b	A13b	0.2	0.0	2.7	0.0	2.8	6.99	2.93	0.4	0.0	6.6	0.0	7.0	0.2	0.0	2.8	0.0	2.9	0.2	0.0	3.8	0.0	4.1
A13b-2	A13b-2	0.0	0.0	0.1	0.0	0.2	0.53	0.31	0.1	0.0	0.4	0.0	0.5	0.1	0.0	0.2	0.0	0.3	0.1	0.0	0.2	0.0	0.2
A13b-3	A13b-3	0.0	0.0	0.4	0.0	0.4	1.39	0.76	0.1	0.0	1.2	0.0	1.4	0.1	0.0	0.7	0.0	0.8	0.1	0.0	0.6	0.0	0.6
A22a	A22a	0.0	0.0	0.0	0.0	0.0	0.69	0.69	0.7	0.0	0.0	0.0	0.7	0.7	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
A22b	A22b	0.1	0.0	0.0	0.0	0.1	0.28	0.28	0.3	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
A22cMDT1	A22cMDT1	0.1	0.0	0.0	3.4	3.5	5.69	1.31	0.2	0.0	0.0	5.5	5.7	0.0	0.0	0.0	1.3	1.3	0.1	0.0	0.0	4.2	4.4
A22cMDT2	A22cMDT2	0.0	0.0	0.0	6.1	6.1	9.86	1.69	0.0	0.0	0.0	9.9	9.9	0.0	0.0	0.0	1.7	1.7	0.0	0.0	0.0	8.2	8.2
A22c-2	A22c-2	7.7	0.0	0.0	0.4	8.1	17.13	1.47	16.3	0.0	0.0	0.8	17.1	1.4	0.0	0.0	0.1	1.5	14.9	0.0	0.0	0.8	15.7
A22c-3	A22c-3	0.2	0.0	0.0	1.5	1.7	3.63	6.19	0.4	0.0	0.0	3.2	3.6	0.7	0.0	0.0	5.5	6.2	-0.3	0.0	0.0	-2.3	-2.6
A22c-1	A22c-1	1.8	0.0	0.0	0.0	1.8	3.83	0.3	3.8	0.0	0.0	0.0	3.8	0.3	0.0	0.0	0.0	0.3	3.5	0.0	0.0	0.0	3.5
A23	A23	3.3	0.0	0.8	0.0	4.2	8.63	5.07	6.9	0.0	1.8	0.0	8.6	4.0	0.0	1.0	0.0	5.1	2.8	0.0	0.7	0.0	3.6
CL-20b	CL-20b	0.0	0.0	0.2	0.0	0.2	0.48	0.56	0.0	0.0	0.5	0.0	0.5	0.0	0.0	0.6	0.0	0.6	0.0	0.0	-0.1	0.0	-0.1
CL-26Ab	CL-26Ab	0.0	0.0	3.0	0.0	3.0	6.61	4.09	0.0	0.0	6.6	0.0	6.6	0.0	0.0	4.1	0.0	4.1	0.0	0.0	2.5	0.0	2.5
CL-10	CL-10	0.0	0.0	28.4	12.2	40.7	85.7	23.07	0.0	0.0	59.9	25.8	85.7	0.0	0.0	16.1	6.9	23.1	0.0	0.0	43.8	18.8	62.6
CL-11a	CL-11a	0.0	0.0	7.5	0.0	7.5	15.93	7.9	0.0	0.0	15.9	0.0	15.9	0.0	0.0	7.9	0.0	7.9	0.0	0.0	8.0	0.0	8.0
CL-15	CL-15	0.0	2.0	11.2	0.0	13.3	32.24	19.17	0.0	5.0	27.3	0.0	32.2	0.0	2.9	16.2	0.0	19.2	0.0	2.0	11.1	0.0	13.1
CL-16	CL-16	0.0	0.2	9.6	0.0	9.8	26.09	15.32	0.0	0.4	25.7	0.0	26.1	0.0	0.2	15.1	0.0	15.3	0.0	0.2	10.6	0.0	10.8
CL-18	CL-18	0.0	0.0	14.4	0.0	14.4	37.44	19.04															
	CL-18-1	0.0	0.0	0.7	0.0	0.7	2.04	0.01															
	CL-20e	0.0	0.0	0.1	0.0	0.1	0.17	0.01															
	Total for CL-18	0.0	0.0	15.1	0.0	15.1	39.65	19.04	0.0	0.0	39.7	0.0	39.7	0.0	0.0	19.0	0.0	19.0	0.0	0.0	20.6	0.0	20.6
CL-19	CL-19	0.0	0.0	1.6	0.0	1.6	4.49	2.59	0.0	0.0	4.5	0.0	4.5	0.0	0.0	2.6	0.0	2.6	0.0	0.0	1.9	0.0	1.9
CL-19-1	CL-19-1	0.0	0.0	1.7	0.0	1.7	4.31	2.22	0.0	0.0	4.3	0.0	4.3	0.0	0.0	2.2	0.0	2.2	0.0	0.0	2.1	0.0	2.1
CL-20a	CL-20a	0.0	0.0	0.7	0.0	0.7	1.76	0.88	0.0	0.0	1.8	0.0	1.8	0.0	0.0	0.9	0.0	0.9	0.0	0.0	0.9	0.0	0.9
CL-20c	CL-20c	0.0	0.0	1.4	0.0	1.4	3.79	1.11	0.0	0.0	3.8	0.0	3.8	0.0	0.0	1.1	0.0	1.1	0.0	0.0	2.7	0.0	2.7
CL-20d	CL-20d	0.0	0.0	0.1	0.0	0.1	0.6	1.6	0.0	0.0	0.6	0.0	0.6	0.0	0.0	1.6	0.0	1.6	0.0	0.0	-1.0	0.0	-1.0
CL-21	CL-21	0.8	6.1	24.3	0.0	31.2	68.17	36.21															
	CL-23	0.0	0.0	1.1	0.0	1.1	2.88	0.01															
	Total for CL-21	0.8	6.1	25.4	0.0	32.3	71.05	36.21	1.7	13.5	55.9	0.0	71.1	0.8	6.9	28.5	0.0	36.2	0.8	6.6	27.4	0.0	34.8
CL-21-1	CL-21-1	0.0	0.0	0.0	0.0	0.0	0.26	0.01	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3
CL-21-2	CL-21-2	0.0	0.0	0.0	0.0	0.0	0.1	0.01	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
CL-21-3	CL-21-3	0.0	0.0	0.0	0.0	0.0	0.16	0.01	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2
CL-25	CL-25	0.0	0.0	1.3	0.0	1.3	4.28	4.18	0.0	0.0	4.3	0.0	4.3	0.0	0.0	4.2	0.0	4.2	0.0	0.0	0.1	0.0	0.1
CL-26Aa	CL-26Aa	0.0	0.0	6.5	0.0	6.5	14.9	7.7	0.0	0.0	14.9	0.0	14.9	0.0	0.0	7.7	0.0	7.7	0.0	0.0	7.2	0.0	7.2
CL-29a	CL-29a	0.0	0.0	0.6	0.0	0.6	1.63	0.99	0.0	0.0	1.6	0.0	1.6	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.6	0.0	0.6
CL-29b	CL-29b	0.0	0.0	1.5	0.0	1.5	3.58	1.47	0.0	0.0	3.6	0.0	3.6	0.0	0.0	1.5	0.0	1.5	0.0	0.0	2.1	0.0	2.1
CL-29c	CL-29c	0.0	0.0	0.1	0.0	0.1	0.24	0.66	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.7	0.0	0.7	0.0	0.0	-0.4	0.0	-0.4
CL-29d	CL-29d	0.0	0.0	2.4	0.0	2.4	6.73	3.64	0.0	0.0	6.7	0.0	6.7	0.0	0.0	3.6	0.0	3.6	0.0	0.0	3.1	0.0	3.1
CL-2a	CL-2a	0.0	0.0	0.1	0.0	0.1	0.13	11.75	0.0	0.0	0.1	0.0	0.1	0.0	0.0	11.8	0.0	11.8	0.0	0.0	-11.6	0.0	-11.6
CL-2b	CL-2b	0.4	0.0	1.1	0.0	1.5	2.87	5.39	0.8	0.0	2.1	0.0	2.9	1.5	0.0	3.9	0.0	5.4	-0.7	0.0	-1.8	0.0	-2.5
CL-2c	CL-2c	0.0	3.7	4.3	0.5	8.5	15.45	53.6	0.0	6.7	7.8	0.9	15.5	0.0	23.3	27.0	3.3	53.6	0.0	-16.6	-19.3	-2.3	-38.2
CL-30	CL-30	0.0	0.0	10.6	0.0	10.6	24.41	11.83	0.0	0.0	24.4	0.0	24.4	0.0	0.0	11.8	0.0	11.8	0.0	0.0	12.6	0.0	12.6
CL-31a	CL-31a	0.0	0.0	1.2	0.0	1.2	3.45	2.04	0.0	0.0	3.5	0.0	3.5	0.0	0.0	2.0	0.0	2.0	0.0	0.0	1.4	0.0	1.4
CL-31b	CL-31b	0.0	0.0	0.4	0.0	0.4	1.67	1.05	0.0	0.1	1.6	0.0	1.7	0.0	0.1	1.0	0.0	1.1	0.0	0.0	0.6	0.0	0.6
CL-31c	CL-31c	0.0	0.0	0.3	0.0	0.3	0.82	0.52	0.0	0.0	0.8	0.0	0.8	0.0	0.0	0.5	0.0	0.5	0.0	0.0	0.3	0.0	0.3
CL-32a	CL-32a	0.0	3.5	3.2	0.0	6.7	15.75	8.86	0.0	8.3	7.4	0.0	15.8	0.0	4.7	4.2	0.0	8.9	0.0	3.6	3.3	0.0	6.9
CL-33a	CL-33a	0.0	0.0	3.7	0.0	3.7	10.69	4.38	0.0	0.0	10.7	0.0	10.7	0.0	0.0	4.4	0.0	4.4	0.0	0.0	6.3	0.0	6.3

A-5: Crystal Lake TP Load Analysis and Credit - Average Conditions

	Directly Connected Impervious Area by Subwatershed and MS4 from GIS						P8 Model Output		Distribution of Subwatershed TP Load (Existing Conditions without BMPs)					Distribution of TP Load Reduction					Distribution of TP Load Accounting for 2008 BMPs[3] (Existing Conditions with BMPs)				
P8 Device Name	**P8 Subwatershed Tributary to Device**	**Burnsville (acres)**	**County (acres)**	**Lakeville (acres)**	**MnDOT (acres)**	**Total Directly Connected Impervious Area by Subwatershed (acres)**	**P8 Total Subwatershed TP Load (lbs/yr)[1]**	**P8 TP Load Removed (lbs/yr)[2]**	**Burnsville (lbs/yr)**	**County (lbs/yr)**	**Lakeville (lbs/yr)**	**MnDOT (lbs/yr)**	**Total TP Load by Subwatershed without 2008 BMPs (lbs/yr)**	**Burnsville (lbs/yr)**	**County (lbs/yr)**	**Lakeville (lbs/yr)**	**MnDOT (lbs/yr)**	**Total TP Load Reduction by Subwatershed (lbs/yr)**	**Burnsville (lbs/yr)**	**County (lbs/yr)**	**Lakeville (lbs/yr)**	**MnDOT (lbs/yr)**	**Total TP Load by Subwatershed with 2008 BMPs (lbs/yr)**
CL-33b	CL-33b	0.0	0.0	2.0	0.0	2.0	5.27	2.65	0.0	0.0	5.3	0.0	5.3	0.0	0.0	2.7	0.0	2.7	0.0	0.0	2.6	0.0	2.6
CL-3B	CL-3B	0.0	0.8	1.8	0.0	2.7	5.77	1.72															
	CL-3A	0.0	0.0	10.7	0.0	10.7	40.37	0															
	Total for CL-3B	0.0	0.8	12.5	0.0	13.4	46.14	1.72	0.0	2.9	43.3	0.0	46.1	0.0	0.1	1.6	0.0	1.7	0.0	2.8	41.6	0.0	44.4
CL-4A	CL-4A	0.0	0.0	0.9	0.0	0.9	2.25	1.26	0.0	0.0	2.3	0.0	2.3	0.0	0.0	1.3	0.0	1.3	0.0	0.0	1.0	0.0	1.0
CL-5a	CL-5a	0.0	0.0	1.7	0.0	1.7	3.83	21.67															
	CL-7Ca	0.0	2.9	11.4	0.0	14.2	29.08	0															
	CL-7Cb-2	0.0	0.0	0.0	0.0	0.0	0.07	0.01															
	Total for CL-5a	0.0	2.9	13.1	0.0	15.9	32.98	21.68	0.0	6.0	27.0	0.0	33.0	0.0	3.9	17.8	0.0	21.7	0.0	2.0	9.3	0.0	11.3
CL-7A1a	CL-7A1a	0.0	0.6	0.1	5.7	6.4	13.33	8.44	0.1	1.2	0.2	11.8	13.3	0.1	0.8	0.1	7.5	8.4	0.0	0.5	0.1	4.3	4.9
CL-7B	CL-7B	0.0	0.0	10.7	0.0	10.7	23.42	24.2	0.0	0.0	23.3	0.1	23.4	0.0	0.0	24.1	0.1	24.2	0.0	0.0	-0.8	0.0	-0.8
CL-7Ca-1	CL-7Ca-1	0.0	0.0	0.3	0.0	0.3	0.85	0.44	0.0	0.0	0.8	0.0	0.9	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.4	0.0	0.4
CL-7Ca-2	CL-7Ca-2	0.0	0.0	2.3	0.0	2.3	4.71	2.05	0.0	0.0	4.7	0.0	4.7	0.0	0.0	2.1	0.0	2.1	0.0	0.0	2.7	0.0	2.7
CL-7Ca-3	CL-7Ca-3	0.0	0.0	1.8	0.0	1.8	4.01	4.27															
	CL-8	0.0	0.0	3.3	0.0	3.3	7.01	0.02															
	Total for CL-7Ca-3	0.0	0.0	5.1	0.0	5.1	11.02	4.29	0.0	0.0	11.0	0.0	11.0	0.0	0.0	4.3	0.0	4.3	0.0	0.0	6.7	0.0	6.7
CL-7Cb-1	CL-7Cb-1	0.0	0.1	5.4	0.0	5.5	10.87	6.06	0.0	0.2	10.7	0.0	10.9	0.0	0.1	6.0	0.0	6.1	0.0	0.1	4.7	0.0	4.8
CL-8Aa	CL-8Aa	0.0	0.0	0.0	1.9	1.9	3.46	5.7	0.0	0.0	0.0	3.5	3.5	0.0	0.0	0.0	5.7	5.7	0.0	0.0	0.0	-2.2	-2.2
CryLake	CryLake	0.0	0.0	0.0	0.0	0.0	0	0					0.0					0.0					0.0
	A24b	5.1	0.6	8.5	0.0	14.2	21.8	0															
	A24c	2.7	0.0	0.2	0.0	2.9	5.07	0.02															
	Total for CryLake	7.7	0.6	8.7	0.0	17.1	26.87	0.02	12.2	1.0	13.7	0.0	26.9	0.0	0.0	0.0	0.0	0.0	12.2	1.0	13.7	0.0	26.9
A24a	A24a	3.4	0.0	0.0	0.0	3.4	1.54	0															
	BBBay	4.2	0.0	0.0	0.0	4.2	6.57	0															
	BHBay	3.1	0.0	0.0	0.0	3.1	3.55	0															
	CL-31-2	2.4	0.1	0.1	0.0	2.6	6.3	0.01															
	Total for A24a	13.1	0.1	0.1	0.0	13.3	17.96	0.01	17.7	0.1	0.1	0.0	18.0	0.0	0.0	0.0	0.0	0.0	17.7	0.1	0.1	0.0	18.0
									Burnsville (lbs/yr)	County (lbs/yr)	Lakeville (lbs/yr)	MnDOT (lbs/yr)	Total TP Load by Subwatershed without 2008 BMPs (lbs/yr)	Burnsville (lbs/yr)	County (lbs/yr)	Lakeville (lbs/yr)	MnDOT (lbs/yr)	Total TP Load Reduction by Subwatershed (lbs/yr)	Burnsville (lbs/yr)	County (lbs/yr)	Lakeville (lbs/yr)	MnDOT (lbs/yr)	Total TP Load by Subwatershed with 2008 BMPs (lbs/yr)
Total		56	27	215	33	331	**727**	**392**	102	59	502	64	727	36	51	273	33	392	67	8	230	30	335
									Existing Conditions without BMP: See Table 5-3 column 2										Existing Conditions with BMP: See Table 5-3 column 3				

1 - Subwatershed Load from P8 model results: Watershed only, no treatment by BMPs

2 - Amount of phosphorus removed by BMP in Subwatershed as estimated by P8 model. In some cases, the amount removed is greater than the subwatershed load. This is because the BMP is also treating flows from upstream watersheds. However, the "credit" for the TP removal by the BMPs is only applied to those MS4s falling within the subwatershed directly tributary to the BMP.

3 - TP Load Accounting for 2008 BMPs = Total Subwatershed TP Load - Total TP Load Removed by BMP. A negative load indicates a BMP that is highly functioning, removing more phosphorus than its directly tributary watershed generates. This is possible if the BMP treats additional flows from upstream watersheds and

A-6: Keller Lake TP Load Analysis and Credit - Average Conditions

	Directly Connected Impervious Area by Subwatershed and MS4 from GIS					P8 Model Output		Distribution of Subwatershed TP Load (Existing Conditions without BMPs)				Distribution of TP Load Reduction				Distribution of TP Load Accounting for 2008 BMPs[3] (Existing Conditions with BMPs)			
P8 Device Name	P8 Subwatershed Tributary to Device	Apple Valley (acres)	Burnsville (acres)	County (acres)	Total Directly Connected Impervious Area by Subwatershed (acres)	P8 Total Subwatershed TP Load (lbs/yr)[1]	P8 TP Load Removed (lbs/yr)[2]	Apple Valley (lbs/yr)	Burnsville (lbs/yr)	County (lbs/yr)	Total TP Load by Subwatershed without 2008 BMPs (lbs/yr)	Apple Valley (lbs/yr)	Burnsville (lbs/yr)	County (lbs/yr)	Total TP Load Reduction by Subwatershed (lbs/yr)	Apple Valley (lbs/yr)	Burnsville (lbs/yr)	County (lbs/yr)	Total TP Load by Subwatershed with 2008 BMPs (lbs/yr)
A1-1	A1	30.6	0.2	0.9	31.7	80.24	20.30												
A1-2	No SWS	0.0	0.0	0.0	0.0		16.07												
	Total For A1-1/A1-2	30.6	0.2	0.9	31.7	80.24	36.37	77.5	0.5	2.3	80.2	35.1	0.2	1.0	36.4	42.4	0.3	1.2	43.9
A2	A2	14.2	0.0	0.0	14.2	37.59	20.11	37.6	0.0	0.0	37.6	20.1	0.0	0.0	20.1	17.5	0.0	0.0	17.5
A3	A3	0.0	20.2	3.1	23.3	51.59	19.10	0.0	44.8	6.8	51.6	0.0	16.6	2.5	19.1	0.0	28.2	4.3	32.5
A35	A35	0.0	1.5	0.0	1.5	3.40	1.94	0.0	3.4	0.0	3.4	0.0	1.9	0.0	1.9	0.0	1.5	0.0	1.5
A36	A36	0.0	0.7	0.0	0.7	1.91	1.26	0.0	1.9	0.0	1.9	0.0	1.3	0.0	1.3	0.0	0.7	0.0	0.7
A39a	A39a	0.0	0.1	0.0	0.1	0.27	0.27	0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0
A39b	A39b	0.0	0.6	0.0	0.6	1.70	0.93	0.0	1.7	0.0	1.7	0.0	0.9	0.0	0.9	0.0	0.8	0.0	0.8
A40	A40	0.0	1.1	0.0	1.1	3.61	2.02	0.0	3.6	0.0	3.6	0.0	2.0	0.0	2.0	0.0	1.6	0.0	1.6
A41a	A41a	0.0	0.8	0.0	0.8	2.52	1.26	0.0	2.5	0.0	2.5	0.0	1.2	0.0	1.3	0.0	1.2	0.0	1.3
A46a	A41b	0.0	0.0	0.1	0.1	0.29	0.01												
	A46a	0.0	11.9	3.0	14.9	33.77	17.68												
	Total for A46a	0.0	11.9	3.1	15.0	34.06	17.69	0.0	27.1	7.0	34.1	0.0	14.1	3.6	17.7	0.0	13.0	3.4	16.4
A46b	A46b	0.0	0.3	0.0	0.3	0.91	0.95	0.0	0.9	0.0	0.9	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0
A46c	A46c	0.0	0.7	0.0	0.7	1.60	0.44	0.0	1.6	0.0	1.6	0.0	0.4	0.0	0.4	0.0	1.2	0.0	1.2
A46d	A37-38	0.0	1.4	0.7	2.1	5.29	0.01												
	A46d	0.0	0.3	0.9	1.3	3.44	4.42												
	Total for A46d	0.0	1.7	1.7	3.4	8.73	4.43	0.0	4.4	4.3	8.7	0.0	2.2	2.2	4.4	0.0	2.2	2.1	4.3
A6a	A6c	0.0	9.7	0.0	9.7	24.31	0.01												
	A6a	0.0	16.4	0.0	16.4	40.40	36.85												
	Total for A6a	0.0	26.0	0.0	26.0	64.71	36.86	0.0	64.7	0.0	64.7	0.0	36.9	0.0	36.9	0.0	27.9	0.0	27.9
A6b	A6b	0.0	1.0	0.0	1.0	2.81	1.59	0.0	2.8	0.0	2.8	0.0	1.6	0.0	1.6	0.0	1.2	0.0	1.2
A7b-1	A7b-1	0.0	0.8	0.0	0.8	1.85	1.57	0.0	1.9	0.0	1.9	0.0	1.6	0.0	1.6	0.0	0.3	0.0	0.3
KL_IN	A7a	78.0	9.1	3.6	90.7	206.03	0.00	177.2	20.7	8.2	206.0	0.0	0.0	0.0	0.0	177.2	20.7	8.2	206.0
A7b (KL_IN)	A7b	0.0	21.5	0.0	21.5	51.86	0.01	0.0	51.9	0.0	51.9	0.0	0.0	0.0	0.0	0.0	51.9	0.0	51.9
A7c	A7c	0.1	2.8	0.7	3.6	9.24	4.38	0.2	7.2	1.8	9.2	0.1	3.4	0.9	4.4	0.1	3.8	0.9	4.9
WVR-43a	WVR-43a	37.3	0.0	8.0	45.3	12.76	4.71	10.5	0.0	2.3	12.8	3.9	0.0	0.8	4.7	6.6	0.0	1.4	8.1
								Apple Valley (lbs/yr)	Burnsville (lbs/yr)	County (lbs/yr)	Total TP Load by Subwatershed without 2008 BMPs (lbs/yr)	Apple Valley (lbs/yr)	Burnsville (lbs/yr)	County (lbs/yr)	Total TP Load Reduction by Subwatershed (lbs/yr)	Apple Valley (lbs/yr)	Burnsville (lbs/yr)	County (lbs/yr)	Total TP Load by Subwatershed with 2008 BMPs (lbs/yr)
Total		**160**	**101**	**21**	**282**	**578**	**156**	303	242	33	578	59	86	11	156	244	156	22	422
								Existing Conditions without BMP: See Table 5-6 column 2								Existing Conditions with BMP: See Table 5-6 column 3			

1 - Subwatershed Load from P8 model results: Watershed only, no treatment by BMPs

2 - Amount of phosphorus removed by BMP in Subwatershed as estimated by P8 model. In some cases, the amount removed is greater than the subwatershed load. This is because the BMP is also treating flows from upstream watersheds. However, the "credit" for the TP removal by the BMPs is only applied to those MS4s falling within the subwatershed directly tributary to the BMP.

3 - TP Load Accounting for 2008 BMPs = Total Subwatershed TP Load - Total TP Load Removed by BMP. A negative load indicates a BMP that is highly functioning, removing more phosphorus than its directly tributary watershed generates. This is possible if the BMP treats additional flows from upstream watersheds and BMPs.

A-7: Lee Lake TP Load Analysis and Credit - Average Conditions

	Directly Connected Impervious Area by Subwatershed and MS4 from GIS					P8 Model Output		Distribution of Subwatershed TP Load (Existing Conditions without BMPs)				Distribution of TP Load Reduction				Distribution of TP Load Accounting for 2008 BMPs[3] (Existing Conditions with BMPs)			
P8 Device Name	P8 Subwatershed Tributary to Device	County (acres)	Lakeville (acres)	MnDOT (acres)	Total Directly Connected Impervious Area by Subwatershed (acres)	P8 Total Subwatershed TP Load (lbs/yr)[1]	P8 TP Load Removed (lbs/yr)[2]	County (lbs/yr)	Lakeville (lbs/yr)	MnDOT (lbs/yr)	Total TP Load by Subwatershed without 2008 BMPs (lbs/yr)	County (lbs/yr)	Lakeville (lbs/yr)	MnDOT (lbs/yr)	Total TP Load Reduction by Subwatershed (lbs/yr)	County (lbs/yr)	Lakeville (lbs/yr)	MnDOT (lbs/yr)	Total TP Load by Subwatershed with 2008 BMPs (lbs/yr)
CL-12aMDT	CL-12aMDT	0.0	1.7	12.5	14.2	22.81	2.48	0.0	2.7	20.1	22.8	0.0	0.3	2.2	2.5	0.0	2.4	17.9	20.3
LL_IN	CL-12a	1.1	14.1	0.0	15.3	28.91	0	2.1	26.8	0.0	28.9	0.0	0.0	0.0	0.0	2.1	26.8	0.0	28.9
CL-12a-1	CL-12a-1	0.0	6.9	0.1	7.0	16.45	10.44	0.0	16.1	0.3	16.5	0.0	10.2	0.2	10.4	0.0	5.9	0.1	6.0
CL-13a	CL-13a	1.0	1.6	0.0	2.7	6.21	5.45	2.4	3.8	0.0	6.2	2.1	3.3	0.0	5.5	0.3	0.5	0.0	0.8
CL-13b	CL-13b	0.0	2.2	0.0	2.2	5.64	3.83	0.0	5.6	0.0	5.6	0.0	3.8	0.0	3.8	0.0	1.8	0.0	1.8
CL-13b-1	CL-13b-1	0.1	6.3	0.0	6.3	12.63	8.17	0.1	12.5	0.0	12.6	0.1	8.1	0.0	8.2	0.0	4.4	0.0	4.5
CL-13c	CL-13c	0.3	0.5	0.0	0.8	2.12	1.81	0.9	1.3	0.0	2.1	0.7	1.1	0.0	1.8	0.1	0.2	0.0	0.3
CL-13d	CL-13d	0.0	0.6	0.0	0.6	1.66	1.17	0.0	1.7	0.0	1.7	0.0	1.2	0.0	1.2	0.0	0.5	0.0	0.5
CL-13e	CL-13e	1.2	1.6	0.0	2.8	6.81	4.54	3.0	3.8	0.0	6.8	2.0	2.5	0.0	4.5	1.0	1.3	0.0	2.3
CL-13f	CL-13f	0.1	0.1	0.0	0.2	0.83	0.8	0.4	0.4	0.0	0.8	0.4	0.4	0.0	0.8	0.0	0.0	0.0	0.0
								County (lbs/yr)	Lakeville (lbs/yr)	MnDOT (lbs/yr)	Total TP Load by Subwatershed without 2008 BMPs (lbs/yr)	County (lbs/yr)	Lakeville (lbs/yr)	MnDOT (lbs/yr)	Total TP Load Reduction by Subwatershed (lbs/yr)	County (lbs/yr)	Lakeville (lbs/yr)	MnDOT (lbs/yr)	Total TP Load by Subwatershed with 2008 BMPs (lbs/yr)
Total		4	36	13	52	104	39	9	75	20	104	5	31	2	39	4	43	18	65
								Existing Conditions without BMP: See Table 5-9 column 2								Existing Conditions with BMP: See Table 5-9 column 3			

1 - Subwatershed Load from P8 model results: Watershed only, no treatment by BMPs

2 - Amount of phosphorus removed by BMP in Subwatershed as estimated by P8 model. In some cases, the amount removed is greater than the subwatershed load. This is because the BMP is also treating flows from upstream watersheds. However, the "credit" for the TP removal by the BMPs is only applied to those MS4s falling within the subwatershed directly tributary to the BMP.

3 - TP Load Accounting for 2008 BMPs = Total Subwatershed TP Load - Total TP Load Removed by BMP. A negative load indicates a BMP that is highly functioning, removing more phosphorus than its directly tributary watershed generates. This is possible if the BMP treats additional flows from upstream watersheds and BMPs.

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Appendix B

Crystal Lake TMDL Modeling Summary

B-1: Crystal Lake Water Quality Data
Average (2006) Climatic Conditions

Date	Secchi Disc Depth (m)	Estimated Depth to Thermocline (m)	Sample Depth (m)	Chl-a (ug/l)	D.O. (mg/l)	Temp. (oC)	Total P (mg/L)
5/16/2006	**2.6**	**9**	**0-2**	**7.5**		**14**	**0.024**
5/16/2006			0.1		10.8	14	
5/16/2006			0.1		10.8	14	
5/16/2006			1.7		10.7	14	
5/16/2006			2.6		10.7	14	
5/16/2006			3.5		10.7	14	
5/16/2006			4.0		10.6	13	0.035
5/16/2006			4.7		10.1	13	
5/16/2006			5.2		9.8	13	
5/16/2006			6.0		9.3	13	
5/16/2006			6.7		8.6	13	
5/16/2006			7.0				0.028
5/16/2006			7.5		6.4	13	
5/16/2006			7.8		5.0	12	
5/16/2006			9.0				0.042
5/16/2006			9.2		2.6	12	
5/16/2006			9.3		1.9	12	
5/31/2006	**4**	**3**	**0-2**	**5.7**		**24**	**0.02**
5/31/2006			1.0		10.1	24	
5/31/2006			1.9		10.1	24	
5/31/2006			2.9		11.2	21	
5/31/2006			3.5		12.0	18	
5/31/2006			4.0		11.1	17	0.022
5/31/2006			4.4		9.6	16	
5/31/2006			4.8		9.3	15	
5/31/2006			5.3		8.3	14	
5/31/2006			6.1		6.7	14	
5/31/2006			6.6		5.7	13	
5/31/2006			7.0		3.4	13	0.051
5/31/2006			8.0		0.9	12	
5/31/2006			9.0		0.3	12	0.107
6/15/2006	**3**	**4**	**0-2**	**10**		**22**	**0.031**
6/15/2006			0.5		11.0	22	
6/15/2006			1.0		13.7	22	
6/15/2006			2.0		13.8	22	
6/15/2006			3.1		13.4	21	
6/15/2006			3.5		12.0	21	
6/15/2006			4.0				0.049
6/15/2006			4.1		10.8	20	
6/15/2006			4.5		8.8	19	
6/15/2006			5.0		6.6	18	
6/15/2006			5.5		5.2	16	
6/15/2006			6.0		2.5	15	
6/15/2006			7.0		1.2	13	0.046
6/15/2006			8.0		0.6	12	
6/15/2006			9.0				0.153
6/28/2006	**1.3**	**5**	**0-2**	**32**		**23**	**0.048**
6/28/2006			0.2		10.5	23	
6/28/2006			1.0		10.2	23	
6/28/2006			2.0		10.1	23	
6/28/2006			3.0		9.8	23	
6/28/2006			4.0		6.9	23	0.048
6/28/2006			4.5		4.9	22	
6/28/2006			5.0		0.7	20	
6/28/2006			6.0		0.5	16	
6/28/2006			7.0		0.4	14	0.058
6/28/2006			8.0		0.3	13	
6/28/2006			8.5				0.24
7/5/2006	**1.4**	**5**	**0-2**	**26**		**25**	**0.05**
7/5/2006			0.2		11.2	25	
7/5/2006			1.0		10.9	25	
7/5/2006			1.9		10.9	25	
7/5/2006			3.0		10.8	25	
7/5/2006			3.8		10.8	25	
7/5/2006			4.0				0.046
7/5/2006			4.5		9.0	25	
7/5/2006			5.2		3.1	23	
7/5/2006			5.5		0.8	22	
7/5/2006			6.0		0.4	20	
7/5/2006			6.5		0.4	18	
7/5/2006			7.0				0.051
7/5/2006			7.2		0.3	16	
7/5/2006			8.0		0.4	14	
7/5/2006			8.6		0.4	13	
7/5/2006			9.0		0.3	13	0.388
7/24/2006	**1.5**	**5**	**0-2**	**80**		**26**	**0.04**
7/24/2006			0.2		10.9	26	
7/24/2006			1.0		10.8	26	
7/24/2006			2.0		10.7	26	
7/24/2006			3.0		7.4	25	

B-2: Stage/Storage/Discharge Rating Curve

Crystal Lake

Elevation	Area[1]	Cumulative Storage	Discharge
(ft MSL)	(ac)	(ac-ft)	(cfs)
895.4	0.0	0	0
908.4	32.8	130	0
918.4	67.2	613	0
924.4	114.3	1158	0
926.4	144.0	1415	0
928.4	183.0	1742	0
933.4	292.5	2931	0.0
933.6	293.1	2989	2.9
933.8	293.7	3048	8.2
934.0	294.3	3107	15.1
934.2	294.8	3166	23.2
934.4	295.4	3225	32.0
934.6	296.0	3284	35.0
934.8	296.6	3343	38.0
935.0	297.1	3402	42
935.6	298.9	3581	54
936.0	300.0	3701	60
938.0	331.0	4332	80

1 - Source: Crystal-Keller Lake UAA (Barr, 2003)

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B-3: Crystal Lake Average Climatic Conditions
P8 Loading Summary - Calibration (2006 Watershed Conditions)

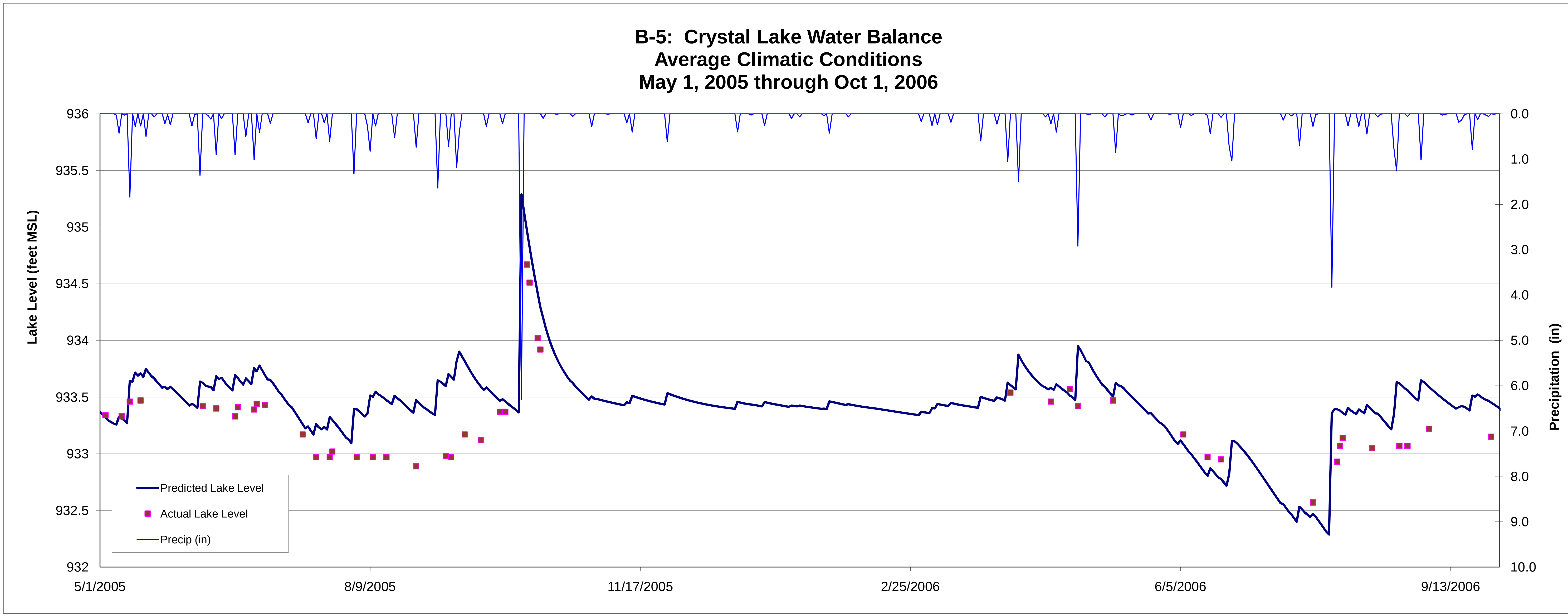
	Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc (ug/L)
Steady State Year (May 1, 2005 - April 30, 2006)		37.0	1046	391	138
(Oct 1, 2005 - April 30, 2006)		17.3	534	189	130
5/1/2006	**5/16/2006**	1.0	35	11.4	121
5/17/2006	**5/31/2006**	0.2	3	1.5	158
6/1/2006	**6/15/2006**	0.4	8	4.1	182
6/16/2006	**6/28/2006**	2.3	59	24.2	152
6/29/2006	**7/5/2006**	0.0	0	0.0	0
7/6/2006	**7/24/2006**	1.2	27	12.9	174
7/25/2006	**8/10/2006**	4.4	125	43.0	127
8/11/2006	**8/28/2006**	2.6	67	26.5	145
8/29/2006	**9/7/2006**	1.0	27	10.9	151
9/8/2006	**9/18/2006**	0.4	8	3.2	141
9/19/2006	**9/23/2006**	0.9	23	8.2	130
9/24/2006	**9/30/2006**	0.1	1	0.4	107
Growing Season Load (June 1, 2006 - Sept 30, 2006)		13.3	346	133	142
Total Load (2006 Water Year - Oct 1, 2005 - Sept 30, 2006)		31.8	919	335	134

B-4: Crystal Lake Average Climatic Conditions
Water Balance Summary
Calibration Conditions (2006 Watershed Conditions)

	Sample Period		A	B	C	D	E	F	G	H	I	J	K	L
			Total Lake Volume at the Start of the Period (acre-ft)	Direct Precipitation (acre-ft)	Evaporation (acre-ft)	Watershed Runoff (acre-ft)	Pumping to Keller Lake (acre-ft)	Discharge from Keller Lake (acre-ft)	Discharge from Lee Lake (acre-ft)	Groundwater Exchange (acre-ft)	Discharge from Crystal Lake (acre-ft)	Change in Lake Volume (acre-ft)	Total Lake Volume at the End of the Period (acre-ft)	Lake Level at End of Period (ft MSL)
				+	-	+	-	+	+	-	-			
Steady State Year (May 1, 2005 - April 30, 2006)	5/1/2005	4/30/2006	2930	900	661	1046	454	707	7	320	1088	138	3068	933.9
(Oct 1, 2005 - April 30, 2006)	10/1/2005	4/30/2006	2937	421	126	534	114	311	7	186	715	131	3068	933.9
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/16/2006	3068	25	53	35	51	36	0	14	71	-93	2975	933.6
	5/17/2006	5/31/2006	2975	4	49	3	41	14	0	13	6	-88	2887	933.2
	6/1/2006	6/15/2006	2887	9	66	8	44	7	0	13	0	-98	2789	932.8
	6/16/2006	6/28/2006	2789	53	56	59	41	52	0	11	0	55	2844	933.0
	6/29/2006	7/5/2006	2844	0	38	0	25	8	0	7	0	-62	2782	932.8
	7/6/2006	7/24/2006	2782	27	85	27	48	21	0	15	0	-73	2709	932.5
	7/25/2006	8/10/2006	2709	99	64	125	22	96	0	14	0	219	2929	933.4
	8/11/2006	8/28/2006	2929	63	56	67	44	52	0	16	17	50	2978	933.6
	8/29/2006	9/7/2006	2978	25	23	27	32	33	0	9	26	-4	2974	933.5
	9/8/2006	9/18/2006	2974	10	21	8	35	16	0	10	8	-39	2935	933.4
	9/19/2006	9/23/2006	2935	22	9	23	16	21	0	4	5	32	2967	933.5
	9/24/2006	9/30/2006	2967	2	13	1	22	13	0	6	7	-31	2936	933.4
Total for Growing Season (June 1, 2006- Sept 30, 2006)	6/1/2006	9/30/2006	2887	311	431	346	330	320	0	105	63	49	2936	933.4
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)	10/1/2005	9/30/2006	2937	761	659	919	536	681	7	318	855	-1	2936	933.4

Annual (2006 Water Year) Water Load to Crystal Lake (acre-ft)	10/1/2005	9/30/2006	2367	Water Load = B + D + F + G

A - Based on the daily water balance model (calibrated to lake level data and using the lake stage-storage-discharge curve). See Appendix B-2.
B - Based on precipitation data used for the P8 modeling and the daily water balance model (Direct Precip Volume = Depth of Precip * Lake Surface Area) See Appendix B-3.
C - Based on adjusted pan evaporation data from the University of Minnesota St. Paul Campus Climatological Observatory and the daily water balance model (Evap Volume = 0.7 * Depth of Evap * Lake Surface Area). See Appendix B-6.
D - Based on the water loads from the P8 model. See Appendix B-3.
E - Based on the ferric chloride system pump logs and pump settings. See Appendix F.
F - Based on the estimated discharge from the Keller Lake daily water balance model. See Appendix C-4.
G - Based on the estimated discharge from the Lee Lake daily water balance model. See Appendix D-4.
H - Groundwater exchange fit to 2008 lake levels and watershed conditions. The estimated groundwater exchange was applied to all climatic conditions.
I - Based on the estimated discharge from the Crystal Lake daily water balance model
J - Change in Lake Volume = B - C + D - E + F + G - H - I
K- Total Lake Volume @ End of Period = A + J
L - Estimated lake level based on the total lake volume and the stage-storage-discharge curve. See Appendix B-2.



B-5: Crystal Lake Water Balance
Average Climatic Conditions
May 1, 2005 through Oct 1, 2006
Lake Level (feet MSL)
Precipitation (in)
936
935.5
935
934.5
934
933.5
933
932.5
932
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
5/1/2005
8/9/2005
11/17/2005
2/25/2006
6/5/2006
9/13/2006
Predicted Lake Level
Actual Lake Level
Precip (in)

B-6: St. Paul Campus Monthly Pan Evaporation Data

ST. PAUL CAMPUS CLIMATOLOGICAL OBSERVATORY 21-8450-6

Source http://climate.umn.edu/img/wxsta/pan-evaporation.htm

		MONTHLY PAN EVAPORATION, INCHES							
Year		APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	TOTAL
		21-30						1-10	
1972	*	1.86	6.08	8.03	6.76	5.62	4.08	0.92	33.35
1973		1.75	5.82	8.45	8.73	7.64	4.33	0.89	37.61
1974		2.03	5.54	7.46	9.46	6.49	4.62	1.29	36.89
1975		0.7	7.02	6.34	9.41	6.58	4.29	2.08	36.42
1976	*	1.86	8.4	11.08	10.96	10.54	6.62	1.61	51.07
1977		2.94	9.42	8.48	9.2	6.65	4.06	0.96	41.71
1978		1.61	8	7.21	6.87	8.3	6.02	1.21	39.22
1979		1.3	6.32	8.53	7.82	5.23	5.33	1.18	35.71
1980		2.88	7.62	7.75	8.83	6.55	4.51	1.47	39.61
1981		1.14	6.45	6.61	7.72	5.83	4.97	0.84	33.56
1982		2.77	6.29	7.49	8.52	7.81	4.21	0.85	37.94
1983	*	1.86	6.53	7.05	8.47	7.23	4.52	1.23	36.89
1984		2.37	7.13	6.88	8.88	7.26	5.24	1.03	38.79
1985		1.98	7.79	7.89	9.07	5.95	4.39	0.95	38.02
1986		1.65	7.21	8.34	7.97	6.71	3.88	1.2	36.96
1987		2.88	8.33	10.96	8.62	7.01	5.36	1.74	44.9
1988		1.77	10.38	11.83	11.73	8.96	5.2	1.54	51.41
1989		1.74	6.47	7.8	8.93	7.26	5.9	1.57	39.67
1990		1.96	6.27	7.24	7.65	6.63	5.45	1.71	36.91
1991		2.09	5.24	7.9	7.44	6.31	4.04	1.08	34.1
1992		1.32	8.83	6.89	5.8	6.69	4.8	1.3	35.63
1993		2.01	5.44	6.46	6.94	6.38	4.1	1.58	32.91
1994		1.32	8.67	7.36	7.02	6.58	3.94	1.18	36.07
1995		1.45	6.16	7.24	7.98	5.8	4.66	0.84	34.13
1996		1.75	5.95	6.53	7.53	7.71	4.6	1.47	35.54
1997		1.99	5.91	7.42	5.43	4.97	4.34	1.51	31.57
1998		2.22	7.5	5.57	7.32	5.79	5.13	0.72	34.25
1999		1.95	6.15	6.26	7.92	5.57	4.71	1.01	33.57
2000		2.2	5.81	6.15	6.89	6.17	4.84	1.38	33.44
2001		2.03	5.29	6.93	8.03	6.28	3.83	1.2	33.59
2002		1.11	6.25	7.25	6.69	6.09	4.47	0.71	32.57
2003		2.09	5.93	6.23	6.88	6.84	5.25	1.39	34.61
2004		1.91	5.41	6.3	6.63	5.14	4.91	1.27	31.57
2005		**1.2**	**4.35**	**6.96**	**8.82**	**6.49**	**4.81**	**1.2**	**33.83**
2006		**1.21**	**5.98**	**7.91**	**9.16**	**5.72**	**3.29**	**1.41**	**34.68**
2007		2.19	6.86	8.81	8.7	6.12	5.38	1.37	39.43
2008	*	1.86	6.83	6.42	8.71	7.83	4.57	1.26	37.48

Bold data indicates data used as part of the water balance modeling. Evaporation from November to March assumed to be negligible.

Pan Coefficient	**0.7**

B-7: Crystal Lake Average Climatic Conditions
Physical Parameter Summary
Calibration Conditions (2006 Watershed Conditions)

Period		A	B	C		D	E	F	G	H
		Atmos. Dep	Water Surface Elev	Depth to Thermocline		Elevation of Thermocline	Epilimnion Volume	Surface Area	Hypolimnion Volume	Hypolimnion Area
From	To	(lbs)	(ft MSL)	(m)	(ft)	(ft MSL)	(acft)	(acre)	(acft)	(ac)
5/1/05	4/30/06	68	933.9	9.0	29.5	904.3	2978	294	89	23
5/1/06	5/16/06	2.8	933.6	9.0	29.5	904.0	2889	293	86	22
5/17/06	5/31/06	2.6	933.2	3.0	9.8	923.4	1821	288	1065	106
6/1/06	6/15/06	2.5	932.8	4.0	13.1	919.7	2059	279	730	77
6/16/06	6/28/06	2.2	933.0	5.0	16.4	916.6	2316	285	528	61
6/29/06	7/5/06	1.1	932.8	5.0	16.4	916.4	2273	280	517	60
7/6/06	7/24/06	3.1	932.5	5.0	16.4	916.1	2209	272	501	59
7/25/06	8/10/06	3.0	933.4	5.0	16.4	917.0	2383	292	545	62
8/11/06	8/28/06	3.2	933.6	6.5	21.3	912.2	2662	293	316	46
8/29/06	9/7/06	1.7	933.5	6.5	21.3	912.2	2659	293	315	46
9/8/06	9/18/06	1.9	933.4	8.9	29.2	904.2	2847	293	88	22
9/19/06	9/23/06	0.7	933.5	8.9	29.2	904.3	2878	293	89	23

A - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) (Barr, 2005) over the surface area of the lake: A = F * (0.000639 lb/ac/d) * (# of Days)
B - Based on the daily water balance model. See Appendix B-4, Column L
C - Estimated based on the available temperature profile data. See Appendix B-1.
D - Elevation of the Thermocline: D = B - C
E - Estimated using the lake stage-storage-discharge curve. See Appendix B-2.
F - Estimated using the lake stage-storage-discharge curve. See Appendix B-2.
G - Estimated using the lake stage-storage-discharge curve. See Appendix B-2.
H - Estimated using the lake stage-storage-discharge curve. See Appendix B-2.

B-8: Crystal Lake Average Climatic Conditions

P8 Particle Class Settling - Estimated Number of Days to Settle Out of Epilimnion & Watershed TP Loads

Calibration Conditions (2006 Watershed Conditions)

			Number of Days to Settle P8 Particle Class[1,2,3]					
P8 Particle Class			P10	P30	P50	P80		
P8 Settling Velocity			vs = 0.03 ft/hr	vs = 0.3 ft/hr	vs = 1.5 ft/hr	vs = 15 ft/hr		
Sample Period		Epilimnion Depth (De)[4] (ft)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Total Watershed TP Load before Particle Settling (lbs)	Watershed TP Load after Particle Settling[2,3] (lbs)
5/1/2006	5/16/2006	29.5	41	4	1	0	11.4	11.0
5/17/2006	5/31/2006	29.5	41	4	1	0	1.5	1.1
6/1/2006	6/15/2006	9.8	14	1	0	0	4.1	3.0
6/16/2006	6/28/2006	13.1	18	2	0	0	24.2	20.1
6/29/2006	7/5/2006	16.4	23	2	0	0	0.0	0.0
7/6/2006	7/24/2006	16.4	23	2	0	0	12.9	10.5
7/25/2006	8/10/2006	16.4	23	2	0	0	43.0	39.7
8/11/2006	8/28/2006	16.4	23	2	0	0	26.5	22.6
8/29/2006	9/7/2006	21.3	30	3	1	0	10.9	9.1
9/8/2006	9/18/2006	21.3	30	3	1	0	3.2	3.0
9/19/2006	9/23/2006	29.2	41	4	1	0	8.2	7.9

1 - Number of Days to Settle Particles = De/vs/24

2 - The P0 particle class in P8 reflects the non-settleable (or dissolved) fraction of the particles. See additional details in Appendix A-3.

3 - The pollutant loading in P8 is based on the build-up and wash-off of particles. There are 5 particle size classes, each with a mass of pollutant associated with it (e.g. phosphorus) as well as a settling velocity. The majority of the phosphorus is associated with the P0 (or non-settleable fraction). The in-lake mass balance model tracks the mass of each particle size class (from the P8 model) and determines how long the particles will remain in the epilimnion (thus impacting observed water quality). The model considers the number of days between the water quality sampling dates and the prior storm events, and only includes the phosphorus load from those particles that would remain in the epilimnion during that period. See Appendix B-3 for a table summarizing the P8 event TP loads.

4 - Epiliminion Depth from Appendix B-7 Column C

B-9: In-Lake Steady State Summary
Crystal Lake - 2006 Calibration Conditions

Parameter	Value[1]	Comments
L=Areal Load (mg/m²/yr) From May to May	216.7	(Watershed Load + Atmospheric Load) / Surface Area
Point Source Loading (mg/yr)	0.0	
Watershed Load (mg/yr)	225535112.0	P8 Watershed Load[2] + Upstream Source Loads[3]
Atmospheric Load (mg/yr)	30958172.0	Atmospheric Deposition Rate * Surface Area = 0.2915 kg/ha/yr * Surface Area
qs =Overflow Rate (m/yr)	2.1	Outflow / Surface Area
V=Volume (m³)	3615056.5	Lake Volume[4]
A=Surface Area (m²)	1183868.9	Surface Area[4]
td= Residence Time (yr)	1.5	Volume / Outflow
z= mean Depth (m)	3.1	Volume / Surface Area
Q=Outflow (m³/yr)	2459778.2	Inflow = Watershed Runoff + Upstream Inflows + Direct Precip = Outflow
r =Flushing Rate (yr-1)	0.7	1 / Residence Time
Dillon and Rigler P=L(1-Rp)/(z*r) With Rp as follows:	**Predicted TP Conc (ug/L)**	
Nurnberg (1984) Rp=15/(18+qs)	26	**See Table 4-2 in the TMDL Report**

1 - Based on May 1, 2005 through April 30, 2006
2 - See Appendix B-14 Column A
3 - See Appendix B-14 Columns C & D
4 - At Normal Water Level; See Appendix B-2

$$P = \frac{L(1-R)}{z\rho}$$

where:

P = total phosphorus concentration at the beginning of the open water season (µg/L)
L = areal total phosphorus loading rate (mg/m²/yr)
R = retention coefficient = $\frac{15}{(18+q_s)}$, Nurnberg (1984)
q_s = annual areal water outflow load (m/yr)
= Q/A
z = lake mean depth (m)
t_d = hydraulic residence time = (V/Q)
ρ = hydraulic flushing rate (1/yr)
= $1/(t_d)$
Q = annual outflow (m³/yr)
V = lake volume (m³)
A = lake surface area (m²)

"internal loading from other sources" in Appendix B-14 as that table only summarizes the (positive) loads to the lake.

7 - For Total Loads, total rounded to the nearest pound for reporting purposes.

B-10: Crystal Lake - Average Climatic Condition (2006) Calibration - In-Lake Growing Season Mass Balance Model Summary[1]

A - See Appendix B-7, Column E. The epilimnion volume represents the predicted epilimnion volume at the end of the time period.
B - Amount of phosphorus present in lake at the beginning of the timestep (based on spring steady state or observed TP concentration and epilimnetic volume from the previous timestep).
C - Based on the Watershed TP Load after Particle Settling. See Appendix B-8.
D - Discharges from Keller and Lee Lakes computed as modeled discharge volume between the dates multiplied by the observed in-lake total phosphorus concentration during that period. See Appendix B-11.
E - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake.
F - Based on a phosphorus release rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Appendix B-12.
G - Based on average daily uptake rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Appendix B-13.
H - Discharge from the lake includes surface discharge, losses to groundwater, and pumping to Keller Lake (via ferric chloride system) multiplied by the total phosphorus concentration from the previous time period. See Appendix B-11.
I - P Remaining in Lake = B + C + D + E + F - G - H
J - In-Lake P before Adj = I / A / 0.00272
K - Water quality monitoring data. See Appendix B-1.
L - Residual Adjustment = K - J. The Residual Adjustment is the calibration parameter used to describe the internal phosphorus loads to the lake not explicitly estimated (e.g. release from bottom sediments, resuspension due to fish activity or wind, etc.), to estimate the uptake of phosphorus from the water column by algae growth, to estimate sedimentation of phosphorus from the water column, as well as to factor in possible error in the monitoring data.
M - Residual Adj Load = L * A * 0.00272. Positive values are treated as a phosphorus source to the lakes such as sediment release while negative values are handled as a sink, such as sedimentation.
N - P In-Lake at End of Period = I + M
O - Predicted In-Lake P is a check against the Observed In-Lake P.

Period Start		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
		Epilimnion Volume	P In-Lake @ Start of Period	P Surface Runoff (after Particulate Settling)[5]	P From Upstream Sources	P Atmospheric	P Release from Curlyleaf Pondweed	P Uptake by Coontail	P Loss due to Discharge	P Remaining in lake	In-Lake P before Adjustment	Observation In-Lake P	Residual Adjustment (Internal Loading / Losses)	Residual Adjustment (Internal Loading / Losses)[6]	P In-Lake @ End of Period	Predicted In-Lake P[2]
		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/l	ug/L	ug/l	lbs	lbs	ug/L
Steady State Total (May 1, 2005 - April 30, 2006)[3,7]		N/A	N/A	391	106	68	N/A[4]	N/A[4]	134	N/A	N/A	N/A	N/A	N/A	N/A	26
(Oct 1, 2005 - April 30, 2006)[3,7]		2978	N/A	189	47	44	0[4]	0[4]	73	N/A	N/A	N/A	N/A	N/A	N/A	26
5/1/06	5/16/06	2889	214	11.0	2.8	2.8	0.0	7.2	9.7	213.4	27.2	24	-3.2	-24.8	188.6	24
5/17/06	5/31/06	1821	189	1.1	1.4	2.6	0.0	6.8	3.9	183.0	36.9	20	-16.9	-83.9	99.1	20
6/1/06	6/15/06	2059	99	3.0	1.4	2.5	36.9	10.2	3.1	129.5	23.1	31	7.9	44.1	173.6	31
6/16/06	6/28/06	2316	174	20.1	8.4	2.2	108.5	12.7	4.4	295.8	46.9	48	1.1	6.7	302.4	48
6/29/06	7/5/06	2273	302	0.0	3.0	1.1	31.4	7.1	4.2	326.5	52.8	50	-2.8	-17.4	309.2	50
7/6/06	7/24/06	2209	309	10.5	8.9	3.1	29.4	19.6	8.5	333.0	55.4	40	-15.4	-92.7	240.3	40
7/25/06	8/10/06	2383	240	39.7	26.8	3.0	4.2	18.1	4.0	291.8	45.0	55	10.0	64.8	356.5	55
8/11/06	8/28/06	2662	357	22.6	15.8	3.2	0.7	19.8	11.5	367.5	50.8	44	-6.8	-48.9	318.6	44
8/29/06	9/7/06	2659	319	9.1	5.4	1.7	0.1	11.3	8.0	315.7	43.7	88	44.3	320.7	636.4	88
9/8/06	9/18/06	2847	636	3.0	7.4	1.9	0.0	12.6	12.6	623.5	80.5	52	-28.5	-220.9	402.6	52
9/19/06	9/23/06	2878	403	7.9	3.5	0.7	0.0	5.8	3.6	405.4	51.8	70	18.2	142.5	547.9	70
Growing Season Total (June 1, 2006 - Sept 30, 2006)[7]		N/A	N/A	116	80	19	211	117	60	N/A	N/A	N/A	N/A	199	N/A	N/A
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[3,7]		N/A	N/A	317	131	68	211	131	146	N/A	N/A	N/A	N/A	90	N/A	N/A
															Growing Season Average[2]	**50**

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General Mass Balance Differencing Equation: Padj = Pobs - Pinitial - Psurf - Pus - Patm - Pclpw + Pcoon + Pdis

1 - Reflective of in-lake water quality model calibration conditions (2006 watershed conditions, ferric chloride system operating)
2 - Growing Season Average includes monitoring data from 5/31/2006; See observed, calibrated, and predicted in-lake TP concentrations in Table 4-2 in the TMDL Report.
3 - An empirical model (Dillon and Rigler (1974) with Nurnberg (1984) retention coefficient) was used to predict the steady state phosphorus concentration at the beginning of the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006.
4 - Phosphorus release from Curlyleaf pondweed and uptake by coontail was not estimated for the Steady State year because phosphorus mass balance modeling was not performed for the period from May 1, 2005 - April 30, 2006. Also, it was assumed that during the period from October 1 - April 30 the phosphorus loading due to Curlyleaf pondweed and uptake by coontail would be negligible due to the growth/die back cycles of these macrophytes during this season.
5 - The reported phosphorus load associated with surface runoff during the Steady State period, as well as the period from October 1, 2005 - April 30, 2006 reflects the total watershed runoff load, not the phosphorus load after particulate settling. Therefore the total water year load in this table is not reflective of the Total Phosphorus Load from watershed runoff as reported in Appendix B-14.
6 - The growing season and water year total phosphorus adjustment values represents the net phosphorus adjustment (including both phosphorus loads to the lake as well as losses such as sedimentation). The total phosphorus adjustment will not match the total

B-11: Crystal Lake Summary of Upstream Loads and Discharges - Average Climatic Conditions
Crystal Lake - 2006 Calibration Conditions

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
		Upstream Inflows						Discharges									
Period		Keller Lake Inflow	Keller Lake [TP]	Keller Load	Lee Lake Inflow	Lee Lake [TP]	Lee Load	Surface Discharge	Discharge [TP]	Surface Discharge	Groundwater Discharge	Discharge [TP]	Groundwater Discharge	Pumping to Keller Lake	Discharge [TP]	Pumping to Keller Lake	Total Discharge
From	To	(acft)	(μg/L)	(lbs)	(acft)	(μg/L)	(lbs)	(acre-ft)	(μg/L)	(lbs)	(acre-ft)	(μg/L)	(lbs)	(acre-ft)	(μg/L)	(lbs)	(lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[1,2]		707	55	106	7	42	1	1088	26	78	320	26	23	454	26	33	134
(Oct 1, 2005 - April 30, 2006)[1,2]		311	55	46	7	42	1	715	26	51	186	26	13	114	26	8	73
5/1/2006	5/16/2006	36	29	2.8	0	49	0.0	71	26	5.1	14	26	1.0	51	26	3.6	9.7
5/17/2006	5/31/2006	14	38	1.4	0	38	0.0	6	24	0.4	13	24	0.9	41	24	2.7	3.9
6/1/2006	6/15/2006	7	68	1.4	0	123	0.0	0	20	0.0	13	20	0.7	44	20	2.4	3.1
6/16/2006	6/28/2006	52	60	8.4	0	95	0.0	0	31	0.0	11	31	0.9	41	31	3.5	4.4
6/29/2006	7/5/2006	8	142	3.0	0	129	0.0	0	48	0.0	7	48	0.9	25	48	3.3	4.2
7/6/2006	7/24/2006	21	158	8.9	0	88	0.0	0	50	0.0	15	50	2.0	48	50	6.5	8.5
7/25/2006	8/10/2006	96	103	26.8	0	51	0.0	0	40	0.0	14	40	1.6	22	40	2.4	4.0
8/11/2006	8/28/2006	52	111	15.8	0	81	0.0	17	55	2.5	16	55	2.4	44	55	6.6	11.5
8/29/2006	9/7/2006	33	60	5.4	0	62	0.0	26	44	3.1	9	44	1.1	32	44	3.8	8.0
9/8/2006	9/18/2006	16	166	7.4	0	106	0.0	8	88	1.9	10	88	2.3	35	88	8.4	12.6
9/19/2006	9/23/2006	21	61	3.5	0	106	0.0	5	52	0.7	4	52	0.6	16	52	2.2	3.6
Growing Season Total (May 1, 2006 - Sept 30, 2006)[2]				**80**			**0**			**8**			**12**			**39**	**60**
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[2]				**131**			**1**			**65**			**28**			**54**	**146**

1 - A phosphorus mass balance was not performed specifically for the Steady State period (May 1, 2005 - April 30, 2006). An empirical model (Dillon and Rigler (1974) with Nurnberg (1984) retention coefficient) was used to predict the steady state phosphorus concentration used as the starting concentration for the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006. See Appendix B-9.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.
A - Based on daily water balance model. See Appendix B-4, Column F
B - Based on in-lake water quality mass balance model for Keller Lake. See Appendix C.
C - Keller Load = A * B * 0.00272
D - Based on daily water balance model. See Appendix B-4, Column G
E - Based on in-lake water quality mass balance model for Lee Lake. See Appendix D.
F - Lee Load = D * E * 0.00272
G - Based on daily water balance model. See Appendix B-4, Column I
H - In-lake TP Concentration from the previous time step
I - Surface Discharge = G * H * 0.00272
J - Based on daily water balance model. See Appendix B-4, Column H
K - In-lake TP Concentration from the previous time step
L - Groundwater Discharge = G * H * 0.00272
M - Based on daily water balance model. See Appendix B-4, Column E
N - In-lake TP Concentration from the previous time step
O - Pumping to Keller = G * H * 0.00272
P - Total Discharge = I + L + O

B-12: Crystal Lake Average Climatic Conditions

Curlyleaf Pondweed Phosphorus Release (Calibration)

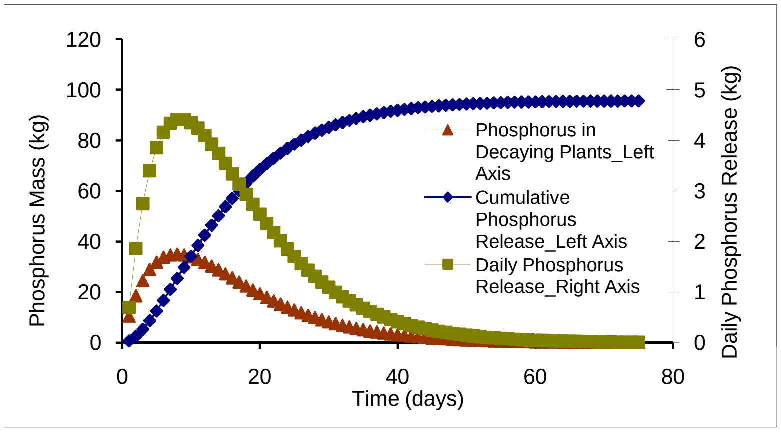
Macrophyte Area = 292.5 acres

% Covered w/Curlyleaf[1] 66% ==> Curlyleaf Area = 193.1

1 - Based on 2006 Macrophyte Survey

Curlyleaf load based on estimated density & coverage

Stem Density	175	stem/m²	(McComas; Barr, 2001)
Mat/stem	0.35	g/stem	(Barr, 2001)
P Content	2000	mg P/kg	(Barr, 2001)
Areal P load	122.5	mg/m²	
P Load	211.0	lbs	
In-lake P conc	42.6	µg/L	

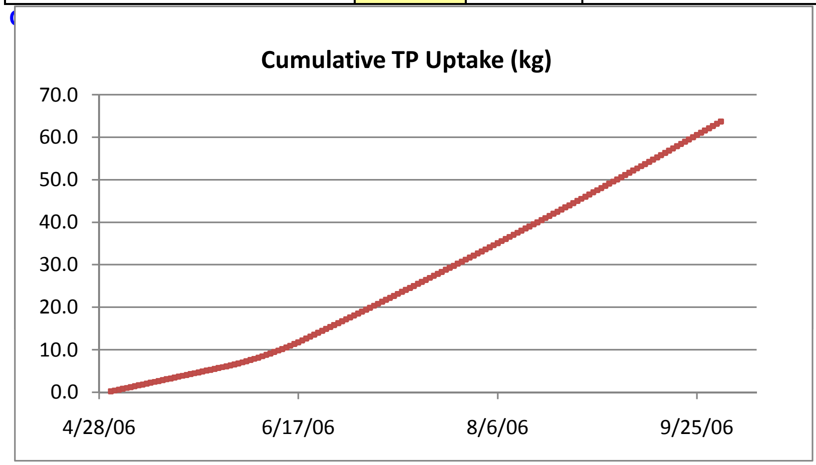


Internal Loading from Curlyleaf Pondweed

Date	Cumulative Load (kg)	Cumulative Load (lbs)	Incremental Load (lbs)
4/30/06	#N/A	0	0.0
5/16/06	#N/A	0	0.0
5/31/06	#N/A	0	0.0
6/15/06	16.7	37	36.8
6/28/06	65.9	145	108.2
7/5/06	80.1	176	31.3
7/24/06	93.5	206	29.4
8/10/06	95.4	210	4.1
8/28/06	95.7	210	0.7
9/7/06	95.7	211	0.1
9/18/06	95.7	211	0.0
9/23/06	95.7	211	0.0

B-13: Crystal Lake Average Climatic Conditions
Coontail Phosphorus Uptake (Calibration)

Date Coontail Uptake Begins	5/1/2006			Date of Aq Plant Survey #1	5/30/2006	Based on 2006 Macrophyte Survey
Maximum Coontail Plant Density	1324	g (wet weight)/m²	(LCMR, 2001; Newman, 2004)	% Covered w/ Coontail	24.2	Based on 2006 Macrophyte Survey
Macrophyte Area =	292	Ac		Coontail Density (0-5)	1.6	Based on 2006 Macrophyte Survey
% Covered w/Coontail at Date Coontail Uptake Begins	24.2		Based on 2006 Macrophyte Survey	Date of Aq Plant Survey #2	9/1/2006	Based on 2006 Macrophyte Survey
Coontail Density at Date Coontail Uptake Begins (0-5)	1.6		Based on 2006 Macrophyte Survey	% Covered w/ Coontail	60.5	Based on 2006 Macrophyte Survey
				Coontail Density (0-5)	1.6	Based on 2006 Macrophyte Survey
				Coontail Uptake Rate (ug/g(ww)/d)	1.68	(Lombardo & Cooke, 2003)



Internal Uptake from Coontail

Date	Cumulative Uptake (kg)	Cumulative Uptake (lbs)	Incremental Uptake (lbs)
4/30/06	#N/A	0	0.0
5/16/06	3.26	7	7.2
5/31/06	6.32	14	6.7
6/15/06	10.95	24	10.2
6/28/06	16.69	37	12.6
7/5/06	19.90	44	7.1
7/24/06	28.81	63	19.6
8/10/06	37.03	81	18.1
8/28/06	46.01	101	19.7
9/7/06	51.11	112	11.2
9/18/06	56.82	125	12.6
9/23/06	59.45	131	5.8

B-14: Crystal Lake Average Climatic Conditions
Phosphorus Load Summary
Calibration Conditions (2006 Watershed Conditions)

	Sample Period		A	B	C	D	E	F	G	H	I
			External TP Load					Internal TP Load			
			Watershed TP Load (lbs)	Atmospheric Deposition (lbs)	Keller Lake (lbs)	Lee Lake (lbs)	Total External TP Load (lbs)	Curlyleaf Pondweed (lbs)	Other Internal Sources (lbs)	Total Internal TP Load (lbs)	Total TP Load (lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[2]	5/1/2005	4/30/2006	390	68	105	1	564	N/A[1]	N/A[1]	N/A[1]	***564***
(Oct 1, 2005 - April 30, 2006)[2]	10/1/2005	4/30/2006	189	44	46	1	279	0	0	0	***279***
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/16/2006	11.4	2.8	2.8	0.0	17.0	0.0	0.0	0.0	***17.0***
	5/17/2006	5/31/2006	1.5	2.6	1.4	0.0	5.5	0.0	0.0	0.0	***5.5***
	6/1/2006	6/15/2006	4.1	2.5	1.4	0.0	8.0	0.0	44.1	44.1	***52.1***
	6/16/2006	6/28/2006	24.2	2.2	8.4	0.0	34.8	36.8	6.7	43.4	***78.2***
	6/29/2006	7/5/2006	0.0	1.1	2.9	0.0	4.0	108.2	0.0	108.2	***112.2***
	7/6/2006	7/24/2006	12.9	3.1	8.9	0.0	24.9	31.3	0.0	31.3	***56.1***
	7/25/2006	8/10/2006	43.0	3.0	26.7	0.0	72.7	29.4	64.8	94.1	***166.8***
	8/11/2006	8/28/2006	26.5	3.2	15.7	0.0	45.5	4.1	0.0	4.1	***49.6***
	8/29/2006	9/7/2006	10.9	1.7	5.4	0.0	18.0	0.7	320.7	321.4	***339.4***
	9/8/2006	9/18/2006	3.2	1.9	7.4	0.0	12.4	0.1	0.0	0.1	***12.5***
	9/19/2006	9/23/2006	8.2	0.7	3.5	0.0	12.5	0.0	142.5	142.5	***155.0***
	9/24/2006	9/30/2006	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	***0.4***
Growing Season Total (June 1, 2006 - Sept 30, 2006)[2]	**6/1/2006**	**9/30/2006**	**133**	**19**	**80**	**0**	**233**	**211**	**578**	**789**	***1022***
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[2]	**10/1/2005**	**9/30/2006**	**335**	**68**	**131**	**1**	**535**	**211**	**578**	**789**	***1323***

1 - The empirical steady-state equations used to estimate the phosphorus concentration in the lake at the beginning of the mass balance calibration period were originally developed based on external phosphorus loadings only; therefore, internal loading for this period was not estimated. See Appendix B-9.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.

A - Based on P8 TP Load. See Appendix B-3.

B - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake. See Appendices B-7 and B-10.

C - Load from Upstream Lake = Water Load * [TP]. See Appendix B-11.

D - Load from Upstream Lake = Water Load * [TP]. See Appendix B-11.
E - External Load = A + B + C + D
F - See Appendix B-12.

G - Load back-calculated as part of the mass balance model calibration. Assumes that internal loading happens only during the calibration period (May 1 - Sept 30) to reflect the available monitoring data. This summary table includes only the estimated phosphorus loads to the lake (estimated losses assumed to be zero). See Appendix B-10 Column M.
H - Internal Load = F + G
I - Total TP Load = E + H

B-15: Crystal Lake Average Climatic Conditions
P8 Loading Summary - Existing Conditions (2008 Watershed Conditions)

	Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc (ug/L)
Steady State Year (May 1, 2005 - April 30, 2006)		37.0	1046	391	138
(Oct 1, 2005 - April 30, 2006)		17.3	534	188.6	130
5/1/2006	**5/16/2006**	1.0	35	11.4	121
5/17/2006	**5/31/2006**	0.2	3	1.5	158
6/1/2006	**6/15/2006**	0.4	8	4.1	182
6/16/2006	**6/28/2006**	2.3	59	24.2	152
6/29/2006	**7/5/2006**	0.0	0	0.0	0
7/6/2006	**7/24/2006**	1.2	27	12.9	174
7/25/2006	**8/10/2006**	4.4	125	43.0	127
8/11/2006	**8/28/2006**	2.6	67	26.5	145
8/29/2006	**9/7/2006**	1.0	27	10.9	151
9/8/2006	**9/18/2006**	0.4	8	3.2	141
9/19/2006	**9/23/2006**	0.9	23	8.2	130
9/24/2006	**9/30/2006**	0.1	1	0.4	107
Growing Season Load (June 1, 2006 - Sept 30, 2006)		13.3	346	133	142
Total Load (2006 Water Year - Oct 1, 2005 - Sept 30, 2006)		31.8	919	335	134

B-16: Crystal Lake Average Climatic Conditions
Water Balance Summary
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

	Sample Period		A	B	C	D	E	F	G	H	I	J	K	L
			Total Lake Volume at the Start of the Period (acre-ft)	**Direct Precipitation (acre-ft)**	**Evaporation (acre-ft)**	**Watershed Runoff (acre-ft)**	**Pumping to Keller Lake (acre-ft)**	**Discharge from Keller Lake (acre-ft)**	**Discharge from Lee Lake (acre-ft)**	**Groundwater Exchange (acre-ft)**	**Discharge from Crystal Lake (acre-ft)**	**Change in Lake Volume (acre-ft)**	**Total Lake Volume at the End of the Period (acre-ft)**	**Lake Level at End of Period (ft MSL)**
				+	-	+	-	+	+	-	-			
Steady State Year (May 1, 2005 - April 30, 2006)	5/1/2005	4/30/2006	2930	902	662	1046	0	315	15	321	1155	141	3071	933.9
(Oct 1, 2005 - April 30, 2006)	10/1/2005	4/30/2006	2953	421	126	534	0	219	15	186	760	118	3071	933.9
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/16/2006	3071	25	53	35	0	2	0	14	83	-88	2983	933.6
	5/17/2006	5/31/2006	2983	4	49	3	0	0	0	13	12	-67	2916	933.3
	6/1/2006	6/15/2006	2916	9	67	8	0	0	0	13	0	-62	2854	933.1
	6/16/2006	6/28/2006	2854	54	57	59	0	0	0	11	0	44	2898	933.3
	6/29/2006	7/5/2006	2898	0	39	0	0	0	0	7	0	-46	2853	933.1
	7/6/2006	7/24/2006	2853	28	88	27	0	0	0	16	0	-49	2804	932.9
	7/25/2006	8/10/2006	2804	103	65	125	0	10	0	15	12	145	2949	933.5
	8/11/2006	8/28/2006	2949	64	57	67	0	11	0	16	29	40	2989	933.6
	8/29/2006	9/7/2006	2989	25	23	27	0	4	0	9	32	-8	2981	933.6
	9/8/2006	9/18/2006	2981	10	21	8	0	0	0	10	16	-29	2952	933.5
	9/19/2006	9/23/2006	2952	22	9	23	0	0	0	4	9	23	2976	933.6
	9/24/2006	9/30/2006	2976	2	13	1	0	0	0	6	11	-26	2949	933.5
Total for Growing Season (June 1, 2006 - Sept 30, 2006)	6/1/2006	9/30/2006	2916	317	438	346	0	25	0	107	110	33	2949	933.5
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)	10/1/2005	9/30/2006	2953	767	666	919	0	245	15	319	964	-3	2950	933.5

Annual (2006 Water Year) Water Load to Crystal Lake (acre-ft)	10/1/2005	9/30/2006	1946	Water Load = B + D + F + G (See **Table 4-3** in the TMDL Report)

A - Based on the daily water balance model (calibrated to lake level data and using the lake stage-storage-discharge curve). See Appendix B-2.
B - Based on precipitation data used for the P8 modeling and the daily water balance model (Direct Precip Volume = Depth of Precip * Lake Surface Area) See Appendix B-15.
C - Based on adjusted pan evaporation data from the University of Minnesota St. Paul Campus Climatological Observatory and the daily water balance model (Evap Volume = 0.7 * Depth of Evap * Lake Surface Area). See Appendix B-6.
D - Based on the water loads from the P8 model. See Appendix B-15.
E - Existing Conditions assumes the ferric chloride system is no longer operating.
F - Based on the estimated discharge from the Keller Lake daily water balance model. See Appendix C-4.
G - Based on the estimated discharge from the Lee Lake daily water balance model. See Appendix D-4.
H - Groundwater exchange fit to 2008 lake levels and watershed conditions. The estimated groundwater exchange was applied to all climatic conditions.
I - Based on the estimated discharge from the Crystal Lake daily water balance model
J - Change in Lake Volume = B - C + D - E + F + G - H - I
K- Total Lake Volume @ End of Period = A + J
L - Estimated lake level based on the total lake volume and the stage-storage-discharge curve. See Appendix B-2.

B-17: Crystal Lake Average Climatic Conditions
Physical Parameter Summary
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

		A	B	C		D	E	F	G	H
Period		Atmos. Dep	Water Surface Elev	Depth to Thermocline		Elevation of Thermocline	Epilimnion Volume	Surface Area	Hypolimnion Volume	Hypolimnion Area
From	To	(lbs)	(ft MSL)	(m)	(ft)	(ft MSL)	(acft)	(acre)	(acft)	(ac)
5/1/05	4/30/06	68	933.9	9.0	29.5	904.4	2981	294	90	23
5/1/06	5/16/06	2.8	933.6	9.0	29.5	904.1	2896	293	87	22
5/17/06	5/31/06	2.6	933.3	3.0	9.8	923.5	1839	291	1076	107
6/1/06	6/15/06	2.6	933.1	4.0	13.1	920.0	2099	285	755	79
6/16/06	6/28/06	2.2	933.3	5.0	16.4	916.9	2359	290	539	62
6/29/06	7/5/06	1.1	933.1	5.0	16.4	916.7	2328	286	531	61
7/6/06	7/24/06	3.2	932.9	5.0	16.4	916.5	2285	281	520	61
7/25/06	8/10/06	3.0	933.5	5.0	16.4	917.1	2401	293	549	63
8/11/06	8/28/06	3.2	933.6	6.5	21.3	912.3	2672	293	318	46
8/29/06	9/7/06	1.7	933.6	6.5	21.3	912.3	2666	293	316	46
9/8/06	9/18/06	1.9	933.5	8.9	29.2	904.3	2864	293	89	22
9/19/06	9/23/06	0.7	933.6	8.9	29.2	904.4	2887	293	90	23

A - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) (Barr, 2005) over the surface area of the lake: A = F * (0.000639 lb/ac/d) * (# of Days)
B - Based on the daily water balance model. See Appendix B-16 Column L
C - Estimated based on the available temperature profile data. See Appendix B-1.
D - Elevation of the Thermocline: D = B - C
E - Estimated using the lake stage-storage-discharge curve. See Appendix B-2.
F - Estimated using the lake stage-storage-discharge curve. See Appendix B-2.
G - Estimated using the lake stage-storage-discharge curve. See Appendix B-2.
H - Estimated using the lake stage-storage-discharge curve. See Appendix B-2.

B-18: Crystal Lake Average Climatic Conditions
P8 Particle Class Settling - Estimated Number of Days to Settle Out of Epilimnion & Watershed TP Loads
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

			Number of Days to Settle P8 Particle Class[1,2,3]					
P8 Particle Class			P10	P30	P50	P80		
P8 Settling Velocity			vs = 0.03 ft/hr	vs = 0.3 ft/hr	vs = 1.5 ft/hr	vs = 15 ft/hr		
Sample Period		Epilimnion Depth (De)[4] (ft)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Total Watershed TP Load before Particle Settling[5] (lbs)	Watershed TP Load after Particle Settling[2,3,5] (lbs)
5/1/2006	5/16/2006	29.5	41	4	1	0	11.4	11.0
5/17/2006	5/31/2006	29.5	41	4	1	0	1.5	1.1
6/1/2006	6/15/2006	9.8	14	1	0	0	4.1	3.0
6/16/2006	6/28/2006	13.1	18	2	0	0	24.2	20.1
6/29/2006	7/5/2006	16.4	23	2	0	0	0.0	0.0
7/6/2006	7/24/2006	16.4	23	2	0	0	12.9	10.5
7/25/2006	8/10/2006	16.4	23	2	0	0	43.0	39.7
8/11/2006	8/28/2006	16.4	23	2	0	0	26.5	22.6
8/29/2006	9/7/2006	21.3	30	3	1	0	10.9	9.1
9/8/2006	9/18/2006	21.3	30	3	1	0	3.2	3.0
9/19/2006	9/23/2006	29.2	41	4	1	0	8.2	7.9

1 - Number of Days to Settle Particles = De/vs/24

2 - The P0 particle class in P8 reflects the non-settleable (or dissolved) fraction of the particles. See additional details in Appendix A-3.

3 - The pollutant loading in P8 is based on the build-up and wash-off of particles. There are 5 particle size classes, each with a mass of pollutant associated with it (e.g. phosphorus) as well as a settling velocity. The majority of the phosphorus is associated with the P0 (or non-settleable fraction). The in-lake mass balance model tracks the mass of each particle size class (from the P8 model) and determines how long the particles will remain in the epilimnion (thus impacting observed water quality). The model considers the number of days between the water quality sampling dates and the prior storm events, and only includes the phosphorus load from those particles that would remain in the epilimnion during that period. See Appendix B-15 for a table summarizing the P8 event TP loads.

4 - Epiliminion Depth from Appendix B-17 Column C

5 - The watershed phosphorus loading values to Crystal Lake for existing conditions (2008 watershed conditions) are the same as for the calibration conditions (2006 watershed conditions) because of minimal changes in the land use within the watershed between these two periods.

B-19: In-Lake Steady State Summary

Crystal Lake - Existing Conditions (2006 climatic conditions, 2008 watershed conditions, ferric chloride not operating)

Parameter	Value[1]	Comments
L=Areal Load (mg/m²/yr) From May to May	196.4	(Watershed Load + Atmospheric Load) / Surface Area
Point Source Loading (mg/yr)	0.0	
Watershed Load (mg/yr)	201576000.4	P8 Watershed Load[2] + Upstream Source Loads[3]
Atmospheric Load (mg/yr)	30958172.0	Atmospheric Deposition Rate * Surface Area = 0.2915 kg/ha/yr * Surface Area
qs =Overflow Rate (m/yr)	1.7	Outflow / Surface Area
V=Volume (m³)	3615056.5	Lake Volume[4]
A=Surface Area (m²)	1183868.9	Surface Area[4]
td= Residence Time (yr)	1.8	Volume / Outflow
z= mean Depth (m)	3.1	Volume / Surface Area
Q=Outflow (m³/yr)	1975988.4	Inflow = Watershed Runoff + Upstream Inflows + Direct Precip = Outflow
r =Flushing Rate (yr-1)	0.5	1 / Residence Time
Dillon and Rigler P=L(1-Rp)/(z*r) With Rp as follows:	**Predicted TP Conc (ug/L)**	
Nurnberg (1984) Rp=15/(18+qs)	28	**See Table 4-2 in the TMDL Report**

1 - Based on May 1, 2005 through April 30, 2006

2 - See Appendix B-22 Column A

3 - See Appendix B-22 Columns C & D

4 - At Normal Water Level; See Appendix B-2

$$P = \frac{L(1-R)}{z\rho}$$

where:

P = total phosphorus concentration at the beginning of the open water season (µg/L)

L = areal total phosphorus loading rate (mg/m²/yr)

R = retention coefficient = $\frac{15}{(18+q_s)}$, Nurnberg (1984)

q_s = annual areal water outflow load (m/yr)

= Q/A

z = lake mean depth (m)

t_d = hydraulic residence time = (V/Q)

ρ = hydraulic flushing rate (1/yr)

= 1/(t_d)

Q = annual outflow (m³/yr)

V = lake volume (m³)

A = lake surface area (m²)

phosphorus adjustment will not match the total "internal loading from other sources" in Appendix B-22 as that table only summarizes the (positive) loads to the lake.

7 - For Total Loads, total rounded to the nearest pound for reporting purposes.

A - See Appendix B-17, Column E. The epilimnion volume represents the predicted epilimnion volume at the end of the time period.

B - Amount of phosphorus present in lake at the beginning of the timestep (based on spring steady state or observed TP concentration and epilimnetic volume from the previous timestep).

C - Based on the Watershed TP Load after Particle Settling. See Appendix B-18.

D - Discharges from Keller and Lee Lakes computed as modeled discharge volume between the dates multiplied by the predicted in-lake total phosphorus concentration during that period (from Keller and Lee in-lake water quality models). See Appendix B-21.

E - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake

F - Based on a phosphorus release rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Appendix B-12.

G - Based on the calibrated water quality model residual adjustment (P loads). The residual adjustment is the calibration parameter used to describe the internal phosphorus loads to the lake not explicitly estimated (e.g. release from bottom sediments, resuspension due to fish activity or wind, etc.), to estimate the uptake of phosphorus from the water column by algae growth, to estimate sedimentation of phosphorus from the water column, as well as to factor in possible error in the monitoring data.

H - Based on average daily uptake rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Appendix B-13.

I - Discharge from the lake includes surface discharge and losses to groundwater, multiplied by the total phosphorus concentration from the previous time period. See Appendices B-21.

J - P in the lake at the end of the period = B + C + D + E + F + G - H - I

K - Predicted In-Lake P = K * A * 0.00272

B-20: Crystal Lake - Average Climatic Condition Existing Conditions - In-Lake Growing Season Mass Balance Model Summary[1]

Period Start		A	B	C	D	E	F	G	H	I	J	K
		Epilimnion Volume	P In-Lake @ Start of Period	P Surface Runoff (after Particulate Settling)[5]	P From Upstream Sources	P Atmospheric	P Release from Curlyleaf Pondweed	P Adjustment Load[6]	P Uptake by Coontail	P Loss due to Discharge	P In-Lake @ End of Period	Predicted In-Lake P[2]
		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/L
Steady State Total (May 1, 2005 - April 30, 2006)[3,7]		N/A	N/A	391	55	68	N/A[4]	N/A	N/A[4]	112	N/A	28
(Oct 1, 2005 - April 30, 2006)[3,7]		2981	N/A	189	39	43	0[4]	N/A	0[4]	72	N/A	28
5/1/06	5/16/06	2896	227	11.0	0.2	2.8	0.0	-24.8	7.2	7.3	201.2	26
5/17/06	5/31/06	1839	201	1.1	0.0	2.6	0.0	-83.9	6.8	1.7	112.5	22
6/1/06	6/15/06	2099	113	3.0	0.0	2.6	36.9	44.1	10.2	0.8	188.0	33
6/16/06	6/28/06	2359	188	20.1	0.0	2.2	108.5	6.7	12.7	1.0	311.9	49
6/29/06	7/5/06	2328	312	0.0	0.0	1.1	31.4	-17.4	7.1	0.9	318.9	50
7/6/06	7/24/06	2285	319	10.5	0.0	3.2	29.4	-92.7	19.6	2.2	247.6	40
7/25/06	8/10/06	2401	248	39.7	5.0	3.0	4.2	64.8	18.1	2.9	343.1	53
8/11/06	8/28/06	2672	343	22.6	5.7	3.2	0.7	-48.9	19.8	6.4	300.2	41
8/29/06	9/7/06	2666	300	9.1	1.8	1.7	0.1	320.7	11.3	4.6	617.7	85
9/8/06	9/18/06	2864	618	3.0	0.0	1.9	0.0	-220.9	12.6	6.1	383.1	49
9/19/06	9/23/06	2887	383	7.9	0.0	0.7	0.0	142.5	5.8	1.7	526.7	67
Growing Season Total (June 1, 2006 - Sept 30, 2006)[7]		N/A	N/A	116	13	20	211	199	117	27	N/A	N/A
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[3,7]		N/A	N/A	317	51	68	211	90	131	108	N/A	N/A

Predictive Mass Balance Equation: Ppredict = Pinitial + Psurf + Pus + Patm + Pclpw + Padj - Pcoon - Pdis

Growing Season Average[2]: **49**

1 - Reflective of in-lake water quality model existing conditions (2008 watershed conditions, ferric chloride system not operating)

2 - Growing Season Average includes monitoring data from 5/31/2006; See observed, calibrated, and predicted in-lake TP concentrations in Table 4-2 in the TMDL Report.

3 - An empirical model (Dillon and Rigler (1974) with Nurnberg (1984) retention coefficient) was used to predict the steady state phosphorus concentration at the beginning of the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006.

4 - Phosphorus release from Curlyleaf pondweed and uptake by coontail was not estimated for the Steady State year because phosphorus mass balance modeling was not performed for the period from May 1, 2005 -

B-21: Crystal Lake Summary of Upstream Loads and Discharges - Average Climatic Conditions
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

Period		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
		Upstream Inflows						Discharges									
		Keller Lake Inflow	Keller Lake [TP]	Keller Load	Lee Lake Inflow	Lee Lake [TP]	Lee Load	Surface Discharge	Discharge [TP]	Surface Discharge	Groundwater Discharge	Discharge [TP]	Groundwater Discharge	Pumping to Keller Lake	Discharge [TP]	Pumping to Keller Lake	Total Discharge
From	To	(acft)	(µg/L)	(lbs)	(acft)	(µg/L)	(lbs)	(acre-ft)	(µg/L)	(lbs)	(acre-ft)	(µg/L)	(lbs)	(acre-ft)	(µg/L)	(lbs)	(lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[1,2]		315	62	53	15	43	2	1155	28	88	321	28	24	0	28	0	112
(Oct 1, 2005 - April 30, 2006)[1,2]		219	62	37	15	43	2	760	28	58	186	28	14	0	28	0	72
5/1/2006	5/16/2006	2	36	0.2	0	50	0.0	83	28	6.3	14	28	1.1	0	28	0.0	7.3
5/17/2006	5/31/2006	0	46	0.0	0	40	0.0	12	26	0.8	13	26	0.9	0	26	0.0	1.7
6/1/2006	6/15/2006	0	84	0.0	0	123	0.0	0	22	0.0	13	22	0.8	0	22	0.0	0.8
6/16/2006	6/28/2006	0	89	0.0	0	96	0.0	0	33	0.0	11	33	1.0	0	33	0.0	1.0
6/29/2006	7/5/2006	0	200	0.0	0	130	0.0	0	49	0.0	7	49	0.9	0	49	0.0	0.9
7/6/2006	7/24/2006	0	252	0.0	0	90	0.0	0	50	0.0	16	50	2.2	0	50	0.0	2.2
7/25/2006	8/10/2006	10	194	5.0	0	54	0.0	12	40	1.3	15	40	1.6	0	40	0.0	2.9
8/11/2006	8/28/2006	11	195	5.7	0	84	0.0	29	53	4.2	16	53	2.3	0	53	0.0	6.4
8/29/2006	9/7/2006	4	150	1.8	0	64	0.0	32	41	3.6	9	41	1.0	0	41	0.0	4.6
9/8/2006	9/18/2006	0	261	0.0	0	106	0.0	16	85	3.8	10	85	2.2	0	85	0.0	6.1
9/19/2006	9/23/2006	0	151	0.0	0	106	0.0	9	49	1.2	4	49	0.6	0	49	0.0	1.7
Growing Season Total (May 1, 2006 - Sept 30, 2006)[2]				**13**			**0**			**14**			**13**			**0**	**27**
Water Year Total (Oct 1, 2005 - Sept 30, 2006)[2]				**49**			**2**			**79**			**29**			**0**	**108**

1 - A phosphorus mass balance was not performed specifically for the Steady State period (May 1, 2005 - April 30, 2006). An empirical model (Dillon and Rigler (1974) with Nurnberg (1984) retention coefficient) was used to predict the steady state phosphorus concentration used as the starting concentration for the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006. See Appendix B-19.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.
A - Based on daily water balance model. See Appendix B-16, Column F
B - Based on in-lake water quality mass balance model for Keller Lake. See Appendix C.
C - Keller Load = A * B * 0.00272
D - Based on daily water balance model. See Appendix B-16, Column G
E - Based on in-lake water quality mass balance model for Lee Lake. See Appendix D.
F - Lee Load = D * E * 0.00272
G - Based on daily water balance model. See Appendix B-16, Column I
H - In-lake TP Concentration from the previous time step
I - Surface Discharge = G * H * 0.00272
J - Based on daily water balance model. See Appendix B-16, Column H
K - In-lake TP Concentration from the previous time step
L - Groundwater Discharge = G * H * 0.00272
M - Based on daily water balance model. See Appendix B-16, Column E
N - In-lake TP Concentration from the previous time step
O - Pumping to Keller = G * H * 0.00272

B-22: Crystal Lake Average Climatic Conditions
Phosphorus Load Summary
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

			A	B	C	D	E	F	G	H	I
			External TP Load					Internal TP Load			
	Sample Period		Watershed TP Load (lbs)	Atmospheric Deposition (lbs)	Keller Lake (lbs)	Lee Lake (lbs)	Total External TP Load (lbs)	Curlyleaf Pondweed (lbs)	Other Internal Sources (lbs)	Total Internal TP Load (lbs)	Total TP Load (lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[2]	5/1/2005	4/30/2006	390	68	53	2	513	N/A[1]	N/A[1]	N/A[1]	***513***
(Oct 1, 2005 - April 30, 2006)[2]	10/1/2005	4/30/2006	189	43	37	2	270	0	0	0	***270***
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/16/2006	11.4	2.8	0.2	0.0	14.4	0.0	0.0	0.0	***14.4***
	5/17/2006	5/31/2006	1.5	2.6	0.0	0.0	4.1	0.0	0.0	0.0	***4.1***
	6/1/2006	6/15/2006	4.1	2.6	0.0	0.0	6.7	0.0	44.1	44.1	***50.8***
	6/16/2006	6/28/2006	24.2	2.2	0.0	0.0	26.4	36.8	6.7	43.4	***69.9***
	6/29/2006	7/5/2006	0.0	1.1	0.0	0.0	1.1	108.2	0.0	108.2	***109.3***
	7/6/2006	7/24/2006	12.9	3.2	0.0	0.0	16.1	31.3	0.0	31.3	***47.4***
	7/25/2006	8/10/2006	43.0	3.0	5.0	0.0	51.0	29.4	64.8	94.1	***145.1***
	8/11/2006	8/28/2006	26.5	3.2	5.7	0.0	35.4	4.1	0.0	4.1	***39.6***
	8/29/2006	9/7/2006	10.9	1.7	1.8	0.0	14.4	0.7	320.7	321.4	***335.8***
	9/8/2006	9/18/2006	3.2	1.9	0.0	0.0	5.0	0.1	0.0	0.1	***5.1***
	9/19/2006	9/23/2006	8.2	0.7	0.0	0.0	9.0	0.0	142.5	142.5	***151.5***
	9/24/2006	9/30/2006	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	***0.4***
Growing Season (June 1, 2006 - Sept 30, 2006)[2]	**6/1/2006**	**9/30/2006**	**133**	**20**	**12**	**0**	**166**	**211**	**579**	**789**	***955***
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[2]	**10/1/2005**	**9/30/2006**	**335**	**68**	**49**	**2**	**454**	**211**	**578**	**789**	***1243***
	TMDL Report References		**Table 5-3**	**Table 5-3**	**Table 5-3**	**Table 5-3**	**Table 4-3**		**Table 4-4**	**Table 4-3; Table 5-3**	**Table 5-3**

1 - The empirical steady-state equations used to estimate the phosphorus concentration in the lake at the beginning of the mass balance calibration period were originally developed based on external phosphorus loadings only; therefore, internal loading for this period was not estimated. See Appendix B-19.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.

A - Based on P8 TP Load. See Appendix B-15.
B - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake. See Appendix B-17.
C - Load from Upstream Lake = Water Load * [TP]. See Appendix B-21.
D - Load from Upstream Lake = Water Load * [TP]. See Appendix B-21.
E - External Load = A + B + C + D
F - See Appendix B-12.
G - Load back-calculated as part of the mass balance model calibration. Assumes that internal loading happens only during the calibration period (May 1 - Sept 30) to reflect the available monitoring data. This summary table includes only the estimated phosphorus loads to the lake (estimated losses assumed to be zero). See Appendix B-20 Column G.
H - Internal Load = F + G
I - Total TP Load = E + H

B-23: Crystal Lake - Average Climatic Condition Phosphorus Reduction Required to Estimate TMDL Load Capacity
Reduction Required to Meet MPCA Standard of 40 ug/L (No MOS)

TP Load Reduction (%)[1]		A	B	C	D	E	F	G	H	I	J	K
21.0		Epilimnion Volume	P In-Lake @ Start of Period	P Surface Runoff (after Particulate Settling)[6]	P From Upstream Sources[1]	P Atmospheric	P Release from Curlyleaf Pondweed	P Adjustment Load	P Uptake by Coontail	P Loss due to Discharge	P In-Lake @ End of Period	Predicted In-Lake P
Period Start		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/L
				+	+	+	+	+	-	-		
(Oct 1, 2005 - April 30, 2006)[5,7]		2981	N/A	189	38	43	0	N/A	0	72	N/A	28
5/1/06	5/16/06	2696	227	8.7	0.3	2.8	0.0	-24.6	7.2	7.5	199.2	25
5/17/06	5/31/06	1839	199	0.9	0.0	2.6	0.0	-83.0	6.8	1.7	111.5	22
6/1/06	6/15/06	2099	111	2.4	0.0	2.6	29.1	34.9	10.2	0.8	169.2	30
6/16/06	6/28/06	2359	169	15.9	0.0	2.2	85.7	5.3	12.7	0.9	264.8	41
6/29/06	7/5/06	2328	265	0.0	0.0	1.1	24.8	-14.6	7.1	0.8	268.2	42
7/6/06	7/24/06	2285	268	8.3	0.0	3.2	23.3	-76.7	19.6	1.9	204.8	33
7/25/06	8/10/06	2401	205	31.4	1.6	3.0	3.3	51.2	18.1	2.4	274.7	42
8/11/06	8/28/06	2672	275	17.9	1.8	3.2	0.5	-38.3	19.8	5.2	234.8	32
8/29/06	9/7/06	2666	235	7.2	0.7	1.7	0.1	253.5	11.3	3.6	483.1	67
9/8/06	9/18/06	2864	483	2.4	0.0	1.9	0.0	-171.9	12.6	4.7	298.1	38
9/19/06	9/23/06	2887	298	6.2	0.0	0.7	0.0	112.6	5.8	1.4	410.6	52
Growing Season Total (June 1, 2006 - Sept 30, 2006)[7]		N/A	N/A	92	4	20	167	156	117	22	N/A	N/A
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[7]		N/A	N/A	290	42	68	167	49	131	103	N/A	N/A

Growing Season Average (ug/L)[2]	40.0
Growing Season Average Chlorophyll-*a* (ug/L)[3]	24.3
Growing Season Average Secchi Depth (m)[4]	1.8

Predictive Mass Balance Equation: Ppredict = Pinitial + Psurf + Pus + Patm + Pclpw + Pint - Pcoon - Pdis

1 - To estimate the Loading Capacity (and the required reduction in existing TP loads), it was assumed that the phosphorus concentrations in Keller and Lee Lakes were meeting the MPCA standard (60 ug/L). P Surface Runoff, P Release from Curlyleaf Pondweed, and P Adjustment Load (See Note G), were reduced equally until the MPCA standard was met.

2 - Growing Season Average includes predicted data from 5/31/2006

data from 5/31/2006

3 - Based on Chla vs TP water quality relationship (Chla = 0.4527 * TP + 6.1637). See Figure 3-5.

4 - Based on SD vs TP water quality relationship (SD = 20.534 * TP ^ (-0.655)). See Figure 3-4.

5 - To estimate the load reduction, it was assumed that the steady-state concentration in the lake at the beginning of the season (May 1) was not impacted by the estimated reductions in total phosphorus loads (same as existing conditions).

6 - Because the phosphorus mass balance modeling was not performed for the Steady State Period, particulate settling from the watershed runoff was not estimated for this time period. The reported phosphorus load associated with surface runoff during the Steady State period, as well as the period from October 1, 2005 - April 30, 2006 reflects the total watershed runoff load, not the phosphorus load after particulate settling.

7 - For Total Loads, total rounded to the nearest pound for reporting purposes.

A - See Appendix B-20. The epilimnion volume represents the predicted epilimnion volume at the end of the time period.

B - See Appendix B-20.

C - P load from surface runoff (See Appendix B-20, Column C) reduced by the TP Load Reduction percentage for all timesteps.

D - Discharges from Keller and Lee Lakes computed as modeled discharge volume between the dates multiplied by the MPCA standard (60 ug/L). See Appendix B-25.

E - See Appendix B-20.

F - P load from Curlyleaf Pondweed (See Appendix B-20, Column F) reduced by the TP Load Reduction percentage for all timesteps.

G - P load adjustment sources (positive values) reduced by TP Load Reduction percentage while P load adjustment sinks (negative values) reduced proportionately based on the mass of TP in epilimnion for individual timesteps.

H - See Appendix B-20.

I - Discharge from the lake includes surface discharge and losses to groundwater multiplied by the total phosphorus concentration from the previous time period.

J - P In-Lake @ End of Period = B + C + D + E + F + G - H - I

K - Predicted In-Lake P = J / A / 0.00272

B-24: Crystal Lake - Average Climatic Condition Phosphorus Reduction Required to Estimate TMDL Load Capacity
Reduction Required to Meet MPCA Standard of 36 ug/L (10% MOS)

TP Load Reduction (%)[1]		A	B	C	D	E	F	G	H	I	J	K
30.7		Epilimnion Volume	P In-Lake @ Start of Period	P Surface Runoff (after Particulate Settling)[6]	P From Upstream Sources	P Atmospheric	P Release from Curlyleaf Pondweed	P Adjustment Load	P Uptake by Coontail	P Loss due to Discharge	P In-Lake @ End of Period	Predicted In-Lake P
Period Start		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/L
				+	+	+	+	+	-	-		
(Oct 1, 2005 - April 30, 2006)[5,7]		2981	N/A	189	38	43	0	N/A	0	72	N/A	28
5/1/06	5/16/06	2896	226.5	7.6	0.3	2.8	0.0	-24.4	7.2	7.3	198.3	25
5/17/06	5/31/06	1839	198.3	0.8	0.0	2.6	0.0	-82.5	6.8	1.7	110.7	22
6/1/06	6/15/06	2099	110.7	2.1	0.0	2.6	25.5	30.6	10.2	0.8	160.4	28
6/16/06	6/28/06	2359	160.4	13.9	0.0	2.2	75.2	4.6	12.7	0.9	242.8	38
6/29/06	7/5/06	2328	242.8	0.0	0.0	1.1	21.7	-13.3	7.1	0.7	244.6	39
7/6/06	7/24/06	2285	244.6	7.3	0.0	3.2	20.4	-69.2	19.6	1.7	184.9	30
7/25/06	8/10/06	2401	184.9	27.5	1.6	3.0	2.9	44.9	18.1	2.2	244.4	37
8/11/06	8/28/06	2672	244.4	15.7	1.8	3.2	0.5	-33.8	19.8	4.6	207.3	29
8/29/06	9/7/06	2666	207.3	6.3	0.7	1.7	0.0	222.2	11.3	3.2	423.9	58
9/8/06	9/18/06	2864	423.9	2.1	0.0	1.9	0.0	-150.3	12.6	4.2	260.7	33
9/19/06	9/23/06	2887	260.7	5.5	0.0	0.7	0.0	98.8	5.8	1.2	358.7	46
Growing Season Total (June 1, 2006 - Sept 30, 2006)[7]		N/A	N/A	80	4	20	146	134	117	19	N/A	N/A
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[7]		N/A	N/A	277	42	68	146	27	131	100	N/A	N/A

Growing Season Average (ug/L)[2]	36.0
Growing Season Average Chlorophyll-*a* (ug/L)[3]	22.5
Growing Season Average Secchi Depth (m)[4]	2.0

Predictive Mass Balance Equation: Ppredict = Pinitial + Psurf + Pus + Patm + Pclpw + Pint - Pcoon - Pdis

1 - To estimate the Loading Capacity (and the required reduction in existing TP loads), it was assumed that the phosphorus concentrations in Keller and Lee Lakes were meeting the MPCA standard (60 ug/L) P Surface Runoff P Release from Curlyleaf Pondweed and P Adjustment Load (See Note G) were reduced equally until the MPCA standard was met   See Table 5 3 in the TMDL Report

ug/L). P Surface Runoff, P Release from Curlyleaf Pondweed, and P Adjustment Load (See Note G), were reduced equally until the MPCA standard was met. See Table 5-3 in the TMDL Report.
2 - Growing Season Average includes predicted data from 5/31/2006
3 - Based on Chla vs TP water quality relationship (Chla = 0.4527 * TP + 6.1637). See Figure 3-5.
4 - Based on SD vs TP water quality relationship (SD = 20.534 * TP ^ (-0.655)). See Figure 3-4.
5 - To estimate the load reduction, it was assumed that the steady-state concentration in the lake at the beginning of the season (May 1) was not impacted by the estimated reductions in total phosphorus loads (same as existing conditions).
6 - Because the phosphorus mass balance modeling was not performed for the Steady State Period, particulate settling from the watershed runoff was not estimated for this time period. The reported phosphorus load associated with surface runoff during the Steady State period, as well as the period from October 1, 2005 - April 30, 2006 reflects the total watershed runoff load, not the phosphorus load after particulate settling.
7 - For Total Loads, total rounded to the nearest pound for reporting purposes.
A - See Appendix B-20. The epilimnion volume represents the predicted epilimnion volume at the end of the time period.
B - See Appendix B-20.
C - P load from surface runoff (See Appendix B-20, Column C) reduced by the TP Load Reduction percentage for all timesteps.
D - Discharges from Keller and Lee Lakes computed as modeled discharge volume between the dates multiplied by the MPCA standard (60 ug/L). See Appendix B-25.
E - See Appendix B-20.
F - P load from Curlyleaf Pondweed (See Appendix B-20, Column F) reduced by the TP Load Reduction percentage for all timesteps.
G - P load adjustment sources (positive values) reduced by TP Load Reduction percentage while P load adjustment sinks (negative values) reduced proportionately based on the mass of TP in epilimnion for individual timesteps.
H - See Appendix B-20.
I - Discharge from the lake includes surface discharge and losses to groundwater multiplied by the total phosphorus concentration from the previous time period.
J - P In-Lake @ End of Period = B + C + D + E + F + G - H - I
K - Predicted In-Lake P = J / A / 0.00272

B-25: Crystal Lake Summary of Upstream Loads and Discharges for Load Capacity Estimate to Meet MPCA Standard of 36 ug/L (10% MOS)
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
		Upstream Inflows						Discharges									
Period		Keller Lake Inflow	Keller Lake [TP]	Keller Load	Lee Lake Inflow	Lee Lake [TP]	Lee Load	Surface Discharge	Discharge [TP]	Surface Discharge	Groundwater Discharge	Discharge [TP]	Groundwater Discharge	Pumping to Keller Lake	Discharge [TP]	Pumping to Keller Lake	Total Discharge
From	To	(acft)	(μg/L)	(lbs)	(acft)	(μg/L)	(lbs)	(acre-ft)	(μg/L)	(lbs)	(acre-ft)	(μg/L)	(lbs)	(acre-ft)	(μg/L)	(lbs)	(lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[1,2]		315	60	51	15	60	2	1155	28	88	321	28	24	0	28	0	112
(Oct 1, 2005 - April 30, 2006)[1,2]		219	60	36	15	60	2	760	28	58	186	28	14	0	28	0	72
5/1/2006	5/16/2006	2	60	0.3	0	60	0.0	83	28	6.3	14	28	1.1	0	28	0.0	7.3
5/17/2006	5/31/2006	0	60	0.0	0	60	0.0	12	25	0.8	13	25	0.9	0	25	0.0	1.7
6/1/2006	6/15/2006	0	60	0.0	0	60	0.0	0	22	0.0	13	22	0.8	0	22	0.0	0.8
6/16/2006	6/28/2006	0	60	0.0	0	60	0.0	0	28	0.0	11	28	0.9	0	28	0.0	0.9
6/29/2006	7/5/2006	0	60	0.0	0	60	0.0	0	38	0.0	7	38	0.7	0	38	0.0	0.7
7/6/2006	7/24/2006	0	60	0.0	0	60	0.0	0	39	0.0	16	39	1.7	0	39	0.0	1.7
7/25/2006	8/10/2006	10	60	1.6	0	60	0.0	12	30	1.0	15	30	1.2	0	30	0.0	2.2
8/11/2006	8/28/2006	11	60	1.8	0	60	0.0	29	37	3.0	16	37	1.6	0	37	0.0	4.6
8/29/2006	9/7/2006	4	60	0.7	0	60	0.0	32	29	2.5	9	29	0.7	0	29	0.0	3.2
9/8/2006	9/18/2006	0	60	0.0	0	60	0.0	16	58	2.6	10	58	1.5	0	58	0.0	4.2
9/19/2006	9/23/2006	0	60	0.0	0	60	0.0	9	33	0.8	4	33	0.4	0	33	0.0	1.2
Growing Season Total (May 1, 2006 - Sept 30, 2006)[2]				4			0			10			9			0	19
Water Year Total (Oct 1, 2005 - Sept 30, 2006)[2]				40			2			75			26			0	100

1 - A phosphorus mass balance was not performed specifically for the Steady State period (May 1, 2005 - April 30, 2006). An empirical model (Dillon and Rigler (1974) with Nurnberg (1984) retention coefficient) was used to predict the steady state phosphorus concentration used as the starting concentration for the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006. See Appendix B-19.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.
A - Based on daily water balance model. See Appendix B-16, Column F
B - Assumed to be at the MPCA water quality standard
C - Keller Load = A * B * 0.00272
D - Based on daily water balance model. See Appendix B-16, Column G
E - Assumed to be at the MPCA water quality standard
F - Lee Load = D * E * 0.00272
G - Based on daily water balance model. See Appendix B-16, Column I
H - In-lake TP Concentration from the previous time step
I - Surface Discharge = G * H * 0.00272
J - Based on daily water balance model. See Appendix B-16, Column H
K - In-lake TP Concentration from the previous time step
L - Groundwater Discharge = G * H * 0.00272
M - Based on daily water balance model. See Appendix B-16, Column E
N - In-lake TP Concentration from the previous time step
O - Pumping to Keller = G * H * 0.00272

B-26: Crystal Lake Average Climatic Conditions
Upstream Lakes Loadings - TMDL Load Capacity
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

	Sample Period		A Keller Lake (lbs)	B Lee Lake (lbs)
(Oct 1, 2005 - April 30, 2006)[1]	10/1/2005	4/30/2006	36	2
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/16/2006	0.3	0.0
	5/17/2006	5/31/2006	0.0	0.0
	6/1/2006	6/15/2006	0.0	0.0
	6/16/2006	6/28/2006	0.0	0.0
	6/29/2006	7/5/2006	0.0	0.0
	7/6/2006	7/24/2006	0.0	0.0
	7/25/2006	8/10/2006	1.6	0.0
	8/11/2006	8/28/2006	1.8	0.0
	8/29/2006	9/7/2006	0.7	0.0
	9/8/2006	9/18/2006	0.0	0.0
	9/19/2006	9/23/2006	0.0	0.0
	9/24/2006	9/30/2006	0.0	0.0
Growing Season Total (May 1, 2006 - Sept 30, 2006)[1]	6/1/06	9/30/2006	4	0
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[1]	10/1/2005	9/30/2006	40	2

1 - For Total Loads, total rounded to the nearest pound for reporting purposes.
A - Load from Keller Lake = Water Load * MPCA standard (60 ug/L)
B - Load from Lee Lake = Water Load * MPCA standard (60 ug/L)

Appendix C

Keller Lake TMDL Modeling Summary

C-1: Keller Lake Water Quality Data
Average (2006) Climatic Conditions

Date	Secchi Disc Depth (m)	Estimated Depth to Thermocline (m)	Sample Depth (m)	Chl-a (ug/l)	D.O. (mg/l)	Temp. (oC)	Total P (mg/L)
5/2/2006	**1.1**	**1.8**	**0-2**	**9.7**		**16.2**	**0.029**
5/2/2006			0.0				
5/2/2006			1.0				
5/2/2006			3.0				
5/15/2006	**1.8**	**1.8**	**0-2**	**5.2**		**14.7**	**0.031**
5/15/2006			0.0				
5/15/2006			1.0				
5/15/2006			3.0				
5/16/2006	**2**	**1.8**	**0-2**	**9.5**		**14.8**	**0.026**
5/16/2006			0.0			14.8	
5/16/2006			0.2		12.16	14.8	
5/16/2006			0.9		13.02	14.6	
5/16/2006			1.8		13.46	12.6	
5/16/2006			1.9		10.96	12.5	
5/16/2006			2.9		10.04	12.6	
5/16/2006			3.0		9.87	12.6	0.038
5/30/2006	**1.8**	**1.8**	**0-2**	**12**		**27.2**	**0.041**
5/30/2006			0.0				
5/30/2006			1.0				
5/30/2006			2.0				
5/31/2006	**2.1**	**1.8**	**0-2**	**14**		**22.8**	**0.034**
5/31/2006			0.0		12.37	24.8	
5/31/2006			0.9		13.27	24.6	
5/31/2006			1.9		14.62	19.0	
5/31/2006			2.5		11.08	18.9	0.038
6/11/2006	**2.5**	**1.8**	**0-2**	**3.8**		**20.5**	**0.07**
6/11/2006			0.0				
6/11/2006			1.0				
6/11/2006			3.0				
6/15/2006	**2.5**	**1.8**	**0-2**	**7.6**		**21.6**	**0.066**
6/15/2006			0.0			22.3	
6/15/2006			1.0		15.32	22.3	
6/15/2006			1.9		12.08	20.2	
6/15/2006			2.5				0.076
6/26/2006	**1.3**	**1.8**	**0-2**	**14**		**25.2**	**0.051**
6/26/2006			0.0				
6/26/2006			1.0				
6/26/2006			3.0				
6/28/2006	**1.7**	**1.8**	**0-2**	**39**		**22.7**	**0.068**
6/28/2006			0.0				0.068
6/28/2006			0.3		13.45	23.1	0.068
6/28/2006			1.0		12.37	22.9	0.068
6/28/2006			2.0		12.04	22.0	0.068
6/28/2006			2.5				0.062
7/5/2006	**1.6**	**1.8**	**0-2**	**52**		**24.3**	**0.142**
7/5/2006			0.0		14.02	24.3	0.142
7/5/2006			0.8		13.88	24.3	0.142
7/5/2006			1.3		13.95	24.3	0.142
7/5/2006			2.2		13.96	24.4	0
7/5/2006			2.5				0.078
7/9/2006	**0.9**	**1.8**	**0-2**	**38**		**26.7**	**0.169**
7/9/2006			0.0				
7/9/2006			1.0				
7/9/2006			2.0				
7/23/2006	**0.3**	**1.8**	**0-2**	**420**		**26.4**	**0.208**
7/23/2006			0.0				
7/23/2006			1.0				
7/23/2006			2.0				
7/24/2006	**0.4**	**1.8**	**0-2**	**280**		**25.5**	**0.096**

C-2: Stage/Storage/Discharge Rating Curve Keller Lake

Elevation	Area[1]	Cumulative Storage	Discharge
(ft MSL)	(ac)	(ac-ft)	(cfs)
926.3	5.23	0.00	0.0
931.3	37.84	116.87	0.0
934.3	52.58	251.25	0.0
934.5	53.44	263.97	2.9
935.0	55.26	291.15	17.9
936.0	61.90	349.72	66.8
937.5	68.92	448.49	172.7
938.0	71.2	482.82	217.7
939.5	82.83	599.11	356.4
940.0	86.6	640.62	411.4
941.5			579.8

1 - Source: Bathymetry developed from depths collected during May 2008 macrophyte survey

C-3: Keller Lake Average Climatic Conditions
P8 Loading Summary - Calibration (2006 Watershed Conditions)

	Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc (ug/L)
Steady State Year (May 1, 2005 - April 30, 2006)		37.0	817	501	226
(Oct 1, 2005 - April 30, 2006)		17.3	445	239	198
5/1/2006	**5/2/2006**	0.0	0	0.0	112
5/3/2006	**5/15/2006**	1.0	17	10.0	215
5/16/2006	**5/16/2006**	0.0	0	0.0	0
5/17/2006	**5/30/2006**	0.2	2	3.1	469
5/31/2006	**5/31/2006**	0.0	0	0.0	0
6/1/2006	**6/11/2006**	0.4	6	8.1	527
6/12/2006	**6/15/2006**	0.0	0	0.1	138
6/16/2006	**6/26/2006**	2.3	42	32.0	282
6/27/2006	**6/28/2006**	0.0	0	0.0	0
6/29/2006	**7/5/2006**	0.0	0	0.0	0
7/6/2006	**7/9/2006**	0.0	0	0.0	0
7/10/2006	**7/23/2006**	0.9	16	15.9	368
7/24/2006	**7/24/2006**	0.3	5	5.8	438
7/25/2006	**8/6/2006**	4.1	93	43.3	171
8/7/2006	**8/10/2006**	0.3	5	4.0	300
8/11/2006	**8/20/2006**	0.5	9	7.7	316
8/21/2006	**8/28/2006**	2.1	39	25.1	235
8/29/2006	**9/4/2006**	1.0	19	14.8	291
9/5/2006	**9/7/2006**	0.0	0	0.0	0
9/8/2006	**9/18/2006**	0.4	6	5.3	335
9/19/2006	**9/20/2006**	0.0	0	0.0	0
9/21/2006	**10/1/2006**	1.0	17	10.4	220
Growing Season Load (June 1, 2006 - Sept 30, 2006)		13.3	257	172	247
Total Load (2006 Water Year - Oct 1, 2005 - Sept 30, 2006)		31.8	721	425	217

C-4: Keller Lake Average Climatic Conditions
Water Balance Summary
Calibration Conditions (2006 Watershed Conditions)

	Sample Period		A	B	C	D	E	F	G	H	I	J
			Total Lake Volume at the Start of the Period (acre-ft)	Direct Precipitation (acre-ft)	Evaporation (acre-ft)	Watershed Runoff (acre-ft)	Pumping from Crystal Lake (acre-ft)	Groundwater Exchange (acre-ft)	Discharge from Keller Lake (acre-ft)	Change in Lake Volume (acre-ft)	Total Lake Volume at the End of the Period (acre-ft)	Lake Level at End of Period (ft MSL)
				+	-	+	+	-	-			
Steady State Year (May 1, 2005 - April 30, 2006)	5/1/2005	4/30/2006	251	157	119	817	454	590	707	11	262	934.5
(Oct 1, 2005 - April 30, 2006)	10/1/2005	4/30/2006	256	71	22	445	114	290	311	7	262	934.5
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/2/2006	262	0	1	0	6	4	5	-4	259	934.4
	5/3/2006	5/15/2006	259	4	8	17	41	25	29	0	259	934.4
	5/16/2006	5/16/2006	259	0	1	0	3	2	2	-1	258	934.4
	5/17/2006	5/30/2006	258	1	8	2	38	27	14	-9	249	934.2
	5/31/2006	5/31/2006	249	0	1	0	3	2	0	1	250	934.2
	6/1/2006	6/11/2006	250	2	9	6	32	21	5	3	253	934.3
	6/12/2006	6/15/2006	253	0	3	0	13	8	2	0	253	934.3
	6/16/2006	6/26/2006	253	10	9	42	35	22	48	8	262	934.5
	6/27/2006	6/28/2006	262	0	2	0	6	4	4	-4	258	934.4
	6/29/2006	7/5/2006	258	0	6	0	22	14	7	-5	253	934.3
	7/6/2006	7/9/2006	253	0	4	0	13	8	2	-1	253	934.3
	7/10/2006	7/23/2006	253	4	13	16	38	27	18	-1	252	934.3
	7/24/2006	7/24/2006	252	1	1	5	0	2	1	2	254	934.3
	7/25/2006	8/6/2006	254	18	10	93	19	26	94	1	256	934.3
	8/7/2006	8/10/2006	256	1	2	5	3	8	2	-3	253	934.3
	8/11/2006	8/20/2006	253	2	6	9	19	19	5	0	253	934.3
	8/21/2006	8/28/2006	253	9	5	39	25	16	47	7	259	934.4
	8/29/2006	9/4/2006	259	4	3	19	22	14	27	2	261	934.4
	9/5/2006	9/7/2006	261	0	1	0	10	6	6	-4	257	934.4
	9/8/2006	9/18/2006	257	2	4	6	35	22	16	1	258	934.4
	9/19/2006	9/20/2006	258	0	1	0	6	4	3	-2	257	934.4
	9/21/2006	10/1/2006	257	5	3	17	32	20	31	-1	256	934.3
Total for Growing Season (June 1, 2006 - Sept 30, 2006)	6/1/2006	9/30/2006	250	59	80	257	330	239	320	6	256	934.3
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)	10/1/2005	9/30/2006	256	134	121	721	536	590	681	0.1	256	934.3

Annual (2006 Water Year) Water Load to Keller Lake (acre-ft)	10/1/2005	9/30/2006	1392	Water Load = B + D + E

A - Based on the daily water balance model (calibrated to lake level data and using the lake stage-storage-discharge curve). See Appendix C-2.
B - Based on precipitation data used for the P8 modeling and the daily water balance model (Direct Precip Volume = Depth of Precip * Lake Surface Area) See Appendix C-3.
C - Based on adjusted pan evaporation data from the University of Minnesota St. Paul Campus Climatological Observatory and the daily water balance model (Evap Volume = 0.7 * Depth of Evap * Lake Surface Area). See Appendix C-6.
D - Based on the water loads from the P8 model. See Appendix C-3.
E - Based on the ferric chloride system pump logs and pump settings. See Appendix F.
F - Groundwater exchange fit to 2008 lake levels and watershed conditions. The estimated groundwater exchange was applied to all climatic conditions.
G - Based on the estimated discharge from the Keller Lake daily water balance model
H - Change in Lake Volume = B - C + D + E - F - G
I- Total Lake Volume @ End of Period = A + H
J - Estimated lake level based on the total lake volume and the stage-storage-discharge curve. See Appendix C-2.

Predicted Lake Level

Actual Lake Level

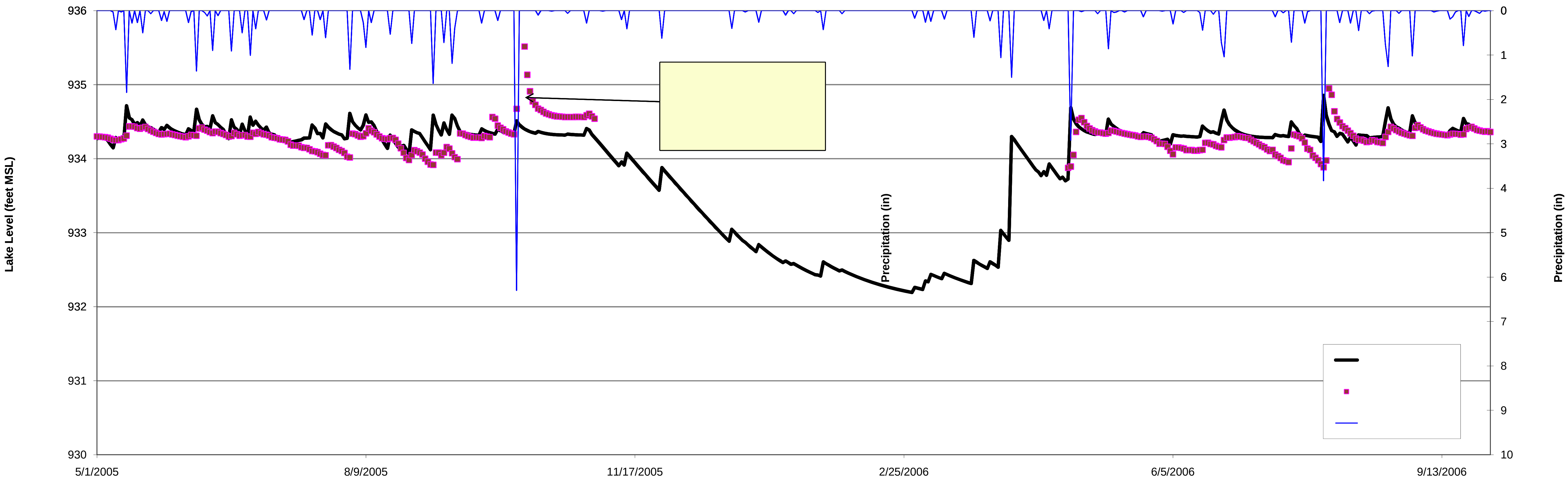
Precip (in)

931 930

8 9 10

5/1/2005 8/9/2005 11/17/2005 2/25/2006 6/5/2006 9/13/2006

C-5: Keller Lake Water Balance
Average Climatic Conditions
May 1, 2005 through October 1, 2006



C-6: St. Paul Campus Monthly Pan Evaporation Data

ST. PAUL CAMPUS CLIMATOLOGICAL OBSERVATORY 21-8450-6

http://climate.umn.edu/img/wxsta/pan-evaporation.htm

		MONTHLY PAN EVAPORATION, INCHES							
Year		APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	TOTAL
		21-30						1-10	
1972	*	1.86	6.08	8.03	6.76	5.62	4.08	0.92	33.35
1973		1.75	5.82	8.45	8.73	7.64	4.33	0.89	37.61
1974		2.03	5.54	7.46	9.46	6.49	4.62	1.29	36.89
1975		0.7	7.02	6.34	9.41	6.58	4.29	2.08	36.42
1976	*	1.86	8.4	11.08	10.96	10.54	6.62	1.61	51.07
1977		2.94	9.42	8.48	9.2	6.65	4.06	0.96	41.71
1978		1.61	8	7.21	6.87	8.3	6.02	1.21	39.22
1979		1.3	6.32	8.53	7.82	5.23	5.33	1.18	35.71
1980		2.88	7.62	7.75	8.83	6.55	4.51	1.47	39.61
1981		1.14	6.45	6.61	7.72	5.83	4.97	0.84	33.56
1982		2.77	6.29	7.49	8.52	7.81	4.21	0.85	37.94
1983	*	1.86	6.53	7.05	8.47	7.23	4.52	1.23	36.89
1984		2.37	7.13	6.88	8.88	7.26	5.24	1.03	38.79
1985		1.98	7.79	7.89	9.07	5.95	4.39	0.95	38.02
1986		1.65	7.21	8.34	7.97	6.71	3.88	1.2	36.96
1987		2.88	8.33	10.96	8.62	7.01	5.36	1.74	44.9
1988		1.77	10.38	11.83	11.73	8.96	5.2	1.54	51.41
1989		1.74	6.47	7.8	8.93	7.26	5.9	1.57	39.67
1990		1.96	6.27	7.24	7.65	6.63	5.45	1.71	36.91
1991		2.09	5.24	7.9	7.44	6.31	4.04	1.08	34.1
1992		1.32	8.83	6.89	5.8	6.69	4.8	1.3	35.63
1993		2.01	5.44	6.46	6.94	6.38	4.1	1.58	32.91
1994		1.32	8.67	7.36	7.02	6.58	3.94	1.18	36.07
1995		1.45	6.16	7.24	7.98	5.8	4.66	0.84	34.13
1996		1.75	5.95	6.53	7.53	7.71	4.6	1.47	35.54
1997		1.99	5.91	7.42	5.43	4.97	4.34	1.51	31.57
1998		2.22	7.5	5.57	7.32	5.79	5.13	0.72	34.25
1999		1.95	6.15	6.26	7.92	5.57	4.71	1.01	33.57
2000		2.2	5.81	6.15	6.89	6.17	4.84	1.38	33.44
2001		2.03	5.29	6.93	8.03	6.28	3.83	1.2	33.59
2002		1.11	6.25	7.25	6.69	6.09	4.47	0.71	32.57
2003		2.09	5.93	6.23	6.88	6.84	5.25	1.39	34.61
2004		1.91	5.41	6.3	6.63	5.14	4.91	1.27	31.57
2005		**1.2**	**4.35**	**6.96**	**8.82**	**6.49**	**4.81**	**1.2**	**33.83**
2006		**1.21**	**5.98**	**7.91**	**9.16**	**5.72**	**3.29**	**1.41**	**34.68**
2007		2.19	6.86	8.81	8.7	6.12	5.38	1.37	39.43
2008	*	1.86	6.83	6.42	8.71	7.83	4.57	1.26	37.48

Bold data indicates data used as part of the water balance modeling. Evaporation from November to March assumed to be negligible.

Pan Coefficient	**0.7**

C-7: Keller Lake Average Climatic Conditions
Physical Parameter Summary
Calibration Conditions (2006 Watershed Conditions)

		A	B	C		D	E	F	G	H
Period		Atmos. Dep	Water Surface Elev	Depth to Thermocline		Elevation of Thermocline	Epilimnion Volume	Surface Area	Hypolimnion Volume	Hypolimnion Area
From	To	(lbs)	(ft MSL)	(m)	(ft)	(ft MSL)	(acft)	(acre)	(acft)	(ac)
5/1/05	4/30/06	12	934.5	1.8	5.9	928.6	209	53.3	54	20
5/1/06	5/2/06	0.0	934.4	1.8	5.9	928.5	207	53.1	52	20
5/3/06	5/15/06	0.4	934.4	1.8	5.9	928.5	207	53.1	53	20
5/16/06	5/16/06	0.0	934.4	1.8	5.9	928.5	206	53.0	52	20
5/17/06	5/30/06	0.4	934.2	1.8	5.9	928.3	201	52.4	48	19
5/31/06	5/31/06	0.0	934.2	1.8	5.9	928.3	202	52.4	48	19
6/1/06	6/11/06	0.3	934.3	1.8	5.9	928.4	203	52.7	50	19
6/12/06	6/15/06	0.1	934.3	1.8	5.9	928.4	203	52.7	50	19
6/16/06	6/26/06	0.3	934.5	1.8	5.9	928.6	208	53.3	54	20
6/27/06	6/28/06	0.0	934.4	1.8	5.9	928.5	206	53.0	52	20
6/29/06	7/5/06	0.2	934.3	1.8	5.9	928.4	203	52.7	50	19
7/6/06	7/9/06	0.1	934.3	1.8	5.9	928.4	203	52.7	50	19
7/10/06	7/23/06	0.4	934.3	1.8	5.9	928.4	203	52.6	49	19
7/24/06	7/24/06	0.0	934.3	1.8	5.9	928.4	204	52.8	50	19
7/25/06	8/6/06	0.4	934.3	1.8	5.9	928.4	205	52.9	51	19
8/7/06	8/10/06	0.1	934.3	1.8	5.9	928.4	203	52.7	50	19
8/11/06	8/20/06	0.3	934.3	1.8	5.9	928.4	203	52.7	50	19
8/21/06	8/28/06	0.2	934.4	2.0	6.6	927.9	222	53.1	37	16
8/29/06	9/4/06	0.2	934.4	1.8	5.9	928.5	208	53.3	53	20
9/5/06	9/7/06	0.1	934.4	1.8	5.9	928.5	206	53.0	52	20
9/8/06	9/18/06	0.3	934.4	1.8	5.9	928.5	206	53.1	52	20
9/19/06	9/20/06	0.0	934.4	1.8	5.9	928.5	205	52.9	51	20
9/21/06	10/1/06	0.3	934.3	1.8	5.9	928.4	205	52.9	51	19

A - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) (Barr, 2005) over the surface area of the lake: A = F * (0.000639 lb/ac/d) * (# of Days)
B - Based on the daily water balance model. See Appendix C-4, Column J
C - Estimated based on the available temperature profile data. See Appendix C-1.
D - Elevation of the Thermocline: D = B - C
E - Estimated using the lake stage-storage-discharge curve. See Appendix C-2.
F - Estimated using the lake stage-storage-discharge curve. See Appendix C-2.
G - Estimated using the lake stage-storage-discharge curve. See Appendix C-2.
H - Estimated using the lake stage-storage-discharge curve. See Appendix C-2.

C-8: Keller Lake Average Climatic Conditions

P8 Particle Class Settling - Estimated Number of Days to Settle Out of Epilimnion & Watershed TP Loads

Calibration Conditions (2006 Watershed Conditions)

			Number of Days to Settle P8 Particle Class[1,2,3]					
P8 Particle Class			P10	P30	P50	P80		
P8 Settling Velocity			vs = 0.03 ft/hr	vs = 0.3 ft/hr	vs = 1.5 ft/hr	vs = 15 ft/hr		
Sample Period		Epilimnion Depth (De)[4] (ft)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Total Watershed TP Load before Particle Settling (lbs)	Watershed TP Load after Particle Settling[2,3] (lbs)
5/1/2006	5/2/2006	5.9	8	1	0	0	0.0	0.0
5/3/2006	5/15/2006	5.9	8	1	0	0	10.0	6.7
5/16/2006	5/16/2006	5.9	8	1	0	0	0.0	0.0
5/17/2006	5/30/2006	5.9	8	1	0	0	3.1	1.5
5/31/2006	5/31/2006	5.9	8	1	0	0	0.0	0.0
6/1/2006	6/11/2006	5.9	8	1	0	0	8.0	3.8
6/12/2006	6/15/2006	5.9	8	1	0	0	0.1	0.1
6/16/2006	6/26/2006	5.9	8	1	0	0	31.9	16.5
6/27/2006	6/28/2006	5.9	8	1	0	0	0.0	0.0
6/29/2006	7/5/2006	5.9	8	1	0	0	0.0	0.0
7/6/2006	7/9/2006	5.9	8	1	0	0	0.0	0.0
7/10/2006	7/23/2006	5.9	8	1	0	0	15.9	8.0
7/24/2006	7/24/2006	5.9	8	1	0	0	5.8	5.8
7/25/2006	8/6/2006	5.9	8	1	0	0	43.3	35.4
8/7/2006	8/10/2006	5.9	8	1	0	0	4.0	4.0
8/11/2006	8/20/2006	5.9	8	1	0	0	7.7	4.4
8/21/2006	8/28/2006	5.9	8	1	0	0	25.1	16.5
8/29/2006	9/4/2006	6.6	9	1	0	0	14.8	8.8
9/5/2006	9/7/2006	5.9	8	1	0	0	0.0	0.0
9/8/2006	9/18/2006	5.9	8	1	0	0	5.3	3.3
9/19/2006	9/20/2006	5.9	8	1	0	0	0.0	0.0
9/21/2006	10/1/2006	5.9	8	1	0	0	10.4	5.0

1 - Number of Days to Settle Particles = De/vs/24

2 - The P0 particle class in P8 reflects the non-settleable (or dissolved) fraction of the particles. See additional details in Appendix A-3.

3 - The pollutant loading in P8 is based on the build-up and wash-off of particles. There are 5 particle size classes, each with a mass of pollutant associated with it (e.g. phosphorus) as well as a settling velocity. The majority of the phosphorus is associated with the P0 (or non-settleable fraction). The in-lake mass balance model tracks the mass of each particle size class (from the P8 model) and determines how long the particles will remain in the epilimnion (thus impacting observed water quality). The model considers the number of days between the water quality sampling dates and the prior storm events, and only includes the phosphorus load from those particles that would remain in the epilimnion during that period. See Appendix C-3 for a table summarizing the P8 event TP loads.

4 - Epiliminion Depth from Appendix C-7 Column C

C-9: In-Lake Steady State Summary
Keller Lake - 2006 Calibration Conditions

Parameter	Value[1]	Comments
L=Areal Load ($mg/m^2/yr$) From May to May	1137.9	(Watershed Load + Atmospheric Load) / Surface Area
Point Source Loading (mg/yr)	0.0	
Watershed Load (mg/yr)	236562244.2	P8 Watershed Load[2] + Upstream Source Loads[3]
Atmosperic Load (mg/yr)	5564491.4	Atmospheric Deposition Rate * Surface Area = 0.2915 kg/ha/yr * Surface Area
qs =Overflow Rate (m/yr)	7.6	Outflow / Surface Area
V=Volume (m^3)	309921.8	Lake Volume[4]
A=Surface Area (m^2)	212791.3	Surface Area[4]
td= Residence Time (yr)	0.2	Volume / Outflow
z= mean Depth (m)	1.5	Volume / Surface Area
Q=Outflow (m^3/yr)	1619867.9	Inflow = Watershed Runoff + Upstream Inflows + Direct Precip = Outflow
r =Flushing Rate (yr-1)	5.2	1 / Residence Time
	Predicted TP Conc (ug/L)	
Reckow (1977) [P] =Lext/(11.6+1.2*qs)	55	**See Table 4-2 in the TMDL Report**

1 - Based on May 1, 2005 through April 30, 2006
2 - See Appendix C-14 Column A
3 - See Appendix C-14 Column C
4 - At Normal Water Level; See Appendix C-2

$$P = \frac{L}{(11.6 + 1.2 * q_s)}$$

where:

P = total phosphorus concentration at the beginning of the open water season (μg/L)

L = areal total phosphorus loading rate ($mg/m^2/yr$)

q_s = annual areal water outflow load (m/yr)

= Q/A

Q = annual outflow (m^3/yr)

A = lake surface area (m^2)

C-8: Keller Lake Average Climatic Conditions
P8 Particle Class Settling - Estimated Number of Days to Settle Out of Epilimnion & Watershed TP Loads
Calibration Conditions (2006 Watershed Conditions)

			Number of Days to Settle P8 Particle Class[1,2,3]					
P8 Particle Class			P10	P30	P50	P80		
P8 Settling Velocity			vs = 0.03 ft/hr	vs = 0.3 ft/hr	vs = 1.5 ft/hr	vs = 15 ft/hr		
Sample Period		Epilimnion Depth (De)[4] (ft)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Total Watershed TP Load before Particle Settling (lbs)	Watershed TP Load after Particle Settling[2,3] (lbs)
5/1/2006	5/2/2006	5.9	8	1	0	0	0.0	0.0
5/3/2006	5/15/2006	5.9	8	1	0	0	10.0	6.7
5/16/2006	5/16/2006	5.9	8	1	0	0	0.0	0.0
5/17/2006	5/30/2006	5.9	8	1	0	0	3.1	1.5
5/31/2006	5/31/2006	5.9	8	1	0	0	0.0	0.0
6/1/2006	6/11/2006	5.9	8	1	0	0	8.0	3.8
6/12/2006	6/15/2006	5.9	8	1	0	0	0.1	0.1
6/16/2006	6/26/2006	5.9	8	1	0	0	31.9	16.5
6/27/2006	6/28/2006	5.9	8	1	0	0	0.0	0.0
6/29/2006	7/5/2006	5.9	8	1	0	0	0.0	0.0
7/6/2006	7/9/2006	5.9	8	1	0	0	0.0	0.0
7/10/2006	7/23/2006	5.9	8	1	0	0	15.9	8.0
7/24/2006	7/24/2006	5.9	8	1	0	0	5.8	5.8
7/25/2006	8/6/2006	5.9	8	1	0	0	43.3	35.4
8/7/2006	8/10/2006	5.9	8	1	0	0	4.0	4.0
8/11/2006	8/20/2006	5.9	8	1	0	0	7.7	4.4
8/21/2006	8/28/2006	5.9	8	1	0	0	25.1	16.5
8/29/2006	9/4/2006	6.6	9	1	0	0	14.8	8.8
9/5/2006	9/7/2006	5.9	8	1	0	0	0.0	0.0
9/8/2006	9/18/2006	5.9	8	1	0	0	5.3	3.3
9/19/2006	9/20/2006	5.9	8	1	0	0	0.0	0.0
9/21/2006	10/1/2006	5.9	8	1	0	0	10.4	5.0

1 - Number of Days to Settle Particles = De/vs/24

2 - The P0 particle class in P8 reflects the non-settleable (or dissolved) fraction of the particles. See additional details in Appendix A-3.

3 - The pollutant loading in P8 is based on the build-up and wash-off of particles. There are 5 particle size classes, each with a mass of pollutant associated with it (e.g. phosphorus) as well as a settling velocity. The majority of the phosphorus is associated with the P0 (or non-settleable fraction). The in-lake mass balance model tracks the mass of each particle size class (from the P8 model) and determines how long the particles will remain in the epilimnion (thus impacting observed water quality). The model considers the number of days between the water quality sampling dates and the prior storm events, and only includes the phosphorus load from those particles that would remain in the epilimnion during that period. See Appendix C-3 for a table summarizing the P8 event TP loads.

4 - Epiliminion Depth from Appendix C-7 Column C

C-7: Keller Lake Average Climatic Conditions
Physical Parameter Summary
Calibration Conditions (2006 Watershed Conditions)

Period		A	B	C		D	E	F	G	H
		Atmos. Dep	Water Surface Elev	Depth to Thermocline		Elevation of Thermocline	Epilimnion Volume	Surface Area	Hypolimnion Volume	Hypolimnion Area
From	To	(lbs)	(ft MSL)	(m)	(ft)	(ft MSL)	(acft)	(acre)	(acft)	(ac)
5/1/05	4/30/06	12	934.5	1.8	5.9	928.6	209	53.3	54	20
5/1/06	5/2/06	0.0	934.4	1.8	5.9	928.5	207	53.1	52	20
5/3/06	5/15/06	0.4	934.4	1.8	5.9	928.5	207	53.1	53	20
5/16/06	5/16/06	0.0	934.4	1.8	5.9	928.5	206	53.0	52	20
5/17/06	5/30/06	0.4	934.2	1.8	5.9	928.3	201	52.4	48	19
5/31/06	5/31/06	0.0	934.2	1.8	5.9	928.3	202	52.4	48	19
6/1/06	6/11/06	0.3	934.3	1.8	5.9	928.4	203	52.7	50	19
6/12/06	6/15/06	0.1	934.3	1.8	5.9	928.4	203	52.7	50	19
6/16/06	6/26/06	0.3	934.5	1.8	5.9	928.6	208	53.3	54	20
6/27/06	6/28/06	0.0	934.4	1.8	5.9	928.5	206	53.0	52	20
6/29/06	7/5/06	0.2	934.3	1.8	5.9	928.4	203	52.7	50	19
7/6/06	7/9/06	0.1	934.3	1.8	5.9	928.4	203	52.7	50	19
7/10/06	7/23/06	0.4	934.3	1.8	5.9	928.4	203	52.6	49	19
7/24/06	7/24/06	0.0	934.3	1.8	5.9	928.4	204	52.8	50	19
7/25/06	8/6/06	0.4	934.3	1.8	5.9	928.4	205	52.9	51	19
8/7/06	8/10/06	0.1	934.3	1.8	5.9	928.4	203	52.7	50	19
8/11/06	8/20/06	0.3	934.3	1.8	5.9	928.4	203	52.7	50	19
8/21/06	8/28/06	0.2	934.4	2.0	6.6	927.9	222	53.1	37	16
8/29/06	9/4/06	0.2	934.4	1.8	5.9	928.5	208	53.3	53	20
9/5/06	9/7/06	0.1	934.4	1.8	5.9	928.5	206	53.0	52	20
9/8/06	9/18/06	0.3	934.4	1.8	5.9	928.5	206	53.1	52	20
9/19/06	9/20/06	0.0	934.4	1.8	5.9	928.5	205	52.9	51	20
9/21/06	10/1/06	0.3	934.3	1.8	5.9	928.4	205	52.9	51	19

A - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) (Barr, 2005) over the surface area of the lake: A = F * (0.000639 lb/ac/d) * (# of Days)
B - Based on the daily water balance model. See Appendix C-4, Column J
C - Estimated based on the available temperature profile data. See Appendix C-1.
D - Elevation of the Thermocline: D = B - C
E - Estimated using the lake stage-storage-discharge curve. See Appendix C-2.
F - Estimated using the lake stage-storage-discharge curve. See Appendix C-2.
G - Estimated using the lake stage-storage-discharge curve. See Appendix C-2.
H - Estimated using the lake stage-storage-discharge curve. See Appendix C-2.

C-6: St. Paul Campus Monthly Pan Evaporation Data

ST. PAUL CAMPUS CLIMATOLOGICAL OBSERVATORY 21-8450-6

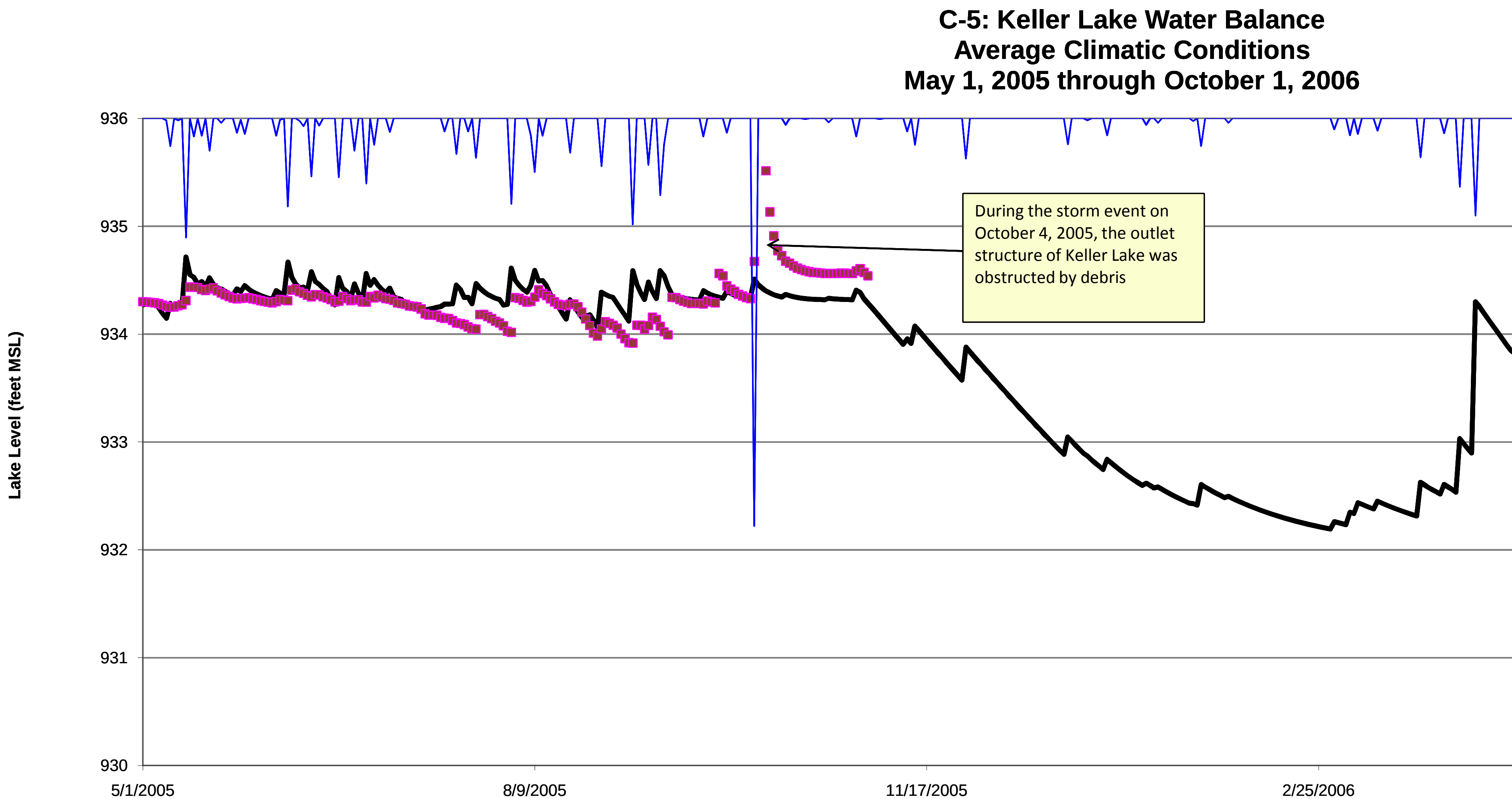
http://climate.umn.edu/img/wxsta/pan-evaporation.htm

MONTHLY PAN EVAPORATION, INCHES

Year		APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	TOTAL
		21-30						1-10	
1972	*	1.86	6.08	8.03	6.76	5.62	4.08	0.92	33.35
1973		1.75	5.82	8.45	8.73	7.64	4.33	0.89	37.61
1974		2.03	5.54	7.46	9.46	6.49	4.62	1.29	36.89
1975		0.7	7.02	6.34	9.41	6.58	4.29	2.08	36.42
1976	*	1.86	8.4	11.08	10.96	10.54	6.62	1.61	51.07
1977		2.94	9.42	8.48	9.2	6.65	4.06	0.96	41.71
1978		1.61	8	7.21	6.87	8.3	6.02	1.21	39.22
1979		1.3	6.32	8.53	7.82	5.23	5.33	1.18	35.71
1980		2.88	7.62	7.75	8.83	6.55	4.51	1.47	39.61
1981		1.14	6.45	6.61	7.72	5.83	4.97	0.84	33.56
1982		2.77	6.29	7.49	8.52	7.81	4.21	0.85	37.94
1983	*	1.86	6.53	7.05	8.47	7.23	4.52	1.23	36.89
1984		2.37	7.13	6.88	8.88	7.26	5.24	1.03	38.79
1985		1.98	7.79	7.89	9.07	5.95	4.39	0.95	38.02
1986		1.65	7.21	8.34	7.97	6.71	3.88	1.2	36.96
1987		2.88	8.33	10.96	8.62	7.01	5.36	1.74	44.9
1988		1.77	10.38	11.83	11.73	8.96	5.2	1.54	51.41
1989		1.74	6.47	7.8	8.93	7.26	5.9	1.57	39.67
1990		1.96	6.27	7.24	7.65	6.63	5.45	1.71	36.91
1991		2.09	5.24	7.9	7.44	6.31	4.04	1.08	34.1
1992		1.32	8.83	6.89	5.8	6.69	4.8	1.3	35.63
1993		2.01	5.44	6.46	6.94	6.38	4.1	1.58	32.91
1994		1.32	8.67	7.36	7.02	6.58	3.94	1.18	36.07
1995		1.45	6.16	7.24	7.98	5.8	4.66	0.84	34.13
1996		1.75	5.95	6.53	7.53	7.71	4.6	1.47	35.54
1997		1.99	5.91	7.42	5.43	4.97	4.34	1.51	31.57
1998		2.22	7.5	5.57	7.32	5.79	5.13	0.72	34.25
1999		1.95	6.15	6.26	7.92	5.57	4.71	1.01	33.57
2000		2.2	5.81	6.15	6.89	6.17	4.84	1.38	33.44
2001		2.03	5.29	6.93	8.03	6.28	3.83	1.2	33.59
2002		1.11	6.25	7.25	6.69	6.09	4.47	0.71	32.57
2003		2.09	5.93	6.23	6.88	6.84	5.25	1.39	34.61
2004		1.91	5.41	6.3	6.63	5.14	4.91	1.27	31.57
2005		**1.2**	**4.35**	**6.96**	**8.82**	**6.49**	**4.81**	**1.2**	**33.83**
2006		**1.21**	**5.98**	**7.91**	**9.16**	**5.72**	**3.29**	**1.41**	**34.68**
2007		2.19	6.86	8.81	8.7	6.12	5.38	1.37	39.43
2008	*	1.86	6.83	6.42	8.71	7.83	4.57	1.26	37.48

Bold data indicates data used as part of the water balance modeling. Evaporation from November to March assumed to be negligible.

Pan Coefficient	**0.7**



C-5: Keller Lake Water Balance
Average Climatic Conditions
May 1, 2005 through October 1, 2006
Lake Level (feet MSL)
936
935
934
933
932
931
930
5/1/2005
8/9/2005
11/17/2005
2/25/2006
During the storm event on October 4, 2005, the outlet structure of Keller Lake was obstructed by debris

C-14: Keller Lake Average Climatic Conditions
Phosphorus Load Summary
Calibration Conditions (2006 Watershed Conditions)

			A	B	C	D	E	F	G	H
			External TP Load				**Internal TP Load**			
	Sample Period		**Watershed TP Load (lbs)**	**Atmospheric Deposition (lbs)**	**Pumping from Crystal Lake (lbs)**	**Total External TP Load (lbs)**	**Curlyleaf Pondweed (lbs)**	**Other Internal Sources (lbs)**	**Total Internal TP Load (lbs)**	**Total TP Load (lbs)**
Steady State Year (May 1, 2005 - April 30, 2006)[2]	5/1/2005	4/30/2006	500	12	20	532	N/A[1]	N/A[1]	N/A[1]	***532***
(Oct 1, 2005 - April 30, 2006)[2]	10/1/2005	4/30/2006	239	8	5	252	0	0	0	***252***
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/2/2006	0.0	0.0	0.3	0.3	0.0	0.0	0.0	***0.3***
	5/3/2006	5/15/2006	10.0	0.4	1.8	12.2	0.0	0.0	0.0	***12.2***
	5/16/2006	5/16/2006	0.0	0.0	0.1	0.1	0.0	0.0	0.0	***0.1***
	5/17/2006	5/30/2006	3.1	0.4	1.7	5.2	0.0	10.6	10.6	***15.8***
	5/31/2006	5/31/2006	0.0	0.0	0.1	0.1	0.0	0.0	0.0	***0.1***
	6/1/2006	6/11/2006	8.1	0.3	1.4	9.8	0.0	20.0	20.0	***29.8***
	6/12/2006	6/15/2006	0.1	0.1	0.6	0.8	0.0	0.1	0.1	***0.9***
	6/16/2006	6/26/2006	32.0	0.3	1.5	33.8	2.3	0.0	2.3	***36.1***
	6/27/2006	6/28/2006	0.0	0.0	0.3	0.3	3.1	7.7	10.9	***11.2***
	6/29/2006	7/5/2006	0.0	0.2	1.0	1.2	12.9	33.0	45.9	***47.1***
	7/6/2006	7/9/2006	0.0	0.1	0.6	0.7	6.3	13.3	19.5	***20.2***
	7/10/2006	7/23/2006	15.9	0.4	1.7	18.0	12.1	26.2	38.3	***56.3***
	7/24/2006	7/24/2006	5.8	0.0	0.0	5.8	0.4	0.0	0.4	***6.2***
	7/25/2006	8/6/2006	43.3	0.4	0.8	44.5	3.0	0.4	3.4	***47.9***
	8/7/2006	8/10/2006	4.0	0.1	0.1	4.2	0.4	1.8	2.1	***6.3***
	8/11/2006	8/20/2006	7.7	0.3	0.8	8.9	0.5	0.0	0.5	***9.3***
	8/21/2006	8/28/2006	25.1	0.2	1.1	26.5	0.1	35.4	35.5	***62.0***
	8/29/2006	9/4/2006	14.8	0.2	1.0	16.0	0.1	0.0	0.1	***16.0***
	9/5/2006	9/7/2006	0.0	0.1	0.4	0.5	0.0	0.0	0.0	***0.5***
	9/8/2006	9/18/2006	5.3	0.3	1.5	7.1	0.0	78.2	78.2	***85.3***
	9/19/2006	9/20/2006	0.0	0.0	0.3	0.3	0.0	0.0	0.0	***0.3***
	9/21/2006	10/1/2006	10.4	0.3	1.5	12.3	0.0	7.0	7.0	***19.2***
Growing Season (June 1, 2006 - Sept 30, 2006)[2]	**6/1/2006**	**10/1/2006**	**172**	**4**	**15**	**190**	**41**	**223**	**264**	***455***
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[2]	**10/1/2005**	**9/30/2006**	**425**	**12**	**23**	**461**	**41**	**234**	**275**	***736***

1 - The empirical steady-state equations used to estimate the phosphorus concentration in the lake at the beginning of the mass balance calibration period were originally developed based on external phosphorus loadings only; therefore, internal loading for this period was not estimated. See Appendix C-9.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.

A - Based on P8 TP Load. See Appendix C-3.

B - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake. See Appendices C-7 and C-10.

C - Load from Upstream Lake = Water Load * [TP]. See Appendix C-11.

D - External Load = A + B + C
E - See Appendix C-12.

F - Load back-calculated as part of the mass balance model calibration. Assumes that internal loading happens only during the calibration period (May 1 - Sept 30) to reflect the available monitoring data. This summary table includes only the estimated phosphorus loads to the lake (estimated losses assumed to be zero). See Appendix C-10 Column M.
G - Internal Load = E + F
H - Total TP Load = D + G

C-15: Keller Lake Average Climatic Conditions
P8 Loading Summary - Existing Conditions (2008 Watershed Conditions)

	Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc (ug/L)
Steady State Year (May 1, 2005 - April 30, 2006)		37.0	817	496	224
(Oct 1, 2005 - April 30, 2006)		17.3	445	238	197
5/1/2006	**5/2/2006**	0.0	0	0.0	117
5/3/2006	**5/15/2006**	1.0	17	9.8	211
5/16/2006	**5/16/2006**	0.0	0	0.0	0
5/17/2006	**5/30/2006**	0.2	2	3.0	460
5/31/2006	**5/31/2006**	0.0	0	0.0	0
6/1/2006	**6/11/2006**	0.4	6	7.8	510
6/12/2006	**6/15/2006**	0.0	0	0.1	139
6/16/2006	**6/26/2006**	2.3	42	31.4	278
6/27/2006	**6/28/2006**	0.0	0	0.0	0
6/29/2006	**7/5/2006**	0.0	0	0.0	0
7/6/2006	**7/9/2006**	0.0	0	0.0	0
7/10/2006	**7/23/2006**	0.9	16	15.5	358
7/24/2006	**7/24/2006**	0.3	5	5.7	428
7/25/2006	**8/6/2006**	4.1	93	43.3	171
8/7/2006	**8/10/2006**	0.3	5	3.9	294
8/11/2006	**8/20/2006**	0.5	9	7.5	308
8/21/2006	**8/28/2006**	2.1	39	24.9	233
8/29/2006	**9/4/2006**	1.0	19	14.5	284
9/5/2006	**9/7/2006**	0.0	0	0.0	0
9/8/2006	**9/18/2006**	0.4	6	5.2	329
9/19/2006	**9/20/2006**	0.0	0	0.0	0
9/21/2006	**10/1/2006**	1.0	17	10.3	217
Growing Season Load (June 1, 2006 - Sept 30, 2006)		13.3	257	170	244
Total Load (2006 Water Year - Oct 1, 2005 - Sept 30, 2006)		31.8	721	422	216

C-16: Keller Lake Average Climatic Conditions
Water Balance Summary
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

			A	B	C	D	E	F	G	H	I	J
	Sample Period		Total Lake Volume at the Start of the Period (acre-ft)	Direct Precipitation (acre-ft)	Evaporation (acre-ft)	Watershed Runoff (acre-ft)	Pumping from Crystal Lake (acre-ft)	Groundwater Exchange (acre-ft)	Discharge from Keller Lake (acre-ft)	Change in Lake Volume (acre-ft)	Total Lake Volume at the End of the Period (acre-ft)	Lake Level at End of Period (ft MSL)
				+	-	+	+	-	-			
Steady State Year (May 1, 2005 - April 30, 2006)	5/1/2005	4/30/2006	251	155	115	817	0	533	315	8	259	934.4
(Oct 1, 2005 - April 30, 2006)	10/1/2005	4/30/2006	226	71	22	445	0	243	219	33	259	934.4
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/2/2006	259	0	1	0	0	4	2	-7	252	934.3
	5/3/2006	5/15/2006	252	4	8	17	0	25	0	-11	241	934.0
	5/16/2006	5/16/2006	241	0	1	0	0	2	0	-2	239	934.0
	5/17/2006	5/30/2006	239	1	8	2	0	26	0	-30	209	933.3
	5/31/2006	5/31/2006	209	0	1	0	0	2	0	-2	206	933.3
	6/1/2006	6/11/2006	206	1	8	6	0	19	0	-20	187	932.8
	6/12/2006	6/15/2006	187	0	3	0	0	5	0	-7	180	932.7
	6/16/2006	6/26/2006	180	9	8	42	0	15	0	28	208	933.3
	6/27/2006	6/28/2006	208	0	1	0	0	4	0	-5	203	933.2
	6/29/2006	7/5/2006	203	0	5	0	0	12	0	-17	186	932.8
	7/6/2006	7/9/2006	186	0	3	0	0	5	0	-8	178	932.6
	7/10/2006	7/23/2006	178	3	11	16	0	12	0	-4	174	932.5
	7/24/2006	7/24/2006	174	1	1	5	0	1	0	4	178	932.6
	7/25/2006	8/6/2006	178	15	9	93	0	18	10	72	251	934.2
	8/7/2006	8/10/2006	251	1	2	5	0	8	0	-4	247	934.2
	8/11/2006	8/20/2006	247	2	6	9	0	19	0	-13	233	933.9
	8/21/2006	8/28/2006	233	9	4	39	0	15	11	18	251	934.3
	8/29/2006	9/4/2006	251	4	3	19	0	14	4	2	253	934.3
	9/5/2006	9/7/2006	253	0	1	0	0	6	0	-7	246	934.2
	9/8/2006	9/18/2006	246	2	4	6	0	21	0	-17	230	933.8
	9/19/2006	9/20/2006	230	0	1	0	0	4	0	-4	225	933.7
	9/21/2006	10/1/2006	225	4	3	17	0	19	0	0	225	933.7
Total for Growing Season (June 1, 2006 - Sept 30, 2006)	6/1/2006	9/30/2006	206	52	72	257	0	194	25	19	225	933.7
Total for Water Year 2006 (Oct 1 , 2005 - Sept 30, 2006)	10/1/2005	9/30/2006	226	128	112	721	0	494	245	-1	225	933.7

Annual (2006 Water Year) Water Load to Keller Lake (acre-ft)	10/1/2005	9/30/2006	850	Water Load = B + D + E (See **Table 4-5** in the TMDL Report)

A - Based on the daily water balance model (calibrated to lake level data and using the lake stage-storage-discharge curve). See Appendix C-2.
B - Based on precipitation data used for the P8 modeling and the daily water balance model (Direct Precip Volume = Depth of Precip * Lake Surface Area) See Appendix C-15.
C - Based on adjusted pan evaporation data from the University of Minnesota St. Paul Campus Climatological Observatory and the daily water balance model (Evap Volume = 0.7 * Depth of Evap * Lake Surface Area). See Appendix C-6.
D - Based on the water loads from the P8 model. See Appendix C-15.
E - Existing Conditions assumes the ferric chloride system is no longer operating.
F - Groundwater exchange fit to 2008 lake levels and watershed conditions. The estimated groundwater exchange was applied to all climatic conditions.
G - Based on the estimated discharge from the Keller Lake daily water balance model
H - Change in Lake Volume = B - C + D + E - F - G
I - Total Lake Volume @ End of Period = A + H
J - Estimated lake level based on the total lake volume and the stage-storage-discharge curve. See Appendix C-2.

C-17: Keller Lake Average Climatic Conditions
Physical Parameter Summary
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

		A	B	C		D	E	F	G	H
Period		Atmos. Dep	Water Surface Elev	Depth to Thermocline		Elevation of Thermocline	Epilimnion Volume	Surface Area	Hypolimnion Volume	Hypolimnion Area
From	To	(lbs)	(ft MSL)	(m)	(ft)	(ft MSL)	(acft)	(acre)	(acft)	(ac)
5/1/05	4/30/06	12	934.4	1.8	5.9	928.5	207	53.1	52	20
5/1/06	5/2/06	0.0	934.3	1.8	5.9	928.4	203	52.7	50	19
5/3/06	5/15/06	0.4	934.0	1.8	5.9	928.1	198	51.5	44	17
5/16/06	5/16/06	0.0	934.0	1.8	5.9	928.1	196	51.2	43	17
5/17/06	5/30/06	0.4	933.3	1.8	5.9	927.4	182	47.9	27	13
5/31/06	5/31/06	0.0	933.3	1.8	5.9	927.4	181	47.6	26	12
6/1/06	6/11/06	0.3	932.8	1.8	5.9	926.9	171	45.5	15	10
6/12/06	6/15/06	0.1	932.7	1.8	5.9	926.8	168	44.7	12	8
6/16/06	6/26/06	0.3	933.3	1.8	5.9	927.4	181	47.8	26	13
6/27/06	6/28/06	0.0	933.2	1.8	5.9	927.3	179	47.2	24	12
6/29/06	7/5/06	0.2	932.8	1.8	5.9	926.9	171	45.4	15	9
7/6/06	7/9/06	0.1	932.6	1.8	5.9	926.7	167	44.5	11	8
7/10/06	7/23/06	0.4	932.5	1.8	5.9	926.6	165	44.1	9	8
7/24/06	7/24/06	0.0	932.6	1.8	5.9	926.7	167	44.6	11	8
7/25/06	8/6/06	0.4	934.2	1.8	5.9	928.3	202	52.5	49	19
8/7/06	8/10/06	0.1	934.2	1.8	5.9	928.3	200	52.1	47	18
8/11/06	8/20/06	0.3	933.9	1.8	5.9	928.0	194	50.6	40	16
8/21/06	8/28/06	0.2	934.3	2.0	6.6	927.7	218	52.6	34	15
8/29/06	9/4/06	0.2	934.3	1.8	5.9	928.4	203	52.7	50	19
9/5/06	9/7/06	0.1	934.2	1.8	5.9	928.2	200	52.0	46	18
9/8/06	9/18/06	0.3	933.8	1.8	5.9	927.9	192	50.2	38	16
9/19/06	9/20/06	0.0	933.7	1.8	5.9	927.8	190	49.7	35	15
9/21/06	10/1/06	0.3	933.6	1.8	5.9	927.7	189	49.4	34	15

A - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) (Barr, 2005) over the surface area of the lake: A = F * (0.000639 lb/ac/d) * (# of Days)
B - Based on the daily water balance model. See Appendix C-16 Column J
C - Estimated based on the available temperature profile data. See Appendix C-1.
D - Elevation of the Thermocline: D = B - C
E - Estimated using the lake stage-storage-discharge curve. See Appendix C-2.
F - Estimated using the lake stage-storage-discharge curve. See Appendix C-2.
G - Estimated using the lake stage-storage-discharge curve. See Appendix C-2.
H - Estimated using the lake stage-storage-discharge curve. See Appendix C-2.

C-18: Keller Lake Average Climatic Conditions
P8 Particle Class Settling - Estimated Number of Days to Settle Out of Epilimnion & Watershed TP Loads
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

			Number of Days to Settle P8 Particle Class[1,2,3]					
P8 Particle Class			P10	P30	P50	P80		
P8 Settling Velocity			vs = 0.03 ft/hr	vs = 0.3 ft/hr	vs = 1.5 ft/hr	vs = 15 ft/hr		
Sample Period		Epilimnion Depth (De)[4] (ft)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Total Watershed TP Load before Particle Settling (lbs)	Watershed TP Load after Particle Settling[2,3] (lbs)
5/1/2006	5/2/2006	5.9	8	1	0	0	0.0	0.0
5/3/2006	5/15/2006	5.9	8	1	0	0	9.8	6.6
5/16/2006	5/16/2006	5.9	8	1	0	0	0.0	0.0
5/17/2006	5/30/2006	5.9	8	1	0	0	3.0	1.4
5/31/2006	5/31/2006	5.9	8	1	0	0	0.0	0.0
6/1/2006	6/11/2006	5.9	8	1	0	0	7.8	3.7
6/12/2006	6/15/2006	5.9	8	1	0	0	0.1	0.1
6/16/2006	6/26/2006	5.9	8	1	0	0	31.4	16.5
6/27/2006	6/28/2006	5.9	8	1	0	0	0.0	0.0
6/29/2006	7/5/2006	5.9	8	1	0	0	0.0	0.0
7/6/2006	7/9/2006	5.9	8	1	0	0	0.0	0.0
7/10/2006	7/23/2006	5.9	8	1	0	0	15.4	7.8
7/24/2006	7/24/2006	5.9	8	1	0	0	5.7	5.7
7/25/2006	8/6/2006	5.9	8	1	0	0	43.3	35.3
8/7/2006	8/10/2006	5.9	8	1	0	0	3.9	3.9
8/11/2006	8/20/2006	5.9	8	1	0	0	7.5	4.3
8/21/2006	8/28/2006	5.9	8	1	0	0	24.9	16.4
8/29/2006	9/4/2006	6.6	9	1	0	0	14.5	8.6
9/5/2006	9/7/2006	5.9	8	1	0	0	0.0	0.0
9/8/2006	9/18/2006	5.9	8	1	0	0	5.2	3.3
9/19/2006	9/20/2006	5.9	8	1	0	0	0.0	0.0
9/21/2006	10/1/2006	5.9	8	1	0	0	10.3	5.0

1 - Number of Days to Settle Particles = De/vs/24

2 - The P0 particle class in P8 reflects the non-settleable (or dissolved) fraction of the particles. See additional details in Appendix A-3.

3 - The pollutant loading in P8 is based on the build-up and wash-off of particles. There are 5 particle size classes, each with a mass of pollutant associated with it (e.g. phosphorus) as well as a settling velocity. The majority of the phosphorus is associated with the P0 (or non-settleable fraction). The in-lake mass balance model tracks the mass of each particle size class (from the P8 model) and determines how long the particles will remain in the epilimnion (thus impacting observed water quality). The model considers the number of days between the water quality sampling dates and the prior storm events, and only includes the phosphorus load from those particles that would remain in the epilimnion during that period. See Appendix C-15 for a table summarizing the P8 event TP loads.
4 - Epilimnion Depth from Appendix C-17 Column C

C-19: In-Lake Steady State Summary
Keller Lake - 2006 (2008 Watershed Conditions, no ferric chloride system)

Parameter	Value[1]	Comments
L=Areal Load (mg/m²/yr) From May to May	1086.2	(Watershed Load + Atmospheric Load) / Surface Area
Point Source Loading (mg/yr)	0.0	
Watershed Load (mg/yr)	225565477.5	P8 Watershed Load[2] + Upstream Source Loads[3]
Atmosperic Load (mg/yr)	5564491.4	Atmospheric Deposition Rate * Surface Area = 0.2915 kg/ha/yr * Surface Area
qs =Overflow Rate (m/yr)	5.0	Outflow / Surface Area
V=Volume (m³)	309921.8	Lake Volume[4]
A=Surface Area (m²)	212791.3	Surface Area[4]
td= Residence Time (yr)	0.3	Volume / Outflow
z= mean Depth (m)	1.5	Volume / Surface Area
Q=Outflow (m³/yr)	1065179.5	Inflow = Watershed Runoff + Upstream Inflows + Direct Precip = Outflow
r =Flushing Rate (yr-1)	3.4	1 / Residence Time
	Predicted TP Conc (ug/L)	
Reckow [P] =Lext/(11.6+1.2*qs)	62	**See Table 4-2 in the TMDL Report**

1 - Based on May 1,2005 through April 30, 2006

2 - See Appendix C-24 Column A

3 - See Appendix C-24 Column C

4 - At Normal Water Level; See Appendix C-2

$$P = \frac{L}{(11.6 + 1.2 * q_s)}$$

where:

P = total phosphorus concentration at the beginning of the open water season (µg/L)

L = areal total phosphorus loading rate (mg/m²/yr)

q_s = annual areal water outflow load (m/yr)

= Q/A

Q = annual outflow (m³/yr)

A = lake surface area (m²)

C-20: Keller Lake - Average Climatic Condition Existing Conditions - In-Lake Growing Season Mass Balance Model Summary[1]

Period Start		A	B	C	D	E	F	G	H	I	J	K
		Epilimnion Volume	P In-Lake @ Start of Period	P Surface Runoff (after Particulate Settling)[5]	P From Upstream Sources	P Atmospheric	P Release from Curlyleaf Pondweed	P Adjustment Load[6]	P Uptake by Coontail	P Loss due to Discharge	P In-Lake @ End of Period	Predicted In-Lake P[2]
		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/L
Steady State Total (May 1, 2005 - April 30, 2006)[3,7]		N/A	N/A	496	0	12	N/A[4]	N/A	N/A[4]	142	N/A	N/A
(Oct 1, 2005 - April 30, 2006)[3,7]		207	N/A	238	0	8	0[4]	N/A	0[4]	77	N/A	62
5/1/2006	5/2/2006	203	34.7	0.0	0.0	0.0	0.0	-13.4	0.5	0.9	20.0	36
5/3/2006	5/15/2006	198	20.0	6.6	0.0	0.4	0.0	-0.4	3.1	2.4	21.1	39
5/16/2006	5/16/2006	196	21.1	0.0	0.0	0.0	0.0	-2.4	0.2	0.2	18.2	34
5/17/2006	5/30/2006	182	18.2	1.4	0.0	0.4	0.0	10.6	3.3	2.4	24.9	50
5/31/2006	5/31/2006	181	24.9	0.0	0.0	0.0	0.0	-3.5	0.2	0.2	20.9	43
6/1/2006	6/11/2006	171	20.9	3.7	0.0	0.3	0.0	20.0	3.0	2.2	39.8	85
6/12/2006	6/15/2006	168	39.8	0.1	0.0	0.1	0.0	0.1	1.2	1.2	37.7	83
6/16/2006	6/26/2006	181	37.7	16.5	0.0	0.3	3.0	-12.1	3.8	3.3	38.3	78
6/27/2006	6/28/2006	179	38.3	0.0	0.0	0.0	4.1	7.7	0.8	0.7	48.7	100
6/29/2006	7/5/2006	171	48.7	0.0	0.0	0.2	16.9	33.0	2.8	3.1	92.8	200
7/6/2006	7/9/2006	167	92.8	0.0	0.0	0.1	8.2	13.3	1.7	2.6	110.0	242
7/10/2006	7/23/2006	165	110.0	7.8	0.0	0.4	15.8	26.2	6.1	8.1	146.1	325
7/24/2006	7/24/2006	167	146.1	5.7	0.0	0.0	0.6	-65.6	0.4	0.8	85.5	188
7/25/2006	8/6/2006	202	85.5	35.3	0.0	0.4	4.0	0.4	5.9	13.9	105.8	193
8/7/2006	8/10/2006	200	105.8	3.9	0.0	0.1	0.5	1.8	1.9	4.0	106.1	195
8/11/2006	8/20/2006	194	106.1	4.3	0.0	0.3	0.6	-4.6	4.8	10.1	91.7	174
8/21/2006	8/28/2006	218	91.7	16.4	0.0	0.2	0.2	35.4	4.0	12.4	127.6	216
8/29/2006	9/4/2006	203	127.6	8.6	0.0	0.2	0.1	-25.0	3.6	10.6	97.3	176
9/5/2006	9/7/2006	200	97.3	0.0	0.0	0.1	0.0	-25.7	1.5	2.8	67.4	124
9/8/2006	9/18/2006	192	67.4	3.3	0.0	0.3	0.0	78.2	5.8	7.0	136.4	261
9/19/2006	9/20/2006	190	136.4	0.0	0.0	0.0	0.0	-55.0	1.1	2.6	77.7	151
9/21/2006	10/1/2006	189	77.7	5.0	0.0	0.3	0.0	7.0	6.0	8.4	75.6	147
Growing Season Total (June 1, 2006 - Sept 30, 2006)[7]		N/A	N/A	111	0	3	54	35	55	94	N/A	N/A
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[3,7]		N/A	N/A	357	0	12	54	26	62	177	N/A	N/A
Predictive Mass Balance Equation: Ppredict = Pinitial + Psurf + Pus + Patm + Pclpw + Padj - Pcoon - Pdis											**Growing Season Average[2]**	**167**

1 - Reflective of in-lake water quality model existing conditions (2008 watershed conditions, ferric chloride system not operating)
2 - Growing Season Average includes monitoring data from 5/31/2006; See observed, calibrated, and predicted in-lake TP concentrations in Table 4-2 in the TMDL Report.
3 - An empirical model (Reckhow, 1977) was used to predict the steady state phosphorus concentration at the beginning of the phosphorus mass balance model developed for the period from May 1, 2006 - September 30,
4 - Phosphorus release from Curlyleaf pondweed and uptake by coontail was not estimated for the Steady State year because phosphorus mass balance modeling was not performed for the period from May 1, 2005 - April 30, 2006. Also, it was assumed that during the period from October 1 - April 30 the phosphorus loading due to Curlyleaf pondweed and uptake by coontail would be negligible due to the growth/die back cycles of these
5 - The reported phosphorus load associated with surface runoff during the Steady State period, as well as the period from October 1, 2005 - April 30, 2006 reflects the total watershed runoff load, not the phosphorus load after particulate settling. Therefore the total water year load in this table is not reflective of the Total Phosphorus Load from watershed runoff as reported in Appendix C-24.
6 - The growing season and water year total phosphorus adjustment values represents the net phosphorus adjustment (including both phosphorus loads to the lake as well as losses such as sedimentation). The total phosphorus adjustment will not match the total "internal loading from other sources" in Appendix C-24 as that table only summarizes the (positive) loads to the lake.
7 - For Total Loads, total rounded to the nearest pound for reporting purposes.
A - See Appendix C-17, Column E. The epilimnion volume represents the predicted epilimnion volume at the end of the time period.
B - Amount of phosphorus present in lake at the beginning of the timestep (based on spring steady state or observed TP concentration and epilimnetic volume from the previous timestep).
C - Based on the Watershed TP Load after Particle Settling. See Appendix C-18.
D - Assumes the ferric chloride system is no longer operating and pumping from Crystal to Keller Lake does not occur. See Appendix C-21.
E - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake
F - Based on a phosphorus release rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information multiplied by a factor to account for the increase in CLPW density due to FeCl3 system not operating. See Appendix C-22.
G - Based on the calibrated water quality model residual adjustment TP loads. The Residual Adjustment is the calibration parameter used to describe the internal phosphorus loads to the lake not explicitly estimated (e.g. release from bottom sediments, resuspension due to fish activity or wind, etc.), to estimate the uptake of phosphorus from the water column by algae growth, to estimate sedimentation of phosphorus from the water column,
H - Based on average daily uptake rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Appendix B-23.
I - Discharge from the lake includes surface discharge and losses to groundwater, multiplied by the total phosphorus concentration from the previous time period. See Appendices C-24.
J - P in the lake at the end of the period = B + C + D + E + F + G - H - I
K - Predicted In-Lake P = K * A * 0.00272

C-21: Keller Lake Summary of Upstream Loads and Discharges
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

		A	B	C	D	E	F	G	H	I	J
		Upstream Inflows			Discharges						
Period		Pumping from Crystal Lake	Pumping from Crystal Lake [TP]	Pumping from Crystal Lake Load	Surface Discharge	Discharge [TP]	Surface Discharge	Groundwater Discharge	Discharge [TP]	Groundwater Discharge	Total Discharge
From	To	(acft)	(µg/L)	(lbs)	(acre-ft)	(µg/L)	(lbs)	(acre-ft)	(µg/L)	(lbs)	(lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[1,2]		0	16	0	315	62	53	533	62	89	142
(Oct 1, 2005 - April 30, 2006)[1,2]		0	16	0	219	62	37	243	62	41	77
5/1/2006	5/2/2006	0	16	0.0	2	62	0.3	4	62	0.7	0.9
5/3/2006	5/15/2006	0	16	0.0	0	36	0.0	25	36	2.4	2.4
5/16/2006	5/16/2006	0	16	0.0	0	39	0.0	2	39	0.2	0.2
5/17/2006	5/30/2006	0	16	0.0	0	34	0.0	26	34	2.4	2.4
5/31/2006	5/31/2006	0	16	0.0	0	50	0.0	2	50	0.2	0.2
6/1/2006	6/11/2006	0	16	0.0	0	43	0.0	19	43	2.2	2.2
6/12/2006	6/15/2006	0	16	0.0	0	85	0.0	5	85	1.2	1.2
6/16/2006	6/26/2006	0	16	0.0	0	83	0.0	15	83	3.3	3.3
6/27/2006	6/28/2006	0	16	0.0	0	78	0.0	4	78	0.7	0.7
6/29/2006	7/5/2006	0	16	0.0	0	100	0.0	12	100	3.1	3.1
7/6/2006	7/9/2006	0	16	0.0	0	200	0.0	5	200	2.6	2.6
7/10/2006	7/23/2006	0	16	0.0	0	242	0.0	12	242	8.1	8.1
7/24/2006	7/24/2006	0	16	0.0	0	325	0.0	1	325	0.8	0.8
7/25/2006	8/6/2006	0	16	0.0	10	188	4.9	18	188	9.0	13.9
8/7/2006	8/10/2006	0	16	0.0	0	193	0.0	8	193	4.0	4.0
8/11/2006	8/20/2006	0	16	0.0	0	195	0.0	19	195	10.1	10.1
8/21/2006	8/28/2006	0	16	0.0	11	174	5.1	15	174	7.3	12.4
8/29/2006	9/4/2006	0	16	0.0	4	216	2.6	14	216	7.9	10.6
9/5/2006	9/7/2006	0	16	0.0	0	176	0.0	6	176	2.8	2.8
9/8/2006	9/18/2006	0	16	0.0	0	124	0.0	21	124	7.0	7.0
9/19/2006	9/20/2006	0	16	0.0	0	261	0.0	4	261	2.6	2.6
9/21/2006	10/1/2006	0	16	0.0	0	151	0.0	21	151	8.4	8.4
Growing Season Total (May 1, 2006 - Sept 30, 2006)[2]				**0**			**13**			**81**	**94**
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[2]				**0**			**50**			**128**	**177**

1 - A phosphorus mass balance was not performed specifically for the Steady State period (May 1, 2005 - April 30, 2006). An empirical model (Reckow, 1977) was used to predict the steady state phosphorus concentration used as the starting concentration for the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006. See Appendix C-19.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.
A - Based on daily water balance model. See Appendix C-16, Column E
B - Based on average total dissolved phosphorus data in the channel.
C - Pumping from Crystal Load = A * B * 0.00272
D - Based on daily water balance model. See Appendix C-16, Column G
E - In-lake TP Concentration from the previous time step
F - Surface Discharge = D * E * 0.00272
G - Based on daily water balance model. See Appendix C-16, Column F
H - In-lake TP Concentration from the previous time step
I - Groundwater Discharge = G * H * 0.00272
J - Total Discharge = F + I

C-22: Keller Lake Average Climatic Conditions

Curlyleaf Pondweed Phosphorus Release (Existing Conditions; No Ferric Chloride System)

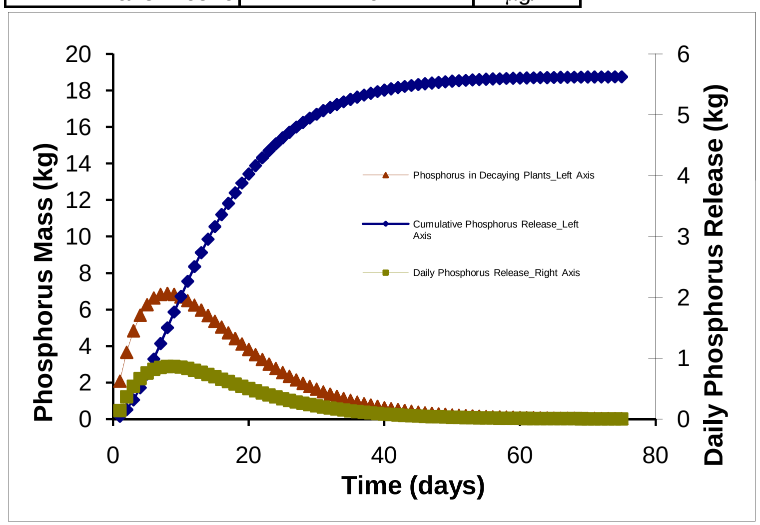
Macrophyte Area = 52.6 acres

% Covered w/Curlyleaf[1] 84% ==> Curlyleaf Area = 44.2

1 - Based on 2006 Macrophyte Survey

Curlyleaf load based on est density

Stem Density	150	stem/m²	(McComas; Barr, 2001)
Mat/stem	0.35	g/stem	(Barr, 2001)
P Content	2000	mg P/kg	(Barr, 2001)
	0.2%		
Areal P load	105	mg/m²	
P Load	41.4	lbs	
In-lake P conc	77.0	µg/L	



Internal Loading from Curlyleaf Pondweed

Increase in CLPW density due to FeCl3 system not operating[2]: 1.306

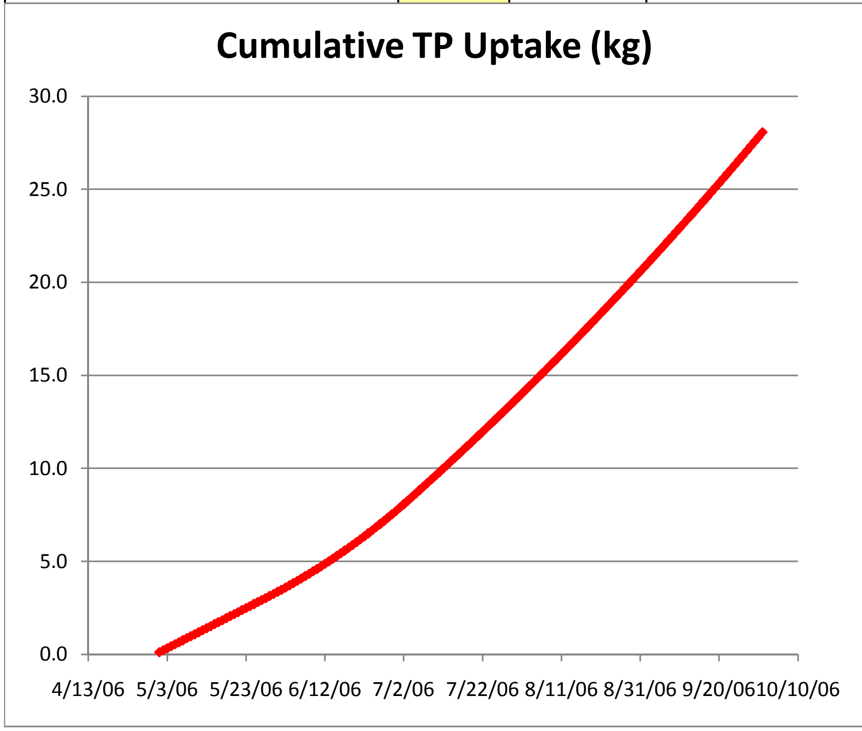
Date	Cumulative Load (kg)	Cumulative Load (lbs)	Adjusted Incremental Load (lbs)
4/30/06	#N/A	0	0.0
5/2/06	#N/A	0	0.0
5/15/06	#N/A	0	0.0
5/16/06	#N/A	0	0.0
5/30/06	#N/A	0	0.0
5/31/06	#N/A	0	0.0
6/11/06	#N/A	0	0.0
6/15/06	#N/A	0	0.0
6/26/06	1.0	2.3	3.0
6/28/06	2.5	5.4	4.1
7/5/06	8.3	18.4	16.9
7/9/06	11.2	24.6	8.2
7/23/06	16.7	36.7	15.8
7/24/06	16.9	37.2	0.6
8/6/06	18.3	40.2	4.0
8/10/06	18.5	40.6	0.5
8/20/06	18.7	41.1	0.6
8/28/06	18.7	41.2	0.2
9/4/06	18.7	41.2	0.1
9/7/06	18.8	41.3	0.0
9/18/06	18.8	41.3	0.0
9/20/06	18.8	41.3	0.0
10/1/06	18.8	41.3	0.0
		Total CLPW Load (lbs)	54

2 - Estimated adjustment factor based on a comparison of macrophyte (Curlyleaf Pondweed) surveys for years when the ferric chloride system was and was not operating.

P:\Mpls\23 MN\19\2319A79 Crystal, Keller, Lee & Earley\WorkFiles\InLake_Modeling\TMDL\Keller_InLake\BMPs\KellerLake_2006Avg_KL1A.xls

C-23: Keller Lake Average Climatic Conditions
Coontail Phosphorus Uptake (Existing Conditions; No Ferric Chloride System)

Date Coontail Uptake Begins	5/1/2006			Date of Aq Plant Survey #	5/28/2006	Based on 2006 Macrophyte Survey
Maximum Coontail Plant Density	1324	g (wet weight)/m²	(LCMR, 2001; Newman, 2004)	% Covered w/ Coontail	57	Based on 2006 Macrophyte Survey
Macrophyte Area =	52.58	Ac		Coontail Density (0-5)	2	Based on 2006 Macrophyte Survey
% Covered w/Coontail at Date Coontail Uptake Begins	57		Based on 2006 Macrophyte Survey	Date of Aq Plant Survey #	8/13/2006	Based on 2006 Macrophyte Survey
Coontail Density at Date Coontail Uptake Begins (0-5)	2		Based on 2006 Macrophyte Survey	% Covered w/ Coontail	97	Based on 2006 Macrophyte Survey
				Coontail Density (0-5)	3.7	Based on 2006 Macrophyte Survey
				Coontail Uptake Rate	1.68	(Lombardo & Cooke, 2003)



Internal Uptake from Coontail

Date	Cumulative Load (kg)	Cumulative Load (lbs)	Incremental Load (lbs)
4/30/06	#N/A	0	0.0
5/2/06	0	0	0.5
5/15/06	2	4	3.1
5/16/06	2	4	0.2
5/30/06	3	7	3.3
5/31/06	3	7	0.2
6/11/06	5	10	3.0
6/15/06	5	12	1.2
6/26/06	7	15	3.8
6/28/06	7	16	0.8
7/5/06	9	19	2.8
7/9/06	9	21	1.7
7/23/06	12	27	6.1
7/24/06	12	27	0.4
8/6/06	15	33	5.9
8/10/06	16	35	1.9
8/20/06	18	40	4.8
8/28/06	20	44	4.0
9/4/06	22	47	3.5
9/7/06	22	49	1.5
9/18/06	25	55	5.8
9/20/06	25	56	1.1
10/1/06	28	62	6.0

C-24: Keller Lake Average Climatic Conditions
Phosphorus Load Summary
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

			A	B	C	D	E	F	G	H
			External TP Load				Internal TP Load			
	Sample Period		Watershed TP Load (lbs)	Atmospheric Deposition (lbs)	Pumping from Crystal Lake (lbs)	Total External TP Load (lbs)	Curlyleaf Pondweed (lbs)	Other Internal Sources (lbs)	Total Internal TP Load (lbs)	Total TP Load (lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[2]	5/1/2005	4/30/2006	495	12	0	507	N/A[1]	N/A[1]	N/A[1]	***507***
(Oct 1, 2005 - April 30, 2006)[2]	10/1/2005	4/30/2006	238	8	0	246	0	0	0	***246***
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/2/2006	0.0	0.0	0.0	0.0	0.0	0.0	0.0	***0.0***
	5/3/2006	5/15/2006	9.8	0.4	0.0	10.2	0.0	0.0	0.0	***10.2***
	5/16/2006	5/16/2006	0.0	0.0	0.0	0.0	0.0	0.0	0.0	***0.0***
	5/17/2006	5/30/2006	3.0	0.4	0.0	3.4	0.0	10.6	10.6	***14.0***
	5/31/2006	5/31/2006	0.0	0.0	0.0	0.0	0.0	0.0	0.0	***0.0***
	6/1/2006	6/11/2006	7.8	0.3	0.0	8.1	0.0	20.0	20.0	***28.1***
	6/12/2006	6/15/2006	0.1	0.1	0.0	0.2	0.0	0.1	0.1	***0.4***
	6/16/2006	6/26/2006	31.4	0.3	0.0	31.7	3.0	0.0	3.0	***34.7***
	6/27/2006	6/28/2006	0.0	0.0	0.0	0.0	4.1	7.7	11.8	***11.8***
	6/29/2006	7/5/2006	0.0	0.2	0.0	0.2	16.9	33.0	49.9	***50.1***
	7/6/2006	7/9/2006	0.0	0.1	0.0	0.1	8.2	13.3	21.5	***21.6***
	7/10/2006	7/23/2006	15.5	0.4	0.0	15.8	15.8	26.2	42.1	***57.9***
	7/24/2006	7/24/2006	5.7	0.0	0.0	5.7	0.6	0.0	0.6	***6.2***
	7/25/2006	8/6/2006	43.3	0.4	0.0	43.7	4.0	0.4	4.4	***48.0***
	8/7/2006	8/10/2006	3.9	0.1	0.0	4.0	0.5	1.8	2.2	***6.2***
	8/11/2006	8/20/2006	7.5	0.3	0.0	7.8	0.6	0.0	0.6	***8.4***
	8/21/2006	8/28/2006	24.9	0.2	0.0	25.2	0.2	35.4	35.5	***60.7***
	8/29/2006	9/4/2006	14.5	0.2	0.0	14.7	0.1	0.0	0.1	***14.7***
	9/5/2006	9/7/2006	0.0	0.1	0.0	0.1	0.0	0.0	0.0	***0.1***
	9/8/2006	9/18/2006	5.2	0.3	0.0	5.5	0.0	78.2	78.2	***83.7***
	9/19/2006	9/20/2006	0.0	0.0	0.0	0.0	0.0	0.0	0.0	***0.0***
	9/21/2006	10/1/2006	10.3	0.3	0.0	10.6	0.0	7.0	7.0	***17.5***
Growing Season (June 1, 2006 - Sept 30, 2006)[2]	**6/1/2006**	**10/1/2006**	**170**	**3**	**0**	**173**	**54**	**223**	**277**	***450***
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[2]	**10/1/2005**	**9/30/2006**	**422**	**12**	**0**	**434**	**54**	**234**	**288**	***722***
	TMDL Report References		**Table 5-6**	**Table 5-6**	**Table 5-6**	**Table 4-5**		**Table 4-6**	**Table 4-5; Table 5-6**	**Table 5-6**

1 - The empirical steady-state equations used to estimate the phosphorus concentration in the lake at the beginning of the mass balance calibration period were originally developed based on external phosphorus loadings only; therefore, internal loading for this period was not estimated. See Appendix C-19.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.

A - Based on P8 TP Load. See Appendix C-15.

B - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake. See Appendix C-17.

C - Load from Upstream Source = Water Load * [TP]. See Appendix C-21.

D - External Load = A + B + C

E - See Appendix C-22.

F - Load back-calculated as part of the mass balance model calibration. Assumes that internal loading happens only during the calibration period (May 1 - Sept 30) to reflect the available monitoring data. This summary table includes only the estimated phosphorus loads to the lake (estimated losses assumed to be zero). See Appendix C-20 Column G.

G - Internal Load = E + F

H - Total TP Load = D + G

C-25: Keller Lake - Average Climatic Condition Phosphorus Reduction Required to Estimate TMDL Load Capacity
Reduction Required to Meet MPCA Standard of 60 ug/L

TP Load Reduction (%)[1]		A	B	C	D	E	F	G	H	I	J	K
58.9		Epilimnion Volume	P In-Lake @ Start of Period	P Surface Runoff (after Particulate Settling)[6]	P From Upstream Sources	P Atmospheric	P Release from Curlyleaf Pondweed	P Adjustment Load	P Uptake by Coontail	P Loss due to Discharge	P In-Lake @ End of Period	Predicted In-Lake P
		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/L
(Oct 1, 2005 - April 30, 2006)[5,7]		207	N/A	238	0	8	0[4]	N/A	0[4]	77	N/A	62
5/1/06	5/2/06	203	34.7	0.0	0.0	0.0	0.0	-13.4	0.5	0.9	20.0	36
5/3/06	5/15/06	198	20.0	2.7	0.0	0.4	0.0	-0.3	3.1	2.4	17.2	32
5/16/06	5/16/06	196	17.2	0.0	0.0	0.0	0.0	-2.0	0.2	0.2	14.8	28
5/17/06	5/30/06	182	14.8	0.6	0.0	0.4	0.0	4.4	3.3	1.9	14.9	30
5/31/06	5/31/06	181	14.9	0.0	0.0	0.0	0.0	-2.1	0.2	0.1	12.4	25
6/1/06	6/11/06	171	12.4	1.5	0.0	0.3	0.0	8.2	3.0	1.3	18.2	39
6/12/06	6/15/06	168	18.2	0.1	0.0	0.1	0.0	0.1	1.2	0.5	16.6	36
6/16/06	6/26/06	181	16.6	6.8	0.0	0.3	1.2	-4.7	3.8	1.4	15.0	30
6/27/06	6/28/06	179	15.0	0.0	0.0	0.0	1.7	3.2	0.8	0.3	18.8	39
6/29/06	7/5/06	171	18.8	0.0	0.0	0.2	6.9	13.6	2.8	1.2	35.4	76
7/6/06	7/9/06	167	35.4	0.0	0.0	0.1	3.4	5.5	1.7	1.0	41.6	92
7/10/06	7/23/06	165	41.6	3.2	0.0	0.4	6.5	10.8	6.1	3.0	53.3	119
7/24/06	7/24/06	167	53.3	2.3	0.0	0.0	0.2	-23.9	0.4	0.3	31.2	69
7/25/06	8/6/06	202	31.2	14.5	0.0	0.4	1.6	0.2	5.9	5.1	36.9	67
8/7/06	8/10/06	200	36.9	1.6	0.0	0.1	0.2	0.7	1.9	1.4	36.2	67
8/11/06	8/20/06	194	36.2	1.8	0.0	0.3	0.2	-1.5	4.8	3.5	28.8	55
8/21/06	8/28/06	218	28.8	6.8	0.0	0.2	0.1	14.5	4.0	3.9	42.6	72
8/29/06	9/4/06	203	42.6	3.5	0.0	0.2	0.0	-8.0	3.6	3.5	31.2	56
9/5/06	9/7/06	200	31.2	0.0	0.0	0.1	0.0	-8.0	1.5	0.9	20.9	38
9/8/06	9/18/06	192	20.9	1.3	0.0	0.3	0.0	32.1	5.8	2.2	46.7	90
9/19/06	9/20/06	190	46.7	0.0	0.0	0.0	0.0	-18.5	1.1	0.9	26.2	51
9/21/06	10/1/06	189	26.2	2.1	0.0	0.3	0.0	2.9	6.0	2.8	22.6	44
Growing Season Total (June 1, 2006 - Sept 30, 2006)[7]		N/A	N/A	45	0	3	22	27	55	33	N/A	N/A
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[7]		N/A	N/A	287	0	12	22	14	62	116	N/A	N/A

Growing Season Average (ug/L)[2]	**60**
Growing Season Average Chlorophyll-*a* (ug/L)[3]	**19.8**
Growing Season Average Secchi Depth (m)[4]	**1.3**

Predictive Mass Balance Equation: Ppredict = Pinitial + Psurf + Pus + Patm + Pclpw + Pint - Pcoon - Pdis

1 - To estimate the Loading Capacity (and the required reduction in existing TP loads), P Surface Runoff, P Release from Curlyleaf Pondweed, and P Adjustment Load (See Note G), were reduced equally until the MPCA standard was met.

2 - Growing Season Average includes predicted data from 5/31/2006

3 - Based on Chla vs TP water quality relationship (Chla = 0.5672 * TP - 14.187). See Figure 3-11.

4 - Based on SD vs TP water quality relationship (SD = 14.282 * TP ^ (-0.577)). See Figure 3-10.

5 - To estimate the load reduction, it was assumed that the steady-state concentration in the lake at the beginning of the season (May 1) was not impacted by the estimated reductions in total phosphorus loads (same as existing conditions).

6 - Because the phosphorus mass balance modeling was not performed for the period from October 1, 2005 - April 30, 2006, the reported value reflects the total watershed runoff load, not the phosphorus load after particulate settling.

7 - For Total Loads, total rounded to the nearest pound for reporting purposes.

A - See Appendix C-20. The epilimnion volume represents the predicted epilimnion volume at the end of the time period.

B - See Appendix C-20.

C - P load from surface runoff (See Appendix C-20, Column C) reduced by the TP Load Reduction percentage for all timesteps.

D - Assumes the ferric chloride system is no longer operating. See Appendix C-27.

E - See Appendix C-20.

F - P load from Curlyleaf Pondweed (See Appendix C-20, Column F) reduced by the TP Load Reduction percentage for all timesteps.

G - P load adjustment sources (positive values) reduced by TP Load Reduction percentage while P load adjustment sinks (negative values) reduced proportionately based on the mass of TP in epilimnion for individual timesteps.

H - See Appendix C-20.

I - Discharge from the lake includes surface discharge and losses to groundwater multiplied by the total phosphorus concentration from the previous time period.

J - P In-Lake @ End of Period = B + C + D + E + F + G - H - I

K - Predicted In-Lake P = J / A / 0.00272

C-26: Keller Lake - Average Climatic Condition Phosphorus Reduction Required to Estimate TMDL Load Capacity
Reduction Required to Meet MPCA Standard of 54 ug/L (10% MOS)

TP Load Reduction (%)[1]		A	B	C	D	E	F	G	H	I	J	K
62.2		Epilimnion Volume[2]	P In-Lake @ Start of Period	P Surface Runoff (after Particulate Settling)[6]	P From Upstream Sources	P Atmospheric	P Release from Curlyleaf Pondweed	P Adjustment Load	P Uptake by Coontail	P Loss due to Discharge	P In-Lake @ End of Period	Predicted In-Lake P
		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/L
(Oct 1, 2005 - April 30, 2006)[5,7]		207	N/A	238	0	8	0[4]	N/A	0[4]	77	N/A	62
5/1/06	5/2/06	203	34.7	0.0	0.0	0.0	0.0	-13.4	0.5	0.9	20.0	36
5/3/06	5/15/06	198	20.0	2.5	0.0	0.4	0.0	-0.3	3.1	2.4	17.0	32
5/16/06	5/16/06	196	17.0	0.0	0.0	0.0	0.0	-2.0	0.2	0.2	14.7	27
5/17/06	5/30/06	182	14.7	0.5	0.0	0.4	0.0	4.0	3.3	1.9	14.3	29
5/31/06	5/31/06	181	14.3	0.0	0.0	0.0	0.0	-2.0	0.2	0.1	12.0	24
6/1/06	6/11/06	171	12.0	1.4	0.0	0.3	0.0	7.6	3.0	1.2	17.0	36
6/12/06	6/15/06	168	17.0	0.1	0.0	0.1	0.0	0.0	1.2	0.5	15.4	34
6/16/06	6/26/06	181	15.4	6.2	0.0	0.3	1.1	-4.3	3.8	1.3	13.6	28
6/27/06	6/28/06	179	13.6	0.0	0.0	0.0	1.5	2.9	0.8	0.3	17.1	35
6/29/06	7/5/06	171	17.1	0.0	0.0	0.2	6.4	12.5	2.8	1.1	32.2	69
7/6/06	7/9/06	167	32.2	0.0	0.0	0.1	3.1	5.0	1.7	0.9	37.8	83
7/10/06	7/23/06	165	37.8	2.9	0.0	0.4	6.0	9.9	6.1	2.8	48.1	107
7/24/06	7/24/06	167	48.1	2.1	0.0	0.0	0.2	-21.6	0.4	0.3	28.1	62
7/25/06	8/6/06	202	28.1	13.3	0.0	0.4	1.5	0.1	5.9	4.6	33.0	60
8/7/06	8/10/06	200	33.0	1.5	0.0	0.1	0.2	0.7	1.9	1.3	32.3	59
8/11/06	8/20/06	194	32.3	1.6	0.0	0.3	0.2	-1.3	4.8	3.1	25.3	48
8/21/06	8/28/06	218	25.3	6.2	0.0	0.2	0.1	13.4	4.0	3.4	37.8	64
8/29/06	9/4/06	203	37.8	3.3	0.0	0.2	0.0	-7.1	3.6	3.1	27.5	50
9/5/06	9/7/06	200	27.5	0.0	0.0	0.1	0.0	-7.0	1.5	0.8	18.3	34
9/8/06	9/18/06	192	18.3	1.2	0.0	0.3	0.0	29.5	5.8	1.9	41.7	80
9/19/06	9/20/06	190	41.7	0.0	0.0	0.0	0.0	-16.5	1.1	0.8	23.3	45
9/21/06	10/1/06	189	23.3	1.9	0.0	0.3	0.0	2.6	6.0	2.5	19.6	38
Growing Season Total (June 1, 2006 - Sept 30, 2006)[7]		N/A	N/A	42	0	3	20	27	55	30	N/A	N/A
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[7]		N/A	N/A	283	0	12	20	13	62	113	N/A	N/A
											Growing Season Average (ug/L)[2]	**54**
											Growing Season Average Chlorophyll-*a* (ug/L)[3]	**16.4**
											Growing Season Average Secchi Depth (m)[4]	**1.4**

Predictive Mass Balance Equation: Ppredict = Pinitial + Psurf + Pus + Patm + Pclpw + Pint - Pcoon - Pdis

1 - To estimate the Loading Capacity (and the required reduction in existing TP loads), P Surface Runoff, P Release from Curlyleaf Pondweed, and P Adjustment Load (See Note G), were reduced equally until the MPCA standard was met.

2 - Growing Season Average includes predicted data from 5/31/2006

3 - Based on Chla vs TP water quality relationship (Chla = 0.5672 * TP - 14.187). See Figure 3-11.

4 - Based on SD vs TP water quality relationship (SD = 14.282 * TP ^ (-0.577)). See Figure 3-10.

5 - To estimate the load reduction, it was assumed that the steady-state concentration in the lake at the beginning of the season (May 1) was not impacted by the estimated reductions in total phosphorus loads (same as existing conditions).

6 - Because the phosphorus mass balance modeling was not performed for the period from October 1, 2005 - April 30, 2006, the reported value reflects the total watershed runoff load, not the phosphorus load after particulate settling.

7 - For Total Loads, total rounded to the nearest pound for reporting purposes.

A - See Appendix C-20. The epilimnion volume represents the predicted epilimnion volume at the end of the time period.

B - See Appendix C-20.

C - P load from surface runoff (See Appendix C-20, Column C) reduced by the TP Load Reduction percentage for all timesteps.

D - Assumes the ferric chloride system is no longer operating. See Appendix C-27.

E - See Appendix C-20.

F - P load from Curlyleaf Pondweed (See Appendix C-20, Column F) reduced by the TP Load Reduction percentage for all timesteps.

G - P load adjustment sources (positive values) reduced by TP Load Reduction percentage while P load adjustment sinks (negative values) reduced proportionately based on the mass of TP in epilimnion for individual timesteps.

H - See Appendix C-20.

I - Discharge from the lake includes surface discharge and losses to groundwater multiplied by the total phosphorus concentration from the previous time period.

J - P In-Lake @ End of Period = B + C + D + E + F + G - H - I

K - Predicted In-Lake P = J / A / 0.00272

C-27: Keller Lake Summary of Upstream Loads and Discharges for Load Capacity Estimate to meet MPCA Standard of 54 ug/L (10% MOS)
Existing Conditions (2008 Watershed Conditions; Ferric Chloride System Not Operating)

		A	B	C	D	E	F	G	H	I	J
		Upstream Inflows			Discharges						
Period		Pumping from Crystal Lake	Pumping from Crystal Lake [TP]	Pumping from Crystal Lake Load	Surface Discharge	Discharge [TP]	Surface Discharge	Groundwater Discharge	Discharge [TP]	Groundwater Discharge	Total Discharge
From	To	(acft)	(µg/L)	(lbs)	(acre-ft)	(µg/L)	(lbs)	(acre-ft)	(µg/L)	(lbs)	(lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[1,2]		0	16	0	315	62	53	533	62	89	142
(Oct 1, 2005 - April 30, 2006)[1,2]		0	16	0	219	62	37	243	62	41	77
5/1/2006	5/2/2006	0	16	0.0	2	62	0.3	4	62	1	0.9
5/3/2006	5/15/2006	0	16	0.0	0	36	0.0	25	36	2	2.4
5/16/2006	5/16/2006	0	16	0.0	0	32	0.0	2	32	0	0.2
5/17/2006	5/30/2006	0	16	0.0	0	27	0.0	26	27	2	1.9
5/31/2006	5/31/2006	0	16	0.0	0	29	0.0	2	29	0	0.1
6/1/2006	6/11/2006	0	16	0.0	0	24	0.0	19	24	1	1.2
6/12/2006	6/15/2006	0	16	0.0	0	36	0.0	5	36	0	0.5
6/16/2006	6/26/2006	0	16	0.0	0	34	0.0	15	34	1	1.3
6/27/2006	6/28/2006	0	16	0.0	0	28	0.0	4	28	0	0.3
6/29/2006	7/5/2006	0	16	0.0	0	35	0.0	12	35	1	1.1
7/6/2006	7/9/2006	0	16	0.0	0	69	0.0	5	69	1	0.9
7/10/2006	7/23/2006	0	16	0.0	0	83	0.0	12	83	3	2.8
7/24/2006	7/24/2006	0	16	0.0	0	107	0.0	1	107	0	0.3
7/25/2006	8/6/2006	0	16	0.0	10	62	1.6	18	62	3	4.6
8/7/2006	8/10/2006	0	16	0.0	0	60	0.0	8	60	1	1.3
8/11/2006	8/20/2006	0	16	0.0	0	59	0.0	19	59	3	3.1
8/21/2006	8/28/2006	0	16	0.0	11	48	1.4	15	48	2	3.4
8/29/2006	9/4/2006	0	16	0.0	4	64	0.8	14	64	2	3.1
9/5/2006	9/7/2006	0	16	0.0	0	50	0.0	6	50	1	0.8
9/8/2006	9/18/2006	0	16	0.0	0	34	0.0	21	34	2	1.9
9/19/2006	9/20/2006	0	16	0.0	0	80	0.0	4	80	1	0.8
9/21/2006	10/1/2006	0	16	0	0	45	0.0	21	45	3	2.5
Growing Season Total (May 1, 2006 - Sept 30, 2006)[2]				**0**			**4**			**26**	**30**
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[2]				**0**			**41**			**72**	**113**

1 - A phosphorus mass balance was not performed specifically for the Steady State period (May 1, 2005 - April 30, 2006). An empirical model (Reckow, 1977) was used to predict the steady state phosphorus concentration used as the starting concentration for the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006. See Appendix C-19.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.
A - Based on daily water balance model. See Appendix C-16, Column E
B - Based on average total dissolved phosphorus data in the channel.
C - Pumping from Crystal Load = A * B * 0.00272
D - Based on daily water balance model. See Appendix C-16, Column G
E - In-lake TP Concentration from the previous time step
F - Surface Discharge = D * E * 0.00272
G - Based on daily water balance model. See Appendix C-16, Column F
H - In-lake TP Concentration from the previous time step
I - Groundwater Discharge = G * H * 0.00272
J - Total Discharge = F + I

Appendix D

Lee Lake TMDL Modeling Summary

D-1: Lee Lake Water Quality Data
Average (2006) Climatic Conditions

Date	Secchi Disc Depth (m)	Estimated Depth to Thermocline (m)	Sample Depth (m)	Chl-a (ug/l)	D.O. (mg/l)	Temp. (oC)	Total P (mg/L)
5/3/06	**2.4**	**2.5**	**0-2**	**11**		**15.7**	**0.037**
5/3/06			0			15.7	0.037
5/3/06			2.0			15.7	
5/3/06			3.0			6.0	
5/3/06			4.0			6.0	
5/16/06	**1.9**	**2.5**	**0-2**	**3.7**		**17.4**	**0.061**
5/16/06			0			17.4	0.061
5/16/06			2.0			17.4	
5/16/06			3.0			10.0	
5/16/06			4.0			10.0	
5/31/06	**2.6**	**2.5**	**0-2**	**2.6**		**26.3**	**0.038**
5/31/06			0			26.3	0.038
5/31/06			2.0			26.3	
5/31/06			3.0			12.3	
5/31/06			4.0			12.3	
6/15/06	**1.7**	**2.5**	**0-2**	**20**		**22.4**	**0.123**
6/15/06			0			22.4	0.123
6/15/06			2.0			22.4	
6/15/06			3.0			12.3	
6/15/06			4.0			12.3	
6/28/06	**1.2**	**2.5**	**0-2**	**17**		**24.6**	**0.095**
6/28/06			0			24.6	0.095
6/28/06			2.0			24.6	
6/28/06			3.0			14.8	
6/28/06			4.0			14.8	
7/13/06	**1.5**	**2.5**	**0-2**	**11**		**29.7**	**0.129**
7/13/06			0			29.7	0.129
7/13/06			2.0			29.7	
7/13/06			3.0			14.8	
7/13/06			4.0			14.8	
7/26/06	**1.6**	**2.5**	**0-2**	**16**		**28.5**	**0.088**
7/26/06			0			28.5	0.088
7/26/06			2.0			28.5	
7/26/06			3.0			14.9	
7/26/06			4.0			14.9	
8/8/06	**1.6**	**2.5**	**0-2**	**18**		**28.5**	**0.051**
8/8/06			0			28.5	0.051
8/8/06			2.0			28.5	
8/8/06			3.0			15.3	
8/8/06			4.0			15.3	
8/22/06	**1.6**	**2.5**	**0-2**	**21**		**25.2**	**0.081**
8/22/06			0			25.2	0.081
8/22/06			2.0			25.2	
8/22/06			3.0			15.6	
8/22/06			4.0			15.6	
9/6/06	**1.6**	**3.5**	**0-2**	**17**		**23**	**0.062**
9/6/06			0			23	0.062
9/6/06			2.0			23	
9/6/06			3.0			23	
9/6/06			4.0			17	
9/20/06	**1.2**	**4**	**0-2**	**19**		**18.8**	**0.106**
9/20/06			0			18.8	0.106
9/20/06			2.0			18.8	
9/20/06			3.0			18.8	
9/20/06			4.0			16.8	

Bold data indicate surface water quality samples

D-2: Stage/Storage/Discharge Rating Curve

Lee Lake

Elevation	Area[1]	Cumulative Storage	Discharge
(ft MSL)	(ac)	(ac-ft)	(cfs)
932.0	0.33	0.00	0
937.0	4.93	13.16	0
942.0	12.93	57.82	0
944.0	16.41	87.16	0
946.7	19.23	135.28	0
947.0	20.44	141.23	0
948.0	22.23	162.56	0
948.5	22.59	173.77	0
956.0	27.99	363.45	26.94

1 - Source: 2002 Sounding map of Lee Lake Bathymetry (McComas, 2008)

D-3: Lee Lake Average Climatic Conditions
P8 Loading Summary - Calibration (2006 Watershed Conditions)

	Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc (ug/L)
Steady State Year (May 1, 2005 - April 30, 2006)		37.0	117	75	235
(Oct 1, 2005 - April 30, 2006)		17.3	61	32	195
5/1/2006	**5/3/2006**	0.0	0	0.0	0
5/4/2006	**5/16/2006**	1.0	2	1.5	232
5/17/2006	**5/31/2006**	0.2	0	0.5	722
6/1/2006	**6/15/2006**	0.4	1	1.4	757
6/16/2006	**6/28/2006**	2.3	6	5.1	310
6/29/2006	**7/13/2006**	0.1	0	0.3	481
7/14/2006	**7/26/2006**	1.1	2	3.1	497
7/27/2006	**8/8/2006**	4.1	14	6.5	176
8/9/2006	**8/22/2006**	0.8	2	2.0	357
8/23/2006	**9/6/2006**	3.1	9	6.5	266
9/7/2006	**9/20/2006**	0.4	1	0.8	479
9/21/2006	**9/30/2006**	1.0	3	1.6	237
Growing Season Load (June 1, 2006 - Sept 30, 2006)		13.3	37	27	272
Total Load (2006 Water Year - Oct 1, 2005 - Sept 30, 2006)		31.8	101	62	226

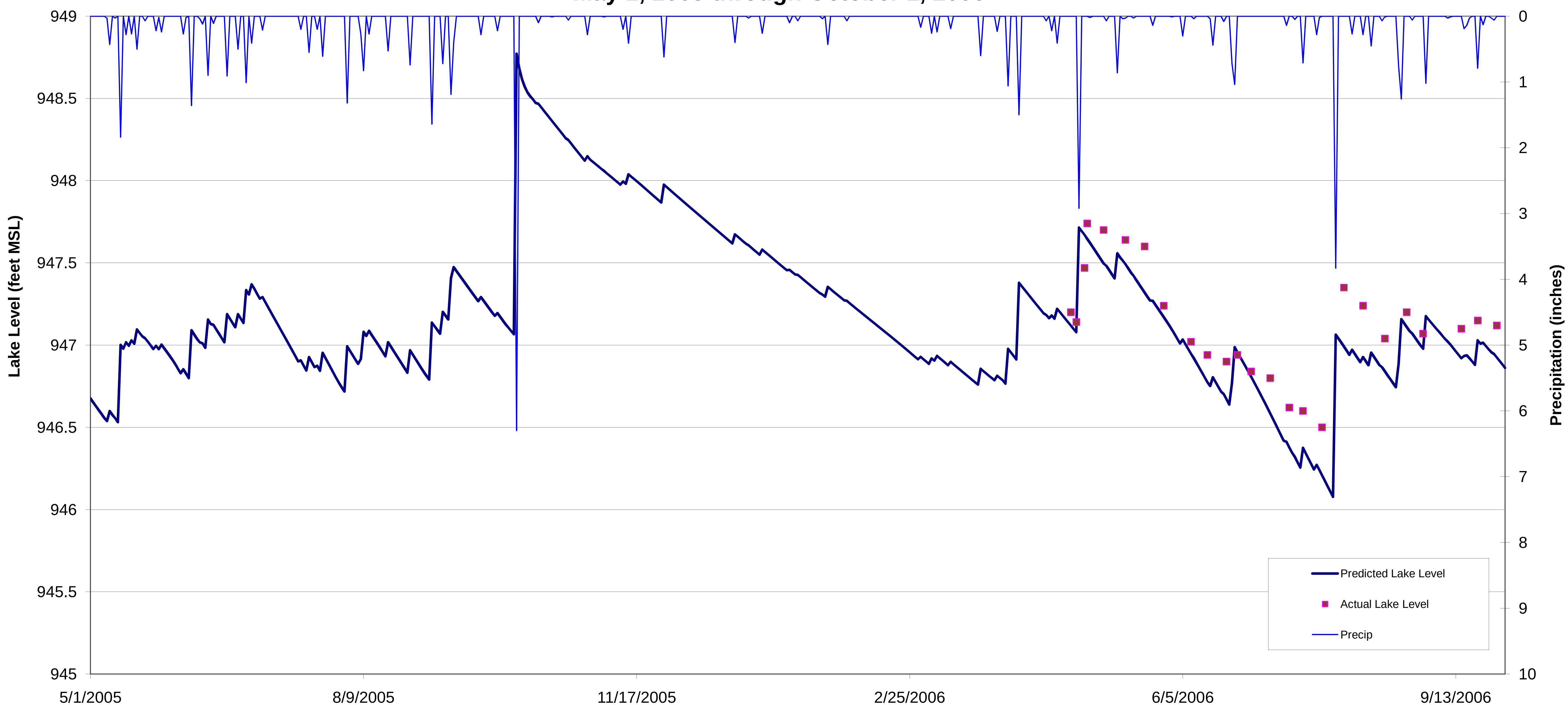
D-4: Lee Lake Average Climatic Conditions
Water Balance Summary
Calibration Conditions (2006 Watershed Conditions)

	Sample Period		A	B	C	D	E	F	G	H	I
			Total Lake Volume at the Start of the Period (acre-ft)	Direct Precipitation (acre-ft)	Evaporation (acre-ft)	Watershed Runoff (acre-ft)	Groundwater Exchange (acre-ft)	Discharge from Lee Lake (acre-ft)	Change in Lake Volume (acre-ft)	Total Lake Volume at the End of the Period (acre-ft)	Lake Level at End of Period (ft MSL)
				+	-	+	-	-			
Steady State Year (May 1, 2005 - April 30, 2006)	5/1/2005	4/30/2006	135	63	47	117	106	7	20	156	947.7
(Oct 1, 2005 - April 30, 2006)	10/1/2005	4/30/2006	144	30	9	61	63	7	12	156	947.7
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/3/2006	156	0	1	0	1	0	-2	154	947.6
	5/4/2006	5/16/2006	154	2	3	2	4	0	-3	151	947.5
	5/17/2006	5/31/2006	151	0	4	0	4	0	-7	144	947.1
	6/1/2006	6/15/2006	144	1	5	1	4	0	-8	136	946.8
	6/16/2006	6/28/2006	136	4	4	6	4	0	2	139	946.9
	6/29/2006	7/13/2006	139	0	5	0	4	0	-8	130	946.4
	7/14/2006	7/26/2006	130	2	4	2	3	0	-4	127	946.2
	7/27/2006	8/8/2006	127	6	3	14	4	0	13	140	946.9
	8/9/2006	8/22/2006	140	1	3	2	4	0	-4	136	946.7
	8/23/2006	9/6/2006	136	5	3	9	4	0	7	143	947.1
	9/7/2006	9/20/2006	143	1	2	1	4	0	-4	139	946.9
	9/21/2006	9/30/2006	139	2	1	3	3	0	0	139	946.9
Total for Growing Season (June 1, 2006 - Sept 30, 2006)	6/1/2006	9/30/2006	144	21	30	37	34	0	-5	139	946.9
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)	10/1/2005	9/30/2006	144	53	47	101	105	7	-5	139	946.9

Annual (2006 Water Year) Water Load to Lee Lake (acre-ft)	10/1/2005	9/30/2006	154	Water Load = B + D

A - Based on the daily water balance model (calibrated to lake level data and using the lake stage-storage-discharge curve). See Appendix D-2.
B - Based on precipitation data used for the P8 modeling and the daily water balance model (Direct Precip Volume = Depth of Precip * Lake Surface Area) See Appendix D-3.
C - Based on adjusted pan evaporation data from the University of Minnesota St. Paul Campus Climatological Observatory and the daily water balance model (Evap Volume = 0.7 * Depth of Evap * Lake Surface Area). See Appendix D-6.
D - Based on the water loads from the P8 model. See Appendix D-3.
E - Groundwater exchange fit to 2008 lake levels and watershed conditions. The estimated groundwater exchange was applied to all climatic conditions.
F - Based on the estimated discharge from the Lee Lake daily water balance model
G - Change in Lake Volume = B - C + D - E - F
H - Total Lake Volume @ End of Period = A + G
I - Estimated lake level based on the total lake volume and the stage-storage-discharge curve. See Appendix D-2.

D-5: Lee Lake Water Balance
Average Climatic Conditions
May 1, 2005 through October 1, 2006



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D-6: St. Paul Campus Monthly Pan Evaporation Data

ST. PAUL CAMPUS CLIMATOLOGICAL OBSERVATORY 21-8450-6

http://climate.umn.edu/img/wxsta/pan-evaporation.htm

		MONTHLY PAN EVAPORATION, INCHES							
Year		APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	TOTAL
		21-30						1-10	
1972	*	1.86	6.08	8.03	6.76	5.62	4.08	0.92	33.35
1973		1.75	5.82	8.45	8.73	7.64	4.33	0.89	37.61
1974		2.03	5.54	7.46	9.46	6.49	4.62	1.29	36.89
1975		0.7	7.02	6.34	9.41	6.58	4.29	2.08	36.42
1976	*	1.86	8.4	11.08	10.96	10.54	6.62	1.61	51.07
1977		2.94	9.42	8.48	9.2	6.65	4.06	0.96	41.71
1978		1.61	8	7.21	6.87	8.3	6.02	1.21	39.22
1979		1.3	6.32	8.53	7.82	5.23	5.33	1.18	35.71
1980		2.88	7.62	7.75	8.83	6.55	4.51	1.47	39.61
1981		1.14	6.45	6.61	7.72	5.83	4.97	0.84	33.56
1982		2.77	6.29	7.49	8.52	7.81	4.21	0.85	37.94
1983	*	1.86	6.53	7.05	8.47	7.23	4.52	1.23	36.89
1984		2.37	7.13	6.88	8.88	7.26	5.24	1.03	38.79
1985		1.98	7.79	7.89	9.07	5.95	4.39	0.95	38.02
1986		1.65	7.21	8.34	7.97	6.71	3.88	1.2	36.96
1987		2.88	8.33	10.96	8.62	7.01	5.36	1.74	44.9
1988		1.77	10.38	11.83	11.73	8.96	5.2	1.54	51.41
1989		1.74	6.47	7.8	8.93	7.26	5.9	1.57	39.67
1990		1.96	6.27	7.24	7.65	6.63	5.45	1.71	36.91
1991		2.09	5.24	7.9	7.44	6.31	4.04	1.08	34.1
1992		1.32	8.83	6.89	5.8	6.69	4.8	1.3	35.63
1993		2.01	5.44	6.46	6.94	6.38	4.1	1.58	32.91
1994		1.32	8.67	7.36	7.02	6.58	3.94	1.18	36.07
1995		1.45	6.16	7.24	7.98	5.8	4.66	0.84	34.13
1996		1.75	5.95	6.53	7.53	7.71	4.6	1.47	35.54
1997		1.99	5.91	7.42	5.43	4.97	4.34	1.51	31.57
1998		2.22	7.5	5.57	7.32	5.79	5.13	0.72	34.25
1999		1.95	6.15	6.26	7.92	5.57	4.71	1.01	33.57
2000		2.2	5.81	6.15	6.89	6.17	4.84	1.38	33.44
2001		2.03	5.29	6.93	8.03	6.28	3.83	1.2	33.59
2002		1.11	6.25	7.25	6.69	6.09	4.47	0.71	32.57
2003		2.09	5.93	6.23	6.88	6.84	5.25	1.39	34.61
2004		1.91	5.41	6.3	6.63	5.14	4.91	1.27	31.57
2005		**1.2**	**4.35**	**6.96**	**8.82**	**6.49**	**4.81**	**1.2**	**33.83**
2006		**1.21**	**5.98**	**7.91**	**9.16**	**5.72**	**3.29**	**1.41**	**34.68**
2007		2.19	6.86	8.81	8.7	6.12	5.38	1.37	39.43
2008	*	1.86	6.83	6.42	8.71	7.83	4.57	1.26	37.48

Bold data indicates data used as part of the water balance modeling. Evaporation from November to March assumed to be negligible.

Pan Coefficient	**0.7**

D-7: Lee Lake Average Climatic Conditions
Physical Parameter Summary
Calibration Conditions (2006 Watershed Conditions)

Period		A	B	C		D	E	F	G	H
		Atmos. Dep	Water Surface Elev	Depth to Thermocline		Elevation of Thermocline	Epilimnion Volume	Surface Area	Hypolimnion Volume	Hypolimnion Area
From	To	(lbs)	(ft MSL)	(m)	(ft)	(ft MSL)	(acft)	(acre)	(acft)	(ac)
5/1/05	4/30/06	5	947.6	2.5	8.2	939.4	119	21.5	35	9
5/1/06	5/3/06	0.0	947.6	2.5	8.2	939.4	119	21.5	35	9
5/4/06	5/16/06	0.2	947.5	2.5	8.2	939.3	118	21.3	33	9
5/17/06	5/31/06	0.2	947.1	2.5	8.2	938.9	114	20.7	30	8
6/1/06	6/15/06	0.2	946.8	2.5	8.2	938.6	109	19.4	27	7
6/16/06	6/28/06	0.2	946.9	2.5	8.2	938.7	111	19.9	28	8
6/29/06	7/13/06	0.2	946.4	2.5	8.2	938.2	106	18.9	24	7
7/14/06	7/26/06	0.1	946.2	2.5	8.2	938.0	104	18.7	22	7
7/27/06	8/8/06	0.2	946.9	2.5	8.2	938.7	111	20.1	29	8
8/9/06	8/22/06	0.2	946.7	2.5	8.2	938.5	109	19.4	27	7
8/23/06	9/6/06	0.2	947.1	3.5	11.5	935.6	134	20.6	10	4
9/7/06	9/20/06	0.2	946.9	4.0	13.1	933.8	134	20.0	5	2

A - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) (Barr, 2005) over the surface area of the lake: A = F * (0.000639 lb/ac/d) * (# of Days)
B - Based on the daily water balance model. See Appendix D-4, Column I
C - Estimated based on the available temperature profile data. See Appendix D-1.
D - Elevation of the Thermocline: D = B - C
E - Estimated using the lake stage-storage-discharge curve. See Appendix D-2.
F - Estimated using the lake stage-storage-discharge curve. See Appendix D-2.
G - Estimated using the lake stage-storage-discharge curve. See Appendix D-2.
H - Estimated using the lake stage-storage-discharge curve. See Appendix D-2.

D-8: Lee Lake Average Climatic Conditions
P8 Particle Class Settling - Estimated Number of Days to Settle Out of Epilimnion & Watershed TP Loads
Calibration Conditions (2006 Watershed Conditions)

			Number of Days to Settle P8 Particle Class[1,2,3]					
P8 Particle Class			P10	P30	P50	P80		
P8 Settling Velocity			vs = 0.03 ft/hr	vs = 0.3 ft/hr	vs = 1.5 ft/hr	vs = 15 ft/hr		
Sample Period		Epilimnion Depth (De)[4] (ft)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Total Watershed TP Load before Particle Settling (lbs)	Watershed TP Load after Particle Settling[2,3] (lbs)
5/1/2006	5/3/2006	8.2	11	1	0	0	0.0	0.0
5/4/2006	5/16/2006	8.2	11	1	0	0	1.5	1.0
5/17/2006	5/31/2006	8.2	11	1	0	0	0.5	0.2
6/1/2006	6/15/2006	8.2	11	1	0	0	1.4	0.6
6/16/2006	6/28/2006	8.2	11	1	0	0	5.1	2.4
6/29/2006	7/13/2006	8.2	11	1	0	0	0.3	0.3
7/14/2006	7/26/2006	8.2	11	1	0	0	3.1	1.5
7/27/2006	8/8/2006	8.2	11	1	0	0	6.5	4.7
8/9/2006	8/22/2006	8.2	11	1	0	0	2.0	0.9
8/23/2006	9/6/2006	8.2	11	1	0	0	6.5	3.8
9/7/2006	9/20/2006	11.5	16	2	0	0	0.8	0.4

1 - Number of Days to Settle Particles = De/vs/24

2 - The P0 particle class in P8 reflects the non-settleable (or dissolved) fraction of the particles. See additional details in Appendix A-3.

3 - The pollutant loading in P8 is based on the build-up and wash-off of particles. There are 5 particle size classes, each with a mass of pollutant associated with it (e.g. phosphorus) as well as a settling velocity. The majority of the phosphorus is associated with the P0 (or non-settleable fraction). The in-lake mass balance model tracks the mass of each particle size class (from the P8 model) and determines how long the particles will remain in the epilimnion (thus impacting observed water quality). The model considers the number of days between the water quality sampling dates and the prior storm events, and only includes the phosphorus load from those particles that would remain in the epilimnion during that period. See Appendix D-3 for a table summarizing the P8 event TP loads.

4 - Epilimnion Depth from Appendix D-7 Column C

D-9: In-Lake Steady State Summary
Lee Lake - 2006 Calibration Conditions

Parameter	Value[1]		Comments
W = total phosphorus loading rate (mg/yr)	36142077.2		(Watershed Load[2] + Atmospheric Load[3]) / Surface Area
Q = outflow (m3/yr)	8462.8		From Water Balance Model
V = lake volume (m3)	182199.0		Lake Volume[4]
A=Surface Area (m²)	84917.7		Surface Area[4]
z= mean Depth (m)	2.1		Volume / Surface Area
vs = settling velocity (m/yr)	10.0		Vollenweider, 1976
Ks = first order settling loss rate per year (1/yr) = (vs/z)	4.7		Ks = vs/z
	Predicted TP Conc (ug/L)		
Vollenweider (1976) [P] = W/(Q + KsV)	42		**See Table 4-2 in the TMDL Report**

1 - Based on May 1,2005 through April 30, 2006
2 - See Appendix D-14 Column A
3 - See Appendix D-14 Column B
4 - At Normal Water Level; See Appendix D-2

$$P = \frac{L}{(q_s + K_s * \frac{V}{A})}$$

where:

P = total phosphorus concentration at the beginning of the open water season (μg/L)

L = areal total phosphorus loading rate (mg/m²/yr)

K_s = first order settling loss rate per year

= v_s/z, with v_s= 10 m/yr

[typical values for v_s range from 10 m/yr (Vollenweider, 1975) to 16 m/yr (Chapra & Tarapchak, 1976)]

z = lake mean depth (m)

q_s = annual areal water outflow load (m/yr)

= Q/A

Q = annual outflow (m³/yr)

V = lake volume (m³)

A = lake surface area (m²)

D-10: Lee Lake - Average Climatic Condition (2006) Calibration - In-Lake Growing Season Mass Balance Model Summary[1]

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
		Epilimnion Volume	P In-Lake @ Start of Period	P Surface Runoff (after Particulate Settling)[5]	P From Upstream Sources	P Atmospheric	P Release from Curlyleaf Pondweed	P Uptake by Coontail	P Loss due to Discharge	P Remaining in lake	In-Lake P before Adjustment	Observed In-Lake P	Residual Adjustment (Internal Loading / Losses)	Residual Adjustment (Internal Loading / Losses)[6]	P In-Lake @ End of Period	Predicted In-Lake P[2]
Period Start		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/L	ug/l	ug/l	lbs	lbs	ug/L
Steady State Total (May 1, 2005 - April 30, 2006)[3,7]		N/A	N/A	75	0	5	N/A[4]	N/A[4]	13	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(Oct 1, 2005 - April 30, 2006)[3,7]		119	N/A	32	0	3	0	0	8	N/A	N/A	N/A	N/A	N/A	N/A	42
5/1/05	5/3/06	119	13.7	0.0	0.0	0.0	0.0	0.1	0.1	13.5	41.5	37	-4.5	-1.5	12.0	37
5/4/06	5/16/06	118	12.0	1.0	0.0	0.2	0.0	0.5	0.4	12.2	38.1	61	22.9	7.3	19.5	61
5/17/06	5/31/06	114	19.5	0.2	0.0	0.2	0.0	0.6	0.7	18.6	60.3	38	-22.3	-6.9	11.7	38
6/1/06	6/15/06	109	11.7	0.6	0.0	0.2	1.8	0.7	0.4	13.2	44.4	123	78.6	23.4	36.6	123
6/16/06	6/28/06	111	36.6	2.4	0.0	0.2	5.2	0.6	1.2	42.5	141.4	95	-46.4	-13.9	28.6	95
6/29/06	7/13/06	106	28.6	0.3	0.0	0.2	2.4	0.7	1.0	29.7	102.9	129	26.1	7.5	37.2	129
7/14/06	7/26/06	104	37.2	1.5	0.0	0.1	0.6	0.7	1.2	37.6	132.4	88	-44.4	-12.6	25.0	88
7/27/06	8/8/06	111	25.0	4.7	0.0	0.2	0.1	0.7	0.9	28.4	94.1	51	-43.1	-13.0	15.4	51
8/9/06	8/22/06	109	15.4	0.9	0.0	0.2	0.0	0.7	0.5	15.2	51.3	81	29.7	8.8	24.1	81
8/23/06	9/6/06	134	24.1	3.8	0.0	0.2	0.0	0.8	0.9	26.4	72.5	62	-10.5	-3.8	22.6	62
9/7/06	9/20/06	134	22.6	0.4	0.0	0.2	0.0	0.7	0.7	21.7	59.6	106	46.4	16.9	38.7	106
Growing Season Total (June 1, 2006 - Sept 30, 2006)[7]		N/A	N/A	15	0	1	10	6	7	N/A	N/A	N/A	N/A	13	N/A	N/A
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[3,7]		N/A	N/A	48	0	5	10	7	16	N/A	N/A	N/A	N/A	12	N/A	N/A
															Growing Season Average[2]	**86**

General Mass Balance Differencing Equation: Padj = Pobs - Pinitial - Psurf - Pus - Patm - Pclpw + Pcoon + Pdis

1 - Reflective of in-lake water quality model calibration conditions (2006 watershed conditions)
2 - Growing Season Average includes monitoring data from 5/31/2006; See observed, calibrated, and predicted in-lake TP concentrations in Table 4-2 in the TMDL Report.
3 - An empirical model (Vollenweider, 1976) was used to predict the steady state phosphorus concentration at the beginning of the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006.
4 - Phosphorus release from Curlyleaf pondweed and uptake by coontail was not estimated for the Steady State year because phosphorus mass balance modeling was not performed for the period from May 1, 2005 - April 30, 2006. Also, it was assumed that during the period from October 1 - April 30 the phosphorus loading due to Curlyleaf pondweed and uptake by coontail would be negligible due to the growth/die back cycles of these macrophytes during this season.
5 - The reported phosphorus load associated with surface runoff during the Steady State period, as well as the period from October 1, 2005 - April 30, 2006 reflects the total watershed runoff load, not the phosphorus load after particulate settling. Therefore the total water year load in this table is not reflective of the Total Phosphorus Load from watershed runoff as reported in Appendix D-14.
6 - The growing season and water year total phosphorus adjustment values represents the net phosphorus adjustment (including both phosphorus loads to the lake as well as losses such as sedimentation). The total phosphorus adjustment will not match the total "internal loading from other sources" in Appendix D-14 as that table only summarizes the (positive) loads to the lake.
7 - For Total Loads, total rounded to the nearest pound for reporting purposes.
A - See Appendix D-7, Column E. The epilimnion volume represents the predicted epilimnion volume at the end of the time period.
B - Amount of phosphorus present in lake at the beginning of the timestep (based on spring steady state or observed TP concentration and epilimnetic volume from the previous timestep).
C - Based on the Watershed TP Load after Particle Settling. See Appendix D-8.
D - No upstream sources of phosphorus to Lee Lake.
E - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake
F - Based on a phosphorus release rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Appendix D-12.
G - Based on average daily uptake rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Appendix D-13.
H - Discharge from the lake includes surface discharge and losses to groundwater multiplied by the total phosphorus concentration from the previous time period. See Appendix D-11.
I - P Remaining in Lake = B + C + D + E + F - G - H
J - In-Lake P before Adj = I / A / 0.00272
K - Water quality monitoring data. See Appendix D-1.
L - Residual Adjustment = K - J; The Residual Adjustment is the calibration parameter used to describe the internal phosphorus loads to the lake not explicitly estimated (e.g. release from bottom sediments, resuspension due to fish activity or wind, etc.), to estimate the uptake of phosphorus from the water column by algae growth, to estimate sedimentation of phosphorus from the water column, as well as to factor in possible error in the monitoring data.
M - Residual Adj Load = L * A * 0.00272. Positive values are treated as a phosphorus source to the lakes such as sediment release while negative values are handled as a sink, such as sedimentation.
N - P In-Lake at End of Period = I + M
O - Predicted In-Lake P is a check against the Observed In-Lake P.

D-11: Lee Lake Summary of Discharges
Lee Lake - 2006 Calibration Conditions

Period		A	B	C	D	E	F	G
		Discharges						
		Surface Discharge	Discharge [TP]	Surface Discharge	Groundwater Discharge	Discharge [TP]	Groundwater Discharge	Total Discharge
From	To	(acre-ft)	(μg/L)	(lbs)	(acre-ft)	(μg/L)	(lbs)	(lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[1,2]		7	42	1	106	42	12	13
(Oct 1, 2005 - April 30, 2006)[1,2]		7	42	1	63	42	7	8
5/1/2006	5/3/2006	0	42	0.0	1	42	0.1	0.1
5/4/2006	5/16/2006	0	37	0.0	4	37	0.4	0.4
5/17/2006	5/31/2006	0	61	0.0	4	61	0.7	0.7
6/1/2006	6/15/2006	0	38	0.0	4	38	0.4	0.4
6/16/2006	6/28/2006	0	123	0.0	4	123	1.2	1.2
6/29/2006	7/13/2006	0	95	0.0	4	95	1.0	1.0
7/14/2006	7/26/2006	0	129	0.0	3	129	1.2	1.2
7/27/2006	8/8/2006	0	88	0.0	4	88	0.9	0.9
8/9/2006	8/22/2006	0	51	0.0	4	51	0.5	0.5
8/23/2006	9/6/2006	0	81	0.0	4	81	0.9	0.9
9/7/2006	9/20/2006	0	62	0.0	4	62	0.7	0.7
Growing Season Total (May 1, 2006 - Sept 30, 2006)[2]				0			7	7
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[2]				1			15	16

1 - A phosphorus mass balance was not performed specifically for the Steady State period (May 1, 2005 - April 30, 2006). An empirical model (Vollenweider, 1976) was used to predict the steady state phosphorus concentration used as the starting concentration for the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006. See Appendix C-9.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.
A - Based on daily water balance model. See Appendix D-4, Column F
B - In-lake TP Concentration from the previous time step
C - Surface Discharge = A * B * 0.00272
D - Based on daily water balance model. See Appendix D-4, Column E
E - In-lake TP Concentration from the previous time step
F - Groundwater Discharge = D * e * 0.00272
G - Total Discharge = C + F

D-12: Lee Lake Average Climatic Conditions

Curlyleaf Pondweed Phosphorus Release (Calibration)

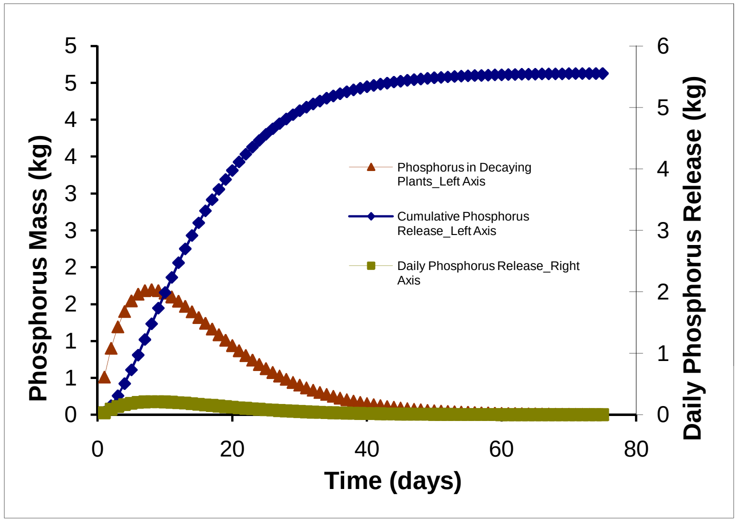
Macrophyte Area = 19.2 acres

% Covered w/Curlyleaf[1] 85% ==> Curlyleaf Area = 16.3

1 - Based on average of the 2003 and 2008 Macrophyte Surveys (2006 data not available)

Curlyleaf load based on est density

Stem Density	100	stem/m²	(McComas; Barr, 2001)
Mat/stem	0.35	g/stem	(Barr, 2001)
P Content	2000	mg P/kg	(Barr, 2001)
Areal P load	70	mg/m²	
P Load	10.2	lbs	
In-lake P conc	31.9	µg/L	

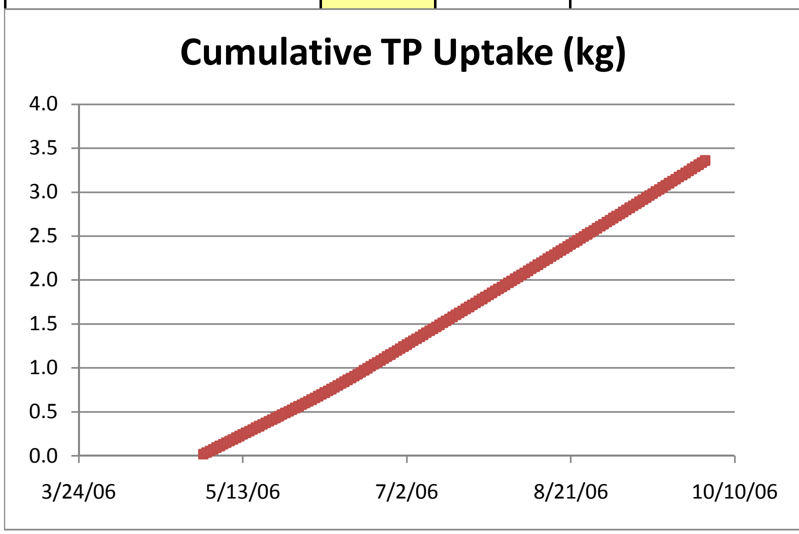


Internal Loading from Curlyleaf Pondweed

Date	Cumulative Load (kg)	Cumulative Load (lbs)	Incremental Load (lbs)
4/30/06	#N/A	0	0.0
5/3/06	#N/A	0	0.0
5/16/06	#N/A	0	0.0
5/31/06	#N/A	0	0.0
6/15/06	0.8	2	1.8
6/28/06	3.2	7	5.2
7/13/06	4.3	9	2.4
7/26/06	4.5	10	0.6
8/8/06	4.6	10	0.1
8/22/06	4.6	10	0.0
9/6/06	4.6	10	0.0
9/20/06	4.6	10	0.0

D-13: Lee Lake Average Climatic Conditions
Coontail Phosphorus Uptake (Calibration)

Date Coontail Uptake Begins	5/1/2006			Date of Aq Plant Survey #1	5/30/2006	Based on Average of 2003 & 2008 Macrophyte Surveys
Maximum Coontail Plant Density	661.9	g (wet weight)/m²	(LCMR, 2001; Newman, 2004)	% Covered w/ Coontail	70	Based on Average of 2003 & 2008 Macrophyte Surveys
Macrophyte Area =	19.23	Ac		Coontail Density (0-5)	1.55	Based on Average of 2003 & 2008 Macrophyte Surveys
% Covered w/Coontail at Date Coontail Uptake Begins	70		Based on Average of 2003 & 2008 Macrophyte Surveys	Date of Aq Plant Survey #2	9/15/2006	Based on Average of 2003 & 2008 Macrophyte Surveys
Coontail Density at Date Coontail Uptake Begins (0-5)	1.55		Based on Average of 2003 & 2008 Macrophyte Surveys	% Covered w/ Coontail	85	Based on Average of 2003 & 2008 Macrophyte Surveys
				Coontail Density (0-5)	1.95	Based on Average of 2003 & 2008 Macrophyte Surveys
				Coontail Uptake Rate (ug/g(ww)/d)	1.68	(Lombardo & Cooke, 2003)



Internal Uptake from Coontail

Date	Cumulative Uptake (kg)	Cumulative Uptake (lbs)	Incremental Load (lbs)
4/30/06	#N/A	0	0.0
5/3/06	0.06	0	0.1
5/16/06	0.30	1	0.5
5/31/06	0.58	1	0.6
6/15/06	0.89	2	0.7
6/28/06	1.18	3	0.6
7/13/06	1.51	3	0.7
7/26/06	1.81	4	0.6
8/8/06	2.11	5	0.7
8/22/06	2.43	5	0.7
9/6/06	2.77	6	0.8
9/20/06	3.10	7	0.7

D-14: Lee Lake Average Climatic Conditions
Phosphorus Load Summary
Calibration Conditions (2006 Watershed Conditions)

	Sample Period		A	B	C	D	E	F	G
			External TP Load			Internal TP Load			
			Watershed TP Load (lbs)	Atmospheric Deposition (lbs)	Total External TP Load (lbs)	Curlyleaf Pondweed (lbs)	Other Internal Sources (lbs)	Total Internal TP Load (lbs)	Total TP Load (lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[2]	5/1/2005	4/30/2006	74	5	79	N/A[1]	N/A[1]	N/A[1]	***79***
(Oct 1, 2005 - April 30, 2006)[2]	10/1/2005	4/30/2006	32	3	35	0	0	0	***35***
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/3/2006	0.0	0.0	0.0	0.0	0.0	0.0	***0.0***
	5/4/2006	5/16/2006	1.5	0.2	1.7	0.0	7.3	7.3	***9.0***
	5/17/2006	5/31/2006	0.5	0.2	0.7	0.0	0.0	0.0	***0.7***
	6/1/2006	6/15/2006	1.4	0.2	1.6	1.8	23.4	25.2	***26.7***
	6/16/2006	6/28/2006	5.1	0.2	5.3	5.2	0.0	5.2	***10.5***
	6/29/2006	7/13/2006	0.3	0.2	0.5	2.4	7.5	10.0	***10.5***
	7/14/2006	7/26/2006	3.1	0.1	3.3	0.6	0.0	0.6	***3.8***
	7/27/2006	8/8/2006	6.5	0.2	6.7	0.1	0.0	0.1	***6.8***
	8/9/2006	8/22/2006	2.0	0.2	2.1	0.0	8.8	8.9	***11.0***
	8/23/2006	9/6/2006	6.5	0.2	6.7	0.0	0.0	0.0	***6.7***
	9/7/2006	9/20/2006	0.8	0.2	1.0	0.0	16.9	16.9	***18.0***
	9/21/2006	9/30/2006	1.6	0.0	1.6	0.0	0.0	0.0	***1.6***
Growing Season Total (June 1, 2006 - Sept 30, 2006)[2]	**6/1/2006**	**9/30/2006**	**27**	**1**	**29**	**10**	**57**	**67**	***96***
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[2]	**10/1/2005**	**9/30/2006**	**62**	**5**	**67**	**10**	**64**	**74**	***141***

1 - The empirical steady-state equations used to estimate the phosphorus concentration in the lake at the beginning of the mass balance calibration period were originally developed based on external phosphorus loadings only; therefore, internal loading for this period was not estimated. See Appendix D-9.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.

A - Based on P8 TP Load. See Appendix D-3.

B - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake. See Appendices D-7 and D-10.

C - External Load = A + B
D - See Appendix D-12.

E - Load back-calculated as part of the mass balance model calibration. Assumes that internal loading happens only during the calibration period (May 1 - Sept 30) to reflect the available monitoring data. This summary table includes only the estimated phosphorus loads to the lake (estimated losses assumed to be zero). See Appendix D-10 Column M.
F - Internal Load = D + E
G - Total TP Load = C + F

D-15: Lee Lake Average Climatic Conditions
P8 Loading Summary - Existing Conditions (2008 Watershed Conditions)

	Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc (ug/L)
Steady State Year (May 1, 2005 - April 30, 2006)		37.0	129	79	226
(Oct 1, 2005 - April 30, 2006)		17.3	66	34	189
5/1/2006	**5/3/2006**	0.0	0	0.0	0
5/4/2006	**5/16/2006**	1.0	3	1.6	220
5/17/2006	**5/31/2006**	0.2	0	0.5	722
6/1/2006	**6/15/2006**	0.4	1	1.4	757
6/16/2006	**6/28/2006**	2.3	7	5.5	292
6/29/2006	**7/13/2006**	0.1	0	0.3	481
7/14/2006	**7/26/2006**	1.1	3	3.2	471
7/27/2006	**8/8/2006**	4.1	15	7.2	171
8/9/2006	**8/22/2006**	0.8	2	2.0	333
8/23/2006	**9/6/2006**	3.1	10	7.0	251
9/7/2006	**9/20/2006**	0.4	1	0.8	479
9/21/2006	**9/30/2006**	1.0	3	1.7	223
Growing Season Load (June 1, 2006 - Sept 30, 2006)		13.3	42	29	257
Total Load (2006 Water Year - Oct 1, 2005 - Sept 30, 2006)		31.8	111	65	217

D-16: Lee Lake Average Climatic Conditions
Water Balance Summary
Existing Conditions (2008 Watershed Conditions)

	Sample Period		A	B	C	D	E	F	G	H	I
			Total Lake Volume at the Start of the Period (acre-ft)	Direct Precipitation (acre-ft)	Evaporation (acre-ft)	Watershed Runoff (acre-ft)	Groundwater Exchange (acre-ft)	Discharge from Lee Lake (acre-ft)	Change in Lake Volume (acre-ft)	Total Lake Volume at the End of the Period (acre-ft)	Lake Level at End of Period (ft MSL)
				+	-	+	-	-			
Steady State Year (May 1, 2005 - April 30, 2006)	5/1/2005	4/30/2006	135	64	47	129	107	15	24	159	947.8
(Oct 1, 2005 - April 30, 2006)	10/1/2005	4/30/2006	150	30	9	66	63	15	8	159	947.8
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/3/2006	159	0	1	0	1	0	-2	157	947.7
	5/4/2006	5/16/2006	157	2	3	3	4	0	-3	155	947.6
	5/17/2006	5/31/2006	155	0	4	0	4	0	-7	147	947.3
	6/1/2006	6/15/2006	147	1	5	1	4	0	-8	139	946.9
	6/16/2006	6/28/2006	139	4	4	7	4	0	3	142	947.1
	6/29/2006	7/13/2006	142	0	5	0	4	0	-9	134	946.6
	7/14/2006	7/26/2006	134	2	4	3	3	0	-4	130	946.4
	7/27/2006	8/8/2006	130	6	3	15	4	0	15	145	947.2
	8/9/2006	8/22/2006	145	1	3	2	4	0	-3	142	947.0
	8/23/2006	9/6/2006	142	5	3	10	4	0	8	150	947.4
	9/7/2006	9/20/2006	150	1	2	1	4	0	-5	145	947.2
	9/21/2006	9/30/2006	145	2	1	3	3	0	0	146	947.2
Total for Growing Season (June 1, 2006 - Sept 30, 2006)	6/1/2006	9/30/2006	147	22	31	42	35	0	-1	146	947.2
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)	10/1/2005	9/30/2006	150	54	47	111	107	15	-5	146	947.2

Annual (2006 Water Year) Water Load to Lee Lake (acre-ft)	10/1/2005	9/30/2006	165	Water Load = B + D (See **Table 4-7** in the TMDL Report)

A - Based on the daily water balance model (calibrated to lake level data and using the lake stage-storage-discharge curve). See Appendix D-2.
B - Based on precipitation data used for the P8 modeling and the daily water balance model (Direct Precip Volume = Depth of Precip * Lake Surface Area) See Appendix D-15.
C - Based on adjusted pan evaporation data from the University of Minnesota St. Paul Campus Climatological Observatory and the daily water balance model (Evap Volume = 0.7 * Depth of Evap * Lake Surface Area). See Appendix D-6.
D - Based on the water loads from the P8 model. See Appendix D-15.
E - Groundwater exchange fit to 2008 lake levels and watershed conditions. The estimated groundwater exchange was applied to all climatic conditions.
F - Based on the estimated discharge from the Lee Lake daily water balance model
G - Change in Lake Volume = B - C + D - E - F
H - Total Lake Volume @ End of Period = A + G
L - Estimated lake level based on the total lake volume and the stage-storage-discharge curve. See Appendix D-2.

D-17: Lee Lake Average Climatic Conditions
Physical Parameter Summary
Existing Conditions (2008 Watershed Conditions)

Period		A	B	C		D	E	F	G	H
		Atmos. Dep	Water Surface Elev	Depth to Thermocline		Elevation of Thermocline	Epilimnion Volume	Surface Area	Hypolimnion Volume	Hypolimnion Area
From	To	(lbs)	(ft MSL)	(m)	(ft)	(ft MSL)	(acft)	(acre)	(acft)	(ac)
5/1/05	4/30/06	5	947.7	2.5	8.2	939.5	121	21.8	36	9
5/1/06	5/3/06	0.0	947.7	2.5	8.2	939.5	121	21.8	36	9
5/4/06	5/16/06	0.2	947.6	2.5	8.2	939.4	120	21.6	35	9
5/17/06	5/31/06	0.2	947.3	2.5	8.2	939.1	115	20.9	32	8
6/1/06	6/15/06	0.2	946.9	2.5	8.2	938.7	111	20.1	28	8
6/16/06	6/28/06	0.2	947.1	2.5	8.2	938.9	113	20.5	30	8
6/29/06	7/13/06	0.2	946.6	2.5	8.2	938.4	108	19.1	26	7
7/14/06	7/26/06	0.1	946.4	2.5	8.2	938.2	106	18.9	24	7
7/27/06	8/8/06	0.2	947.2	2.5	8.2	939.0	114	20.8	31	8
8/9/06	8/22/06	0.2	947.0	2.5	8.2	938.8	112	20.5	29	8
8/23/06	9/6/06	0.2	947.4	3.5	11.5	935.9	140	21.2	10	4
9/7/06	9/20/06	0.2	947.2	4.0	13.1	934.1	140	20.8	5	2

A - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) (Barr, 2005) over the surface area of the lake: A = F * (0.000639 lb/ac/d) * (# of Days)
B - Based on the daily water balance model. See Appendix D-16, Column I
C - Estimated based on the available temperature profile data. See Appendix D-1.
D - Elevation of the Thermocline: D = B - C
E - Estimated using the lake stage-storage-discharge curve. See Appendix D-2.
F - Estimated using the lake stage-storage-discharge curve. See Appendix D-2.
G - Estimated using the lake stage-storage-discharge curve. See Appendix D-2.
H - Estimated using the lake stage-storage-discharge curve. See Appendix D-2.

D-18: Lee Lake Average Climatic Conditions
P8 Particle Class Settling - Estimated Number of Days to Settle Out of Epilimnion & Watershed TP Loads
Existing Conditions (2008 Watershed Conditions)

			Number of Days to Settle P8 Particle Class[1,2,3]					
P8 Particle Class			P10	P30	P50	P80		
P8 Settling Velocity			vs = 0.03 ft/hr	vs = 0.3 ft/hr	vs = 1.5 ft/hr	vs = 15 ft/hr		
Sample Period		Epilimnion Depth (De)[4] (ft)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Particle Settling Time (days)	Total Watershed TP Load before Particle Settling (lbs)	Watershed TP Load after Particle Settling[2,3] (lbs)
5/1/2006	5/3/2006	8.2	11	1	0	0	0.0	0.0
5/4/2006	5/16/2006	8.2	11	1	0	0	1.6	1.0
5/17/2006	5/31/2006	8.2	11	1	0	0	0.5	0.2
6/1/2006	6/15/2006	8.2	11	1	0	0	1.4	0.6
6/16/2006	6/28/2006	8.2	11	1	0	0	5.5	2.6
6/29/2006	7/13/2006	8.2	11	1	0	0	0.3	0.3
7/14/2006	7/26/2006	8.2	11	1	0	0	3.2	1.5
7/27/2006	8/8/2006	8.2	11	1	0	0	7.2	5.3
8/9/2006	8/22/2006	8.2	11	1	0	0	2.0	0.9
8/23/2006	9/6/2006	8.2	11	1	0	0	7.0	4.2
9/7/2006	9/20/2006	11.5	16	2	0	0	0.8	0.4

1 - Number of Days to Settle Particles = De/vs/24

2 - The P0 particle class in P8 reflects the non-settleable (or dissolved) fraction of the particles. See additional details in Appendix A-3.

3 - The pollutant loading in P8 is based on the build-up and wash-off of particles. There are 5 particle size classes, each with a mass of pollutant associated with it (e.g. phosphorus) as well as a settling velocity. The majority of the phosphorus is associated with the P0 (or non-settleable fraction). The in-lake mass balance model tracks the mass of each particle size class (from the P8 model) and determines how long the particles will remain in the epilimnion (thus impacting observed water quality). The model considers the number of days between the water quality sampling dates and the prior storm events, and only includes the phosphorus load from those particles that would remain in the epilimnion during that period. See Appendix D-15 for a table summarizing the P8 event TP loads.

4 - Epiliminion Depth from Appendix D-17 Column C

D-19: In-Lake Steady State Summary
Lee Lake - 2006 (2008 Watershed Conditions)

Parameter	Value[1]	Comments
W = total phosphorus loading rate (mg/yr)	38230895.0	(Watershed Load[2] + Atmospheric Load[3]) / Surface Area
Q = outflow (m3/yr)	18885.4	From Water Balance Model
V = lake volume (m3)	184820.4	Lake Volume[4]
A=Surface Area (m²)	85638.1	Surface Area[4]
z= mean Depth (m)	2.2	Volume / Surface Area
vs = settling velocity (m/yr)	10.0	Vollenweider, 1976
Ks = first order settling loss rate per year (1/yr) = (vs/z)	4.7	Ks = vs/z
	Predicted TP Conc (ug/L)	
Vollenweider (1976) [P] = W/(Q + KsV)	43	**See Table 4-2 in the TMDL Report**

1 - Based on May 1,2005 through April 30, 2006
2 - See Appendix D-22 Column A
3 - See Appendix D-22 Column B
4 - At Normal Water Level; See Appendix D-2

$$P = \frac{L}{(q_s + K_s * \frac{V}{A})}$$

where:

P = total phosphorus concentration at the beginning of the open water season (μg/L)

L = areal total phosphorus loading rate (mg/m²/yr)

K_s = first order settling loss rate per year

= v_s/z, with v_s= 10 m/yr

[typical values for v_s range from 10 m/yr (Vollenweider, 1975) to 16 m/yr (Chapra & Tarapchak, 1976)]

z = lake mean depth (m)

q_s = annual areal water outflow load (m/yr)

= Q/A

Q = annual outflow (m³/yr)

V = lake volume (m³)

A = lake surface area (m²)

D-20: Lee Lake - Average Climatic Condition Existing Conditions - In-Lake Growing Season Mass Balance Model Summary[1]

		A	B	C	D	E	F	G	H	I	J	K
Period Start		Epilimnion Volume	P In-Lake @ Start of Period	P Surface Runoff (after Particulate Settling)[6]	P From Upstream Sources	P Atmospheric	P Release from Curlyleaf Pondweed	P Adjustment Load[6]	P Uptake by Coontail	P Loss due to Discharge	P In-Lake @ End of Period	Predicted In-Lake P[2]
		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/L
Steady State Total (May 1, 2005 - April 30, 2006)[3,7]		N/A	N/A	79	0	5	N/A[4]	N/A	N/A[4]	14	N/A	N/A
(Oct 1, 2005 - April 30, 2006)[3,7]		121	N/A	34	0	3	0	N/A	0	7	N/A	43
5/1/06	5/3/06	121	14.3	0.0	0.0	0.0	0.0	-1.5	0.1	0.1	12.7	38
5/4/06	5/16/06	120	12.7	1.0	0.0	0.2	0.0	7.3	0.5	0.4	20.2	62
5/17/06	5/31/06	115	20.2	0.2	0.0	0.2	0.0	-6.9	0.6	0.7	12.4	40
6/1/06	6/15/06	111	12.4	0.6	0.0	0.2	1.8	23.4	0.7	0.5	37.2	123
6/16/06	6/28/06	113	37.2	2.6	0.0	0.2	5.2	-13.9	0.6	1.2	29.5	96
6/29/06	7/13/06	108	29.5	0.3	0.0	0.2	2.4	7.5	0.7	1.1	38.1	130
7/14/06	7/26/06	106	38.1	1.5	0.0	0.1	0.6	-12.6	0.7	1.2	25.9	90
7/27/06	8/8/06	114	25.9	5.3	0.0	0.2	0.1	-13.0	0.7	0.9	16.9	54
8/9/06	8/22/06	112	16.9	0.9	0.0	0.2	0.0	8.8	0.7	0.6	25.6	84
8/23/06	9/6/06	140	25.6	4.2	0.0	0.2	0.0	-3.8	0.8	1.0	24.4	64
9/7/06	9/20/06	140	24.4	0.4	0.0	0.2	0.0	16.9	0.7	0.7	40.5	106
Growing Season Total (May 1, 2006 - Sept 30, 2006)[7]		N/A	N/A	16	0	1	10	13	6	7	N/A	N/A
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[3,7]		N/A	N/A	51	0	5	10	12	7	16	N/A	N/A
											Growing Season Average[2]	**87**

Predictive Mass Balance Equation: Ppredict = Pinitial + Psurf + Pus + Patm + Pclpw + Padj - Pcoon - Pdis

1 - Reflective of in-lake water quality model existing conditions (2008 watershed conditions)

2 - Growing Season Average includes monitoring data from 5/31/2006; See observed, calibrated, and predicted in-lake TP concentrations in Table 4-2 in the TMDL Report.

3 - A phosphorus mass balance was not performed specifically for the Steady State period (May 1, 2005 - April 30, 2006). An empirical model (Vollenweider, 1976) was used to predict the steady state phosphorus concentration used as the starting in-lake concentration for the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006.

4 - Phosphorus release from Curlyleaf pondweed and uptake by coontail was not estimated for the Steady State year because phosphorus mass balance modeling was not performed for the period from May 1, 2005 - April 30, 2006. Also, it was assumed that during the period from October 1 - April 30, the phosphorus loading due to Curlyleaf pondweed and uptake by coontail would be negligible due to the growth/die back cycles of these macrophytes during this season.

5 - Because the phosphorus mass balance modeling was not performed for the Steady State Period, particulate settling from the watershed runoff was not estimated for this time period. The reported phosphorus load associated with surface runoff during the Steady State period, as well as the period from October 1, 2005 - April 30, 2006 reflects the total watershed runoff load, not the phosphorus load after particulate settling; therefore the total water year load in this table is not reflective of the Total Phosphorus Load from watershed runoff as reported in Appendix D-22.

6 - The growing season and water year total phosphorus adjustment represents the net phosphorus adjustment (including both phosphorus loads to the lake as well as losses such as sedimentation). The total phosphorus adjustment will not match the total "internal loading from other sources" in Appendix D-22 as this table only summarizes the (positive) loads to the lake.

7 - For Total Loads, total rounded to the nearest pound for reporting purposes.

A - See Appendix D-17, Column E. The epilimnion volume represents the predicted epilimnion volume at the end of the time period.

B - Amount of phosphorus present in lake at the beginning of the timestep (based on spring steady state or observed TP concentration and epilimnetic volume from the previous timestep).

C - Based on the Watershed TP Load after Particle Settling. See Appendix D-18.

D - No upstream sources of phosphorus to Lee Lake.

E - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake

F - Based on a phosphorus release rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Appendix D-12.

G - Based on the calibrated water quality model residual adjustment TP loads. The Residual Adjustment is the calibration parameter used to describe the internal phosphorus loads to the lake not explicitly estimated (e.g. release from bottom sediments, resuspension due to fish activity or wind, etc.), to estimate the uptake of phosphorus from the water column by algae growth, to estimate sedimentation of phosphorus from the water column, as well as to factor in possible error in the monitoring data.

H - Based on average daily uptake rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Appendix D-13.

I - Discharge from the lake includes surface discharge and losses to groundwater, multiplied by the total phosphorus concentration from the previous time period. See Appendix D-21.

J - P in the lake at the end of the period = B + C + D + E + F + G - H - I

K - Predicted In-Lake P = K * A * 0.00272

D-21: Lee Lake Summary of Upstream Loads and Discharges
Lee Lake - Existing Conditions (2008 watershed conditions)

Period		A	B	C	D	E	F	G
		Discharges						
		Surface Discharge	Discharge [TP]	Surface Discharge	Groundwater Discharge	Discharge [TP]	Groundwater Discharge	Total Discharge
From	To	(acre-ft)	(μg/L)	(lbs)	(acre-ft)	(μg/L)	(lbs)	(lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[1,2]		15	43	2	107	43	13	14
(Oct 1, 2005 - April 30, 2006)[1,2]		0	43	0	63	43	7	7
5/1/2006	5/3/2006	0	43	0.0	1	43	0.1	0.1
5/4/2006	5/16/2006	0	38	0.0	4	38	0.4	0.4
5/17/2006	5/31/2006	0	62	0.0	4	62	0.7	0.7
6/1/2006	6/15/2006	0	40	0.0	4	40	0.5	0.5
6/16/2006	6/28/2006	0	123	0.0	4	123	1.2	1.2
6/29/2006	7/13/2006	0	96	0.0	4	96	1.1	1.1
7/14/2006	7/26/2006	0	130	0.0	3	130	1.2	1.2
7/27/2006	8/8/2006	0	90	0.0	4	90	0.9	0.9
8/9/2006	8/22/2006	0	54	0.0	4	54	0.6	0.6
8/23/2006	9/6/2006	0	84	0.0	4	84	1.0	1.0
9/7/2006	9/20/2006	0	64	0.0	4	64	0.7	0.7
Growing Season Total (May 1, 2006 - Sept 30, 2006)[2]				0			7	7
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[2]				0			16	16

1 - A phosphorus mass balance was not performed specifically for the Steady State period (May 1, 2005 - April 30, 2006). An empirical model (Vollenweider, 1976) was used to predict the steady state phosphorus concentration used as the starting concentration for the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006. See Appendix C-9.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.
A - Based on daily water balance model. See Appendix D-16, Column F
B - In-lake TP Concentration from the previous time step
C - Surface Discharge = A * B * 0.00272
D - Based on daily water balance model. See Appendix D-16, Column E
E - In-lake TP Concentration from the previous time step
F - Groundwater Discharge = D * e * 0.00272
G - Total Discharge = C + F

D-22: Lee Lake Average Climatic Conditions
Phosphorus Load Summary
Existing Conditions (2008 Watershed Conditions)

	Sample Period		A	B	C	D	E	F	G
			External TP Load			Internal TP Load			
			Watershed TP Load (lbs)	Atmospheric Deposition (lbs)	Total External TP Load (lbs)	Curlyleaf Pondweed (lbs)	Other Internal Sources (lbs)	Total Internal TP Load (lbs)	Total TP Load (lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[2]	5/1/2005	4/30/2006	79	5	84	N/A[1]	N/A[1]	N/A[1]	***84***
(Oct 1, 2005 - April 30, 2006)[2]	10/1/2005	4/30/2006	34	3	37	0	0	0	***37***
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/3/2006	0.0	0.0	0.0	0.0	0.0	0.0	***0.0***
	5/4/2006	5/16/2006	1.6	0.2	1.8	0.0	7.3	7.3	***9.1***
	5/17/2006	5/31/2006	0.5	0.2	0.7	0.0	0.0	0.0	***0.7***
	6/1/2006	6/15/2006	1.4	0.2	1.6	1.8	23.4	25.2	***26.7***
	6/16/2006	6/28/2006	5.5	0.2	5.6	5.2	0.0	5.2	***10.8***
	6/29/2006	7/13/2006	0.3	0.2	0.5	2.4	7.5	10.0	***10.5***
	7/14/2006	7/26/2006	3.2	0.1	3.4	0.6	0.0	0.6	***3.9***
	7/27/2006	8/8/2006	7.2	0.2	7.3	0.1	0.0	0.1	***7.5***
	8/9/2006	8/22/2006	2.0	0.2	2.2	0.0	8.8	8.9	***11.1***
	8/23/2006	9/6/2006	7.0	0.2	7.2	0.0	0.0	0.0	***7.2***
	9/7/2006	9/20/2006	0.8	0.2	1.0	0.0	16.9	16.9	***18.0***
	9/21/2006	9/30/2006	1.7	0.0	1.7	0.0	0.0	0.0	***1.7***
Growing Season Total (June 1, 2006 - Sept 30, 2006)[2]	**6/1/2006**	**9/30/2006**	**29**	**1**	**30**	**10**	**57**	**67**	***97***
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[2]	**10/1/2005**	**9/30/2006**	**65**	**5**	**70**	**10**	**64**	**74**	***144***
	TMDL Report References		**Table 5-9**	**Table 5-9**	**Table 4-7**		**Table 4-8**	**Table 4-7; Table 5-9**	**Table 5-9**

1 - The empirical steady-state equations used to estimate the phosphorus concentration in the lake at the beginning of the mass balance calibration period were originally developed based on external phosphorus loadings only; therefore, internal loading for this period was not estimated. See Appendix D-19.
2 - For Total Loads, total rounded to the nearest pound for reporting purposes.

A - Based on P8 TP Load. See Appendix D-15.

B - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake. See Appendices D-17 and D-20.

C - External Load = A + B
D - See Appendix D-12.

E - Load back-calculated as part of the mass balance model calibration. Assumes that internal loading happens only during the calibration period (May 1 - Sept 30) to reflect the available monitoring data. This summary table includes only the estimated phosphorus loads to the lake (estimated losses assumed to be zero). See Appendix D-20 Column G.
F - Internal Load = D + E
G - Total TP Load = C + F

D-23: Lee Lake - Average Climatic Condition Phosphorus Reduction Required to Estimate TMDL Load Capacity
Reduction Required to Meet MPCA Standard of 60 ug/L

TP Load Reduction (%)[1]		A	B	C	D	E	F	G	H	I	J	K
34.5		Epilimnion Volume	P In-Lake @ Start of Period	P Surface Runoff (after Particulate Settling)[6]	P From Upstream Sources	P Atmospheric	P Release from Curlyleaf Pondweed	P Adjustment Load	P Uptake by Coontail	P Loss due to Discharge	P In-Lake @ End of Period	Predicted In-Lake P
		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/L
(Oct 1, 2005 - April 30, 2006)[5,7]		121	N/A	34	0	3	0	N/A	0	7	N/A	43
5/1/06	5/3/06	121	14.3	0.0	0.0	0.0	0.0	-1.5	0.1	0.1	12.7	38.4
5/4/06	5/16/06	120	12.7	0.7	0.0	0.2	0.0	4.8	0.5	0.4	17.4	53.3
5/17/06	5/31/06	115	17.4	0.2	0.0	0.2	0.0	-5.9	0.6	0.6	10.6	33.7
6/1/06	6/15/06	111	10.6	0.4	0.0	0.2	1.2	15.3	0.7	0.4	26.6	87.9
6/16/06	6/28/06	113	26.6	1.7	0.0	0.2	3.4	-9.8	0.6	0.9	20.6	67.3
6/29/06	7/13/06	108	20.6	0.2	0.0	0.2	1.6	4.9	0.7	0.8	26.0	88.7
7/14/06	7/26/06	106	26.0	1.0	0.0	0.1	0.4	-8.5	0.7	0.8	17.5	60.7
7/27/06	8/8/06	114	17.5	3.4	0.0	0.2	0.1	-8.7	0.7	0.6	11.3	36.3
8/9/06	8/22/06	112	11.3	0.6	0.0	0.2	0.0	5.8	0.7	0.4	16.8	54.9
8/23/06	9/6/06	140	16.8	2.8	0.0	0.2	0.0	-2.5	0.8	0.7	15.8	41.7
9/7/06	9/20/06	140	15.8	0.3	0.0	0.2	0.0	11.1	0.7	0.5	26.2	68.8
Growing Season Total (May 1, 2006 - Sept 30, 2006)[7]		N/A	N/A	10	0	1	7	8	6	5	N/A	N/A
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[7]		N/A	N/A	45	0	5	7	5	7	14	N/A	N/A
											Growing Season Average (ug/L)[2]	60
											Growing Season Average Chlorophyll-*a* (ug/L)[3]	22.5
											Growing Season Average Secchi Depth (m)[4]	1.3

Predictive Mass Balance Equation: Ppredict = Pinitial + Psurf + Pus + Patm + Pclpw + Pint - Pcoon - Pdis

1 - To estimate the Loading Capacity (and the required reduction in existing TP loads), P Surface Runoff, P Release from Curlyleaf Pondweed, and P Adjustment Load (See Note G), were reduced equally until the MPCA standard was met.

2 - Growing Season Average includes predicted data from 5/31/2006

3 - Based on Chla vs TP water quality relationship (Chla = 0.3092 * TP + 3.9315). See Figure 3-17.

4 - Based on SD vs TP water quality relationship (SD = 11.092 * TP ^ (-0.52)). See Figure 3-16.

5 - To estimate the load reduction, it was assumed that the steady-state concentration in the lake at the beginning of the season (May 1) was not impacted by the estimated reductions in total phosphorus loads (same as existing conditions).

6 - Because the phosphorus mass balance modeling was not performed for the period from October 1, 2005 - April 30, 2006, the reported value reflects the total watershed runoff load, not the phosphorus load after particulate settling.

7 - For Total Loads, total rounded to the nearest pound for reporting purposes.

A - See Appendix D-20. The epilimnion volume represents the predicted epilimnion volume at the end of the time period.

B - See Appendix D-20.

C - P load from surface runoff (See Appendix D-20, Column C) reduced by the TP Load Reduction percentage for all timesteps.

D - No upstream sources of phosphorus to Lee Lake.

E - See Appendix D-20.

F - P load from Curlyleaf Pondweed (See Appendix D-20, Column F) reduced by the TP Load Reduction percentage for all timesteps.

G - P load adjustment sources (positive values) reduced by TP Load Reduction percentage while P load adjustment sinks (negative values) reduced proportionately based on the mass of TP in epilimnion for individual timesteps.

H - See Appendix D-20.

I - Discharge from the lake includes surface discharge and losses to groundwater multiplied by the total phosphorus concentration from the previous time period.

J - P In-Lake @ End of Period = B + C + D + E + F + G - H - I

K - Predicted In-Lake P = J / A / 0.00272

D-24: Lee Lake - Average Climatic Condition Phosphorus Reduction Required to Estimate TMDL Load Capacity
Reduction Required to Meet MPCA Standard of 54 ug/L (10% MOS)

TP Load Reduction (%)[1]		A	B	C	D	E	F	G	H	I	J	K
42.1		Epilimnion Volume	P In-Lake @ Start of Period	P Surface Runoff (after Particulate Settling)[6]	P From Upstream Sources	P Atmospheric	P Release from Curlyleaf Pondweed	P Adjustment Load	P Uptake by Coontail	P Loss due to Discharge	P In-Lake @ End of Period	Predicted In-Lake P
		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/L
(Oct 1, 2005 - April 30, 2006)[5,7]		121	N/A	34	0	3	0	N/A	0	7	N/A	43
5/1/06	5/3/06	121	14.3	0.0	0.0	0.0	0.0	-1.5	0.1	0.1	12.7	38.4
5/4/06	5/16/06	120	12.7	0.6	0.0	0.2	0.0	4.2	0.5	0.4	16.7	51.3
5/17/06	5/31/06	115	16.7	0.1	0.0	0.2	0.0	-5.6	0.6	0.6	10.2	32.4
6/1/06	6/15/06	111	10.2	0.3	0.0	0.2	1.0	13.5	0.7	0.4	24.2	80.2
6/16/06	6/28/06	113	24.2	1.5	0.0	0.2	3.0	-8.8	0.6	0.8	18.7	61.0
6/29/06	7/13/06	108	18.7	0.2	0.0	0.2	1.4	4.4	0.7	0.7	23.4	79.7
7/14/06	7/26/06	106	23.4	0.9	0.0	0.1	0.3	-7.6	0.7	0.7	15.7	54.4
7/27/06	8/8/06	114	15.7	3.0	0.0	0.2	0.1	-7.7	0.7	0.5	10.1	32.4
8/9/06	8/22/06	112	10.1	0.5	0.0	0.2	0.0	5.1	0.7	0.4	14.8	48.6
8/23/06	9/6/06	140	14.8	2.5	0.0	0.2	0.0	-2.2	0.8	0.6	14.0	36.8
9/7/06	9/20/06	140	14.0	0.2	0.0	0.2	0.0	9.8	0.7	0.4	23.1	60.6
Growing Season Total (May 1, 2006 - Sept 30, 2006)[7]		N/A	N/A	9	0	1	6	6	6	4	N/A	N/A
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[7]		N/A	N/A	44	0	5	6	4	7	13	N/A	N/A

Growing Season Average (ug/L)[2]	**54.0**
Growing Season Average Chlorophyll-*a* (ug/L)[3]	**20.6**
Growing Season Average Secchi Depth (m)[4]	**1.4**

Predictive Mass Balance Equation: Ppredict = Pinitial + Psurf + Pus + Patm + Pclpw + Pint - Pcoon - Pdis

1 - To estimate the Loading Capacity (and the required reduction in existing TP loads), P Surface Runoff, P Release from Curlyleaf Pondweed, and P Adjustment Load (See Note G), were reduced equally until the MPCA standard was met.
2 - Growing Season Average includes predicted data from 5/31/2006
3 - Based on Chla vs TP water quality relationship (Chla = 0.3092 * TP + 3.9315). See Figure 3-17.
4 - Based on SD vs TP water quality relationship (SD = 11.092 * TP ^ (-0.52)). See Figure 3-16.
5 - To estimate the load reduction, it was assumed that the steady-state concentration in the lake at the beginning of the season (May 1) was not impacted by the estimated reductions in total phosphorus loads (same as existing conditions).
6 - Because the phosphorus mass balance modeling was not performed for the period from October 1, 2005 - April 30, 2006, the reported value reflects the total watershed runoff load, not the phosphorus load after particulate settling.
7 - For Total Loads, total rounded to the nearest pound for reporting purposes.
A - See Appendix D-20. The epilimnion volume represents the predicted epilimnion volume at the end of the time period.
B - See Appendix D-20.
C - P load from surface runoff (See Appendix D-20, Column C) reduced by the TP Load Reduction percentage for all timesteps.
D - No upstream sources of phosphorus to Lee Lake.
E - See Appendix D-20.
F - P load from Curlyleaf Pondweed (See Appendix D-20, Column F) reduced by the TP Load Reduction percentage for all timesteps.
G - P load adjustment sources (positive values) reduced by TP Load Reduction percentage while P load adjustment sinks (negative values) reduced proportionately based on the mass of TP in epilimnion for individual timesteps.
H - See Appendix D-20.
I - Discharge from the lake includes surface discharge and losses to groundwater multiplied by the total phosphorus concentration from the previous time period.
J - P In-Lake @ End of Period = B + C + D + E + F + G - H - I
K - Predicted In-Lake P = J / A / 0.00272

Appendix E

2008 Sediment Core Analysis Summary

Sediment Investigation for the Crystal, Keller, and Lee Lakes TMDL Report

Sediment Cores were collected in June 2008 to determine sediment phosphorus concentrations that can lead to internal phosphorus loading in Crystal, Keller, and Lee Lakes. Phosphorus fractions were determined according to a modified version of Psenner et al. (1988) and internal loading estimates were calculated according to the method developed by Pilgrim et al. (2007). After laboratory analysis, sediment phosphorus concentrations were modeled to determine lake wide internal phosphorus loading rates using Geostatistical Analysis within the ArcMap GIS program. The data are presented below and summarized in the accompanying maps.

Crystal, Keller, Lee, and Earley Lakes Nutrient Impairment TMDL: Sediment Core Analysis Summary

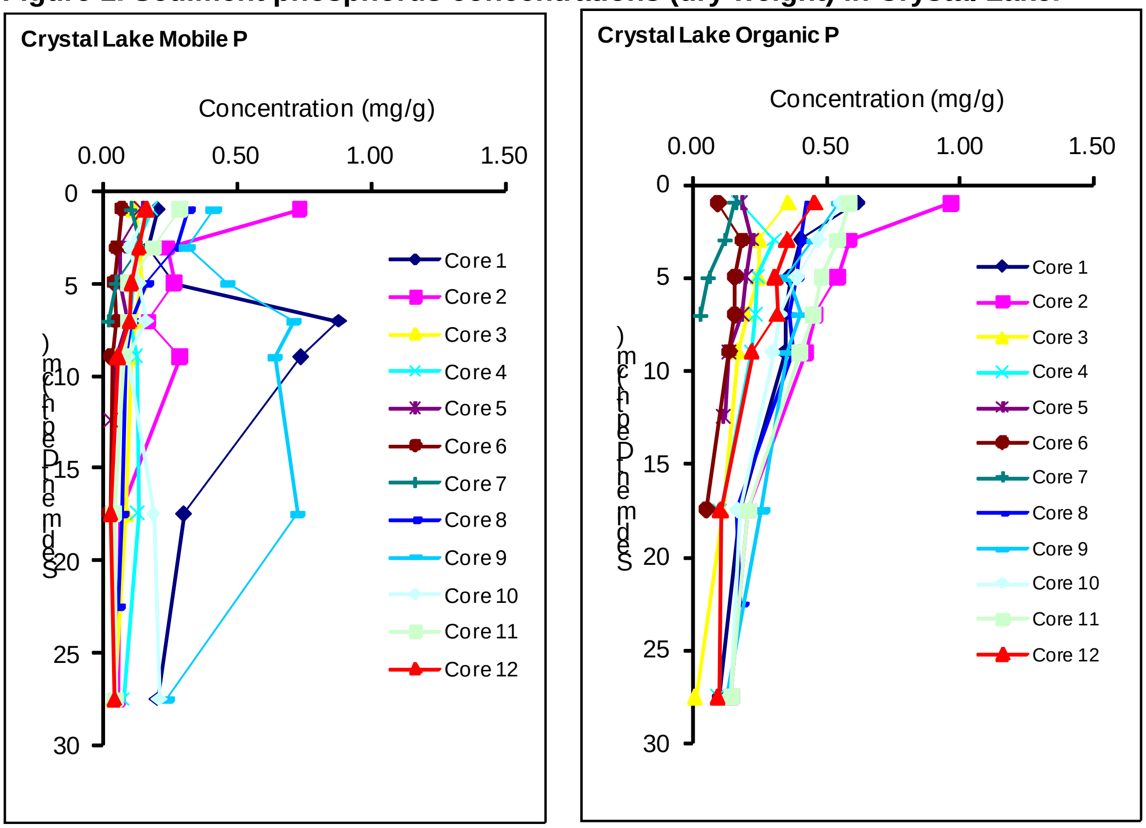
	Crystal Lake	Keller Lake	Lee Lake
Core[1]	**Mobile P ($mg/m^2/d$)**	**Mobile P ($mg/m^2/d$)**	**Mobile P ($mg/m^2/d$)**
1	3.25	0.52	4.78
2	1.51	2.80	13.35
3	0.19	0.57	3.97
4	0.48	--	3.81
5	0.45	--	8.23
6	0.06	--	--
7	3.10	--	--
8	1.38	--	--
9	4.35	--	--
10	0.31	--	--
11	0.90	--	--
12	0.02	--	--
Geostatistical Summary			
Average	1.04	1.00	5.40
Minimum	0.02	0.52	3.44
Maximum	4.37	2.80	13.46

1 - Sediment cores collected June 2008

Results

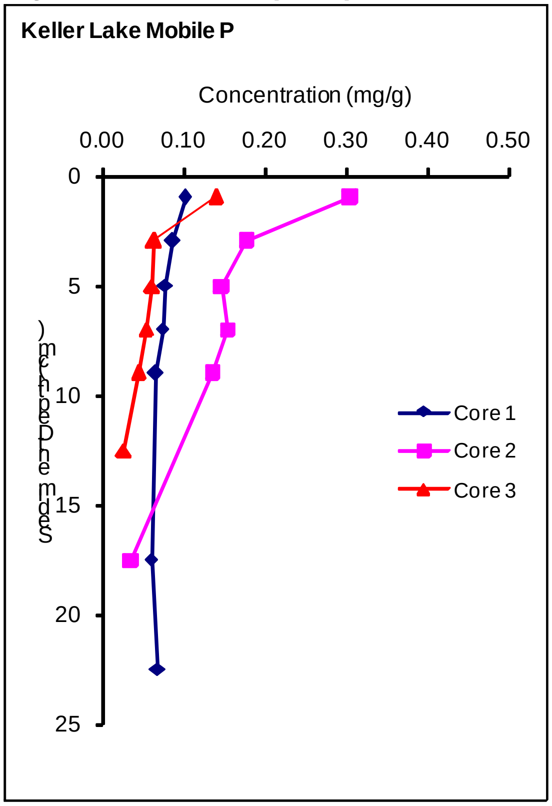
Twelve sediment cores were collected from Crystal Lake and analyzed for mobile phosphorus (contributes directly to internal phosphorus loading) and organic bound phosphorus (Figure 1).

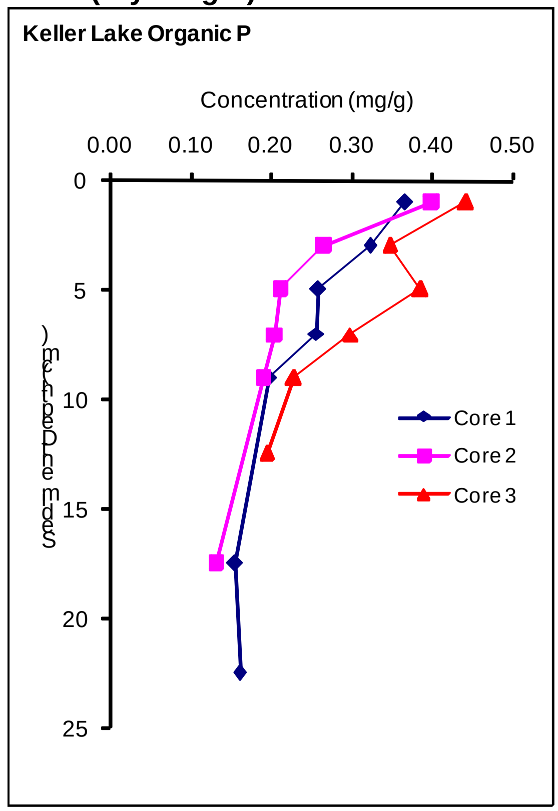
Figure 1. Sediment phosphorus concentrations (dry weight) in Crystal Lake.



Three sediment cores were collected from Keller Lake and analyzed for mobile phosphorus (contributes directly to internal phosphorus loading) and organic bound phosphorus (Figure 2).

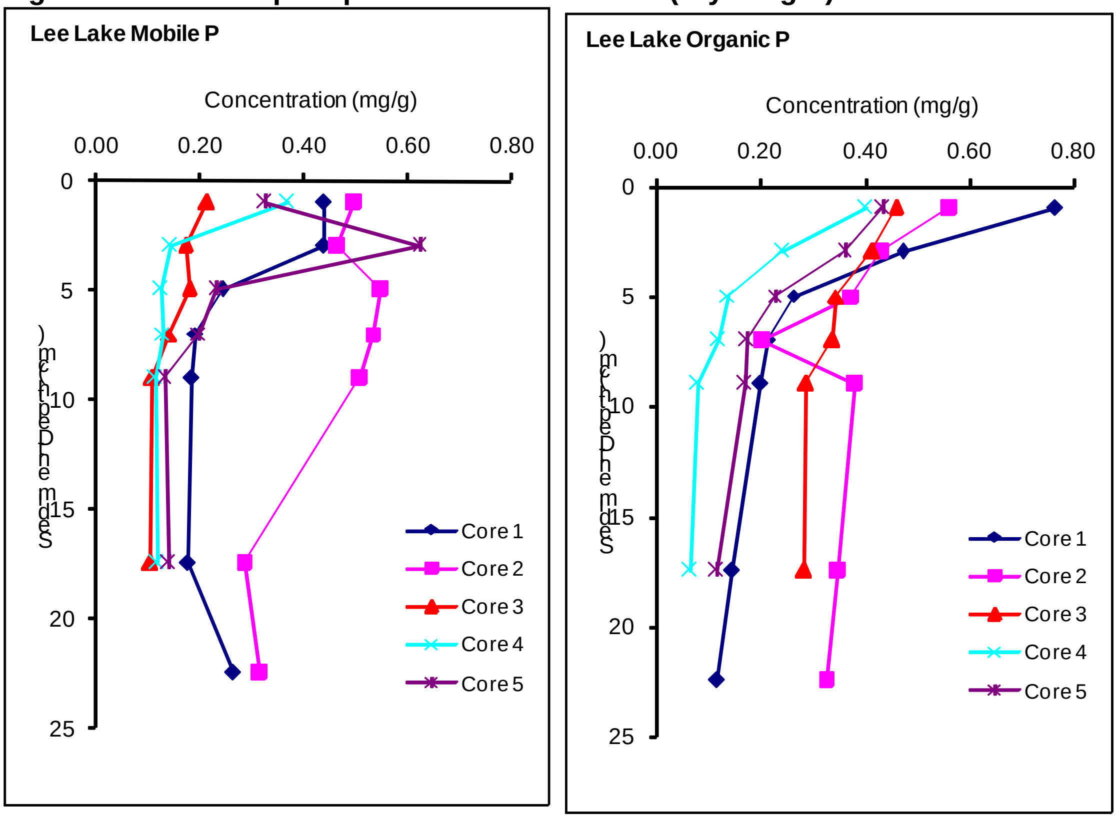
Figure 2. Sediment phosphorus concentrations (dry weight) in Keller Lake.



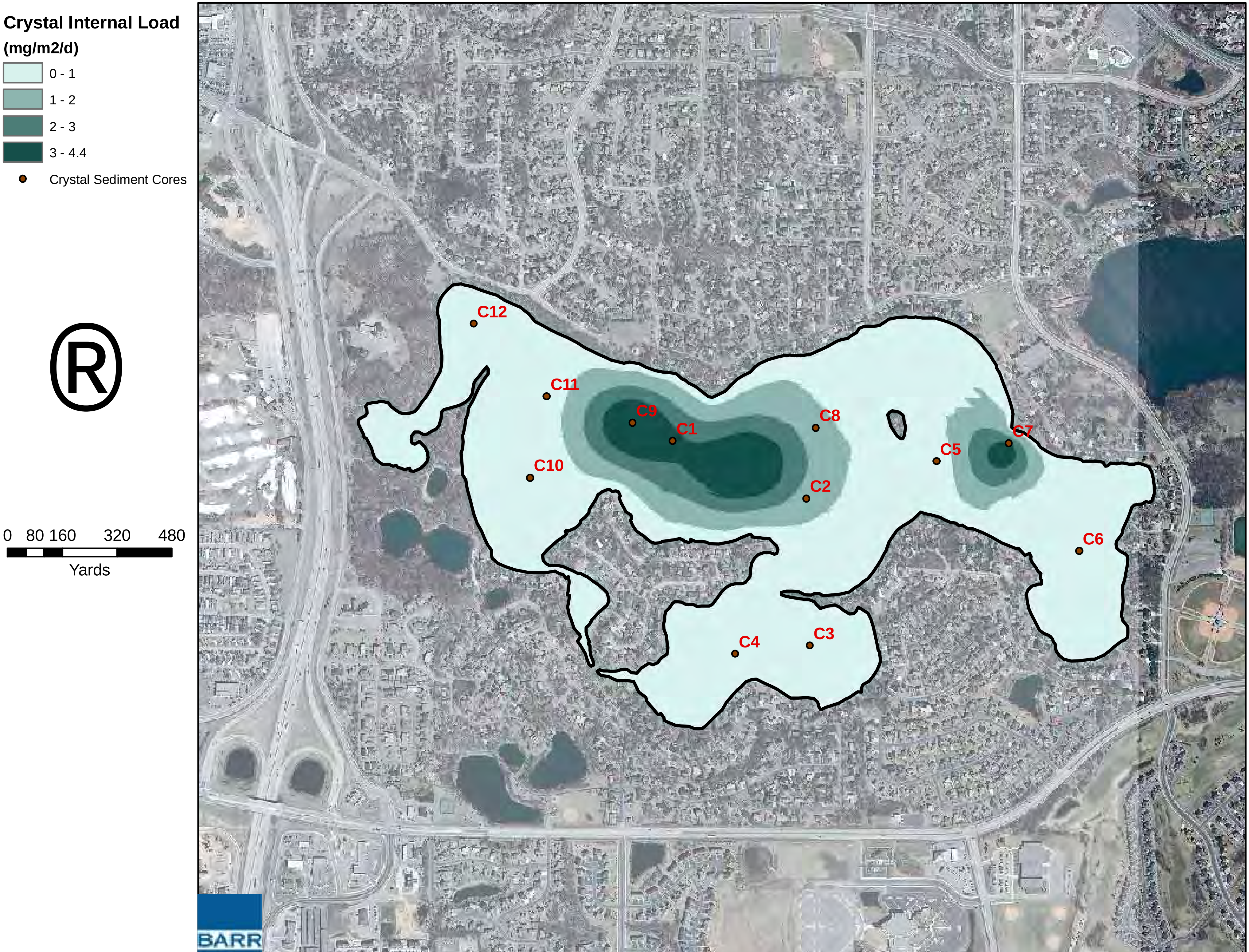


Five sediment cores were collected from Lee Lake and analyzed for mobile phosphorus (contributes directly to internal phosphorus loading) and organic bound phosphorus (Figure 3).

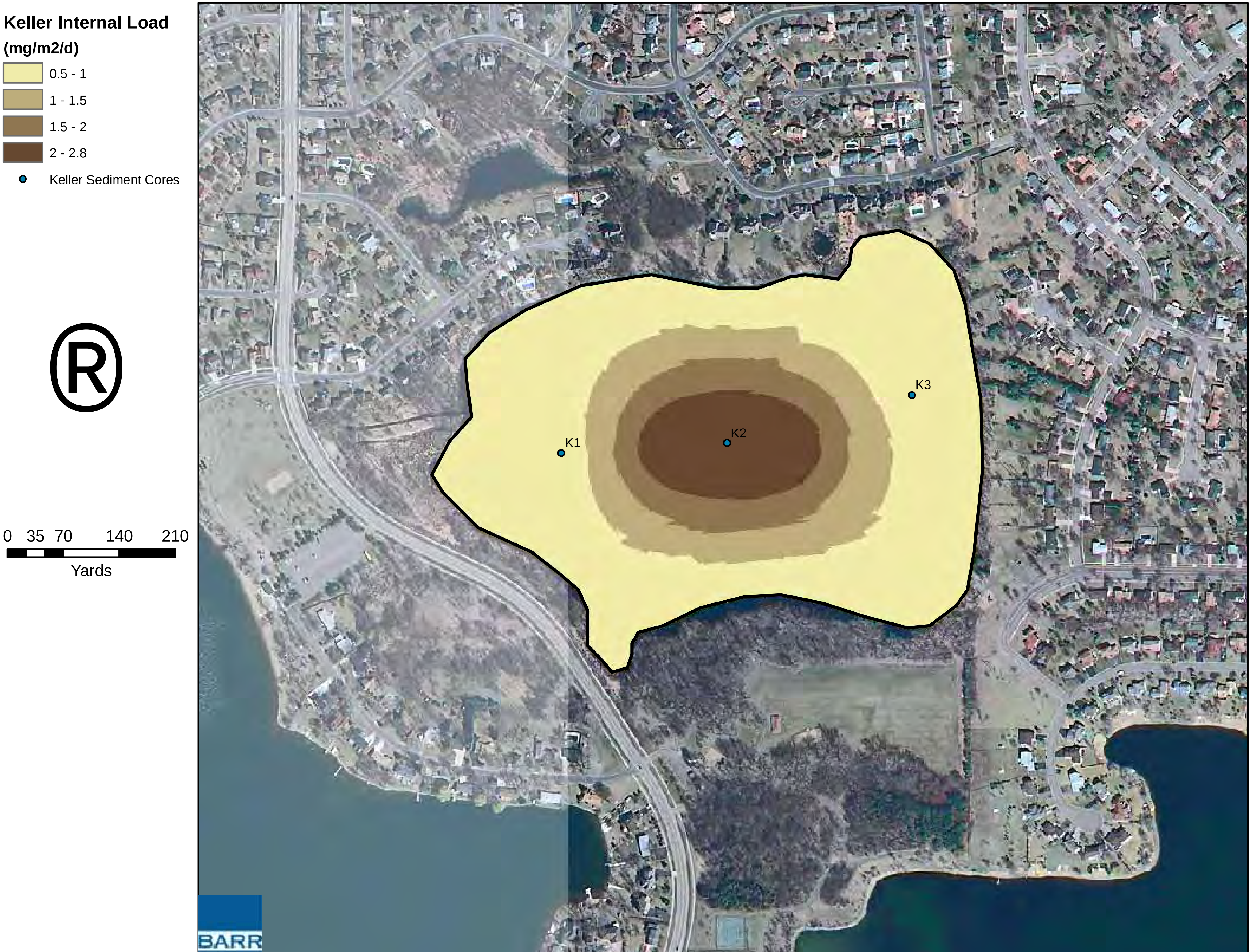
Figure 3. Sediment phosphorus concentrations (dry weight) in Lee Lake.

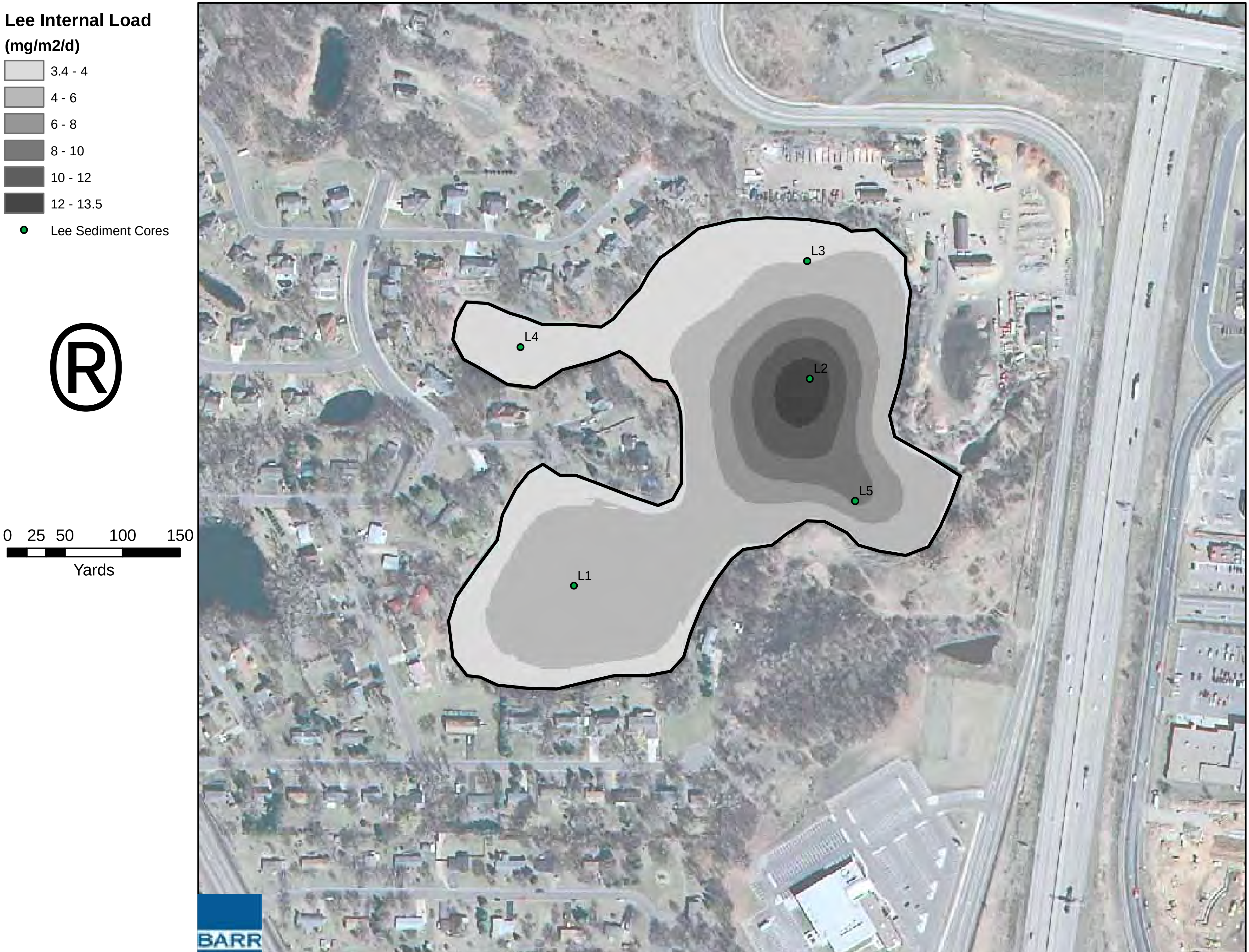


High organic bound phosphorus may indicate that available mobile phosphorus that is exported from the sediment during internal loading is used quickly by algae and/or plants. This is especially likely in shallower areas of the lake where water movement can move phosphorus released from the sediment to the surface water or algae are present near the sediment surface where sufficient light is available for growth. Over time, excess organic phosphorus in the upper part of the sediment will degrade and contribute to the mobile phosphorus pool which can lead to internal phosphorus loading.



Crystal Internal Load
(mg/m2/d)
0 - 1
1 - 2
2 - 3
3 - 4.4
Crystal Sediment Cores
0 80 160 320 480
Yards
C12
C11
C9
C1
C8
C10
C2
C5
C7
C6
C4
C3
BARR


Keller Internal Load
(mg/m2/d)
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.8
Keller Sediment Cores
0 35 70 140 210
Yards
K1
K2
K3
BARR


Lee Internal Load
(mg/m2/d)
3.4 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12 - 13.5
Lee Sediment Cores
0 25 50 100 150
Yards
L1
L2
L3
L4
L5
BARR

Appendix F

Ferric Chloride System Pump Logs - 2006

2006 Ferric Chloride Dosing System Log

Date	Initials	Pump Hours	Pump On (Yes or No)	Chemical Pump Settings Speed	Chemical Pump Settings Stroke	Chemical Remaining (Gal.)	Chemical Added (Gal)	Milfoil Screen Inspected	Status of Screen	Air Burst System Operated (Yes/No)	Comments
25-Apr	SB	17874.4	no	50	5.5		1,050	yes	ok	yes - tested	
27-Apr	SB	17900.3	yes	50	5.5	1,200		no		yes	Started site up for season
11-May	SB	18232.4	yes	50	5.5	800		yes	ok	yes	
17-May	SB	18379.5	yes	50	5.5	700		yes	ok	yes	
24-May	SB	18546.3	yes	50	5.5	600		yes	ok	yes	
31-May	SB	18644.5	yes	50	5.5	580		no		yes	Pump out because overtemp. Called Hayes Electrical. Everything was ok with pump and to watch.
5-Jun	SB	18702	yes	50	5.5	500		no		yes	Changed from upper to lower intake, forgot to switch at start up. Both weekends when the pump went out were hot days.
7-Jun	SB	18752.3	yes	50	5.5	430		yes	ok	no - on lower intake	Ordered more chemical
8-Jun	SB	18779.4	yes	50	5.5	420	1000	yes	ok	no	Added 1000 gal
9-Jun	SB	18804.6	yes	50	5.5	1,400		yes	ok	no	
12-Jun	SB	18870.8	yes	50	5.5	1,320		yes	ok	yes	
16-Jun	SB	18966.9	yes	50	5.5	1200		yes	ok	no	
23-Jun	SB	19140.4	yes	50	5.5	1050		yes	ok	no	
30-Jun	SB	19307.6	yes	50	5.5	900		yes	ok	yes	
12-Jul	SB	19590	yes	50	5.5	740		yes	ok	yes	Switched from lower to upper intake/ installed risers
13-Jul	SB	19639.5	yes	50	5.5	660		yes	ok	yes	
17-Jul	SB	19709.5	yes	50	5.5	600		yes	ok	yes	
21-Jul	JS	19806.3	yes	50	5.5	560		yes	ok	yes	Ordered more chemical
25-Jul	JS	19839.2	yes	50	5.5	1,500	1,000	yes	ok	yes	Pump out because overtemp. Restarted pump.
27-Jul	JS	19887.7	yes	50	5.5	1450		yes	ok	yes	
28-Jul	JS	19913.6	yes	50	5.5	1430		yes	ok	yes	
30-Jul	JS	19934.8	yes	50	5.5	1420		no		yes	Pump out because overtemp. Restarted pump.
31-Jul	KT	19944.8	no	50	5.5	1420				yes	Overtemp light on. Reset pump.
4-Aug	SAS	19950	no	50	5.5	1420		yes	ok		Overtemp light on. Reset pump.
7-Aug	JS	19968.5	no	50	5.5	1400		yes	ok	yes	Pump out because overtemp. Restarted pump.
8-Aug	SB	19991.5	yes	50	5.5	1,380		yes	ok	yes	
11-Aug	JS	20009.2	no	50	5.5	1,370		no		yes	Pump out because overtemp. Restarted pump.
14-Aug	SB	20015.3	no	50	5.5	1350		yes	ok	yes	Pump out because overtemp. Restarted pump.
18-Aug	SB	20081.9	yes	50	5.5	1310		yes	ok	yes	
24-Aug	SB	20231	yes	50	5.5	1240		yes	ok	yes	
28-Aug	SB	20323.9	yes	50	5.5	1,200		yes	ok	yes	
31-Aug	SB	20400.8	yes	50	5.5	1180		yes	ok	yes	
8-Sep	SB	20590.7	yes	50	5.5	1,060		yes	ok	yes	
15-Sep	SB	20758.2	yes	50	5.5	1000		yes	ok	yes	
22-Sep	JS	20923.4	yes	50	5.5	900		yes	ok	yes	
28-Sep	SB	21071.1	yes	50	5.5	820		yes	ok	yes	
6-Oct	JS	21260.6	yes	50	5.5	730		yes	ok	yes	
12-Oct	SB	21406.2	yes	50	5.5	640		yes	ok	yes	Winterized site, Notified Scott of chem level.
16-Oct	SB	21499.4	yes	50	5.5	600		yes	ok	yes	
26-Oct	SB	21743.9	yes	50	5.5	500		yes	ok	yes	
2-Nov	JS	21910.9	yes	50	5.5	400		yes	ok	yes	
13-Nov	SB	22175.9	yes	50	5.5	100		yes	ok	yes	Shut off chem feed. Will put approx 150 gal water to flush system on 11-14.
14-Nov	SB	22175.9	no	100	10	150	150 water	no	-	-	Added 150 gal water flush system & turned pump settings to full
20-Nov	SB	22250.3	yes	100	10	100		yes	ok	yes	Shut site down for winter. Reset pump to orgional settings speed 50% and stroke 5.5

Figure 3. Crystal Lake $FeCl_3$ Treatment System
2006 Operations