Lake Magda Nutrient TMDL
FINAL

Prepared for

Shingle Creek Watershed Management Commission

Minnesota Pollution Control Agency

September 2010

Wenck

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FINAL

Wenck File #1240-22

Prepared for:

SHINGLE CREEK WATERSHED MANAGEMENT COMMISSION

MINNESOTA POLLUTION CONTROL AGENCY

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September 2010

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Engineers • Scientists

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Lake Magda was added to the 303(d) list in 2002 because of excess nutrient concentrations impairing aquatic recreation, as set forth in Minnesota Rules 7050.0150 and 7050.0222. This TMDL was prioritized to start in 2008 and be completed by 2012.</td><td>2-1</td></tr>
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MS400170-Mn/DOT</td><td>0.029</td></tr></table></td></tr>
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TMDL Summary Table		
EPA/MPCA Required Elements	**Summary**	**TMDL Page #**
Reasonable Assurance	Reasonable assurance is provided by the cooperative efforts of the Shingle Creek Watershed Commission, a joint powers organization with statutory responsibility to protect and improve water quality in the water resources in the Shingle Creek watershed in which this lake is located, and by the member cities of this organization. In addition, the entire contributing area to this lake is regulated under the NPDES program, and Minnesota's General Permit requires MS4s to amend their NPDES permit's Storm Water Pollution Prevention Program within 18 months after adoption of a TMDL to set forth a plan to meet the TMDL wasteload allocation.	Section 8
Monitoring	The Shingle Creek Watershed Management Commission periodically monitors these lakes and will continue to do so through the implementation period.	8-3
Implementation	This TMDL sets forth an implementation framework and general load reduction strategies that will be expanded and refined through the development of an Implementation Plan.	Section 7
Public Participation	Public Comment period: March 22, 2010 – April 21, 2010 Three public comments were received on the Draft TMDL.	Section 6

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses a nutrient impairment in Lake Magda (27-0065). The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients.

Lake Magda is located in the City of Brooklyn Park, Hennepin County, Minnesota, in the Shingle Creek watershed. It is a neighborhood lake that provides primarily aesthetic values. The drainage area to the lake is 62 acres of fully developed urban and suburban land. The drainage area is entirely in the City of Brooklyn Park. Lake Magda outlets into wetland on the west side of TH 169, then through storm sewer to Eagle Creek. Eagle Creek is a tributary to Shingle Creek, which ultimately discharges into the Mississippi River. Water quality is considered poor and not supportive of recreational activities, with frequent algal blooms.

Wasteload and Load Allocations to meet State standards indicate that a nutrient load reduction of 69 percent would be required to consistently meet standards under average precipitation conditions. Internal load management and reduction of nonpoint sources of phosphorus in the watershed by retrofitting Best Management Practices (BMPs) would have the most impact on reducing phosphorus load and improving water quality in Lake Magda.

1.0 Introduction

1.1 PURPOSE

This Total Maximum Daily Load (TMDL) study addresses a nutrient impairment in Lake Magda. The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients in Lake Magda. The Lake Magda Nutrient TMDL is being established in accordance with section 303(d) of the Clean Water Act, because the State of Minnesota has determined waters in Lake Magda exceed the State established standards for nutrients.

This TMDL provides waste load allocations (WLAs) and load allocations (LAs) for Lake Magda. Based on the current State standard for nutrients, the TMDL establishes a numeric target of 60 µg/L total phosphorus concentration for shallow lakes in the North Central Hardwood Forest ecoregion.

1.2 PROBLEM IDENTIFICATION

Lake Magda (DNR Lake # 27-0065) was first placed on the State of Minnesota's 303(d) list of impaired waters in 2002 and identified for impairment of aquatic recreation (swimming). Lake Magda is a neighborhood lake located in the city of Brooklyn Park. There is city-owned open space adjacent to the lake. The primary lake use is its aesthetic value, although the lakeshore residents do use it for paddle boating and recreational fishing.

2.0 Water Quality Standards and Numeric Targets

2.1 IMPAIRED WATERS AND MINNESOTA WATER QUALITY STANDARDS

2.1.1 State of Minnesota Standards and Designated Uses

Lake Magda is a small, shallow lake classified as a class 2B water for which aquatic life and recreation are the protected beneficial uses. The MPCA (Minnesota Pollution Control Agency) first included Lake Magda on the 303(d) impaired waters list for Minnesota in 2002. The lake is impaired by excess nutrient concentrations, which inhibit aquatic recreation. The MPCA's projected schedule for TMDL completions, as indicated on the 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. The TMDL was scheduled to be initiated in 2008 and completed by 2012. 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.

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

The numeric target used to list this lake was the numeric translator threshold phosphorus standard for Class 2B waters in the North Central Hardwood Forest ecoregion (40 µg/L) prior to adoption of new standards in 2008 (Table 2.1). Under the new standards (Minnesota Rules 7050.0150 and 7050.0222, Subp. 4), Lake Magda is now considered a shallow lake with a numeric target of ≤60 µg/L for total phosphorus. Therefore, this TMDL presents load and wasteload allocations and estimated load reductions assuming an end point of ≤60 µg/L for total phosphorus.

Although the TMDL is set for the total phosphorus standard, one of the two other eutrophication standards must also be met: chlorophyll-a and Secchi depth (see Table 2.1). All three of these parameters were assessed in this TMDL to assure that the TMDL will result in compliance with State standards. As shown in Table 2.1, Lake Magda numeric standards for chlorophyll-a and Secchi depth are ≤20 μg/L and ≥1.0 meters, respectively.

Table 2.1. Numeric targets for Lakes in the North Central Hardwood Forest Ecoregion.

Parameters	**North Central Hardwood Forest Ecoregion**	
	Shallow[1]	**Deep**
Total phosphorus concentration (μg/L)	**≤60**	≤40
Chlorophyll-a concentration (μg/L)	**≤20**	≤14
Secchi disk transparency (meters)	**≥1.0**	≥1.4

[1] Shallow lakes are defined as lakes with a maximum depth of 15 feet or less, or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone) (Minnesota Rules 7050.0150, Subp.4).

2.1.2 Analysis of Impairment

Lake Magda has been monitored about every three years by volunteers through the Citizen Assisted Monitoring Program (CAMP) administered by the Metropolitan Council and supported by the Shingle Creek Watershed Management Commission. Between 1999 and 2006 the summer average total phosphorus (TP) concentration has ranged from 101 μg/L to 187 μg/L. Chlorophyll-a (chl-a) concentration has ranged from 40 μg/L to 127 μg/L during the same period, while the Secchi depth is typically around 0.5 meters of clarity. All three parameters exceed the State standards for class 2B shallow lakes in the North Central Hardwood Forest ecoregion.

3.0 Watershed and Lake Characterization

3.1 LAKE AND WATERSHED DESCRIPTION

The lake and its drainage area are located within the City of Brooklyn Park (see Figure 3.1). Lake Magda is a small lake in a fully developed suburban residential watershed, with a state trunk highway abutting the lake on the west. Lake morphometry is shown in Table 3.1. A small wetland area abuts the lake to the north (see Figure 3.3). Lake Magda outlets into wetland on the west side of TH 169, then through storm sewer to Eagle Creek. Eagle Creek joins with Bass Creek to form Shingle Creek, which ultimately discharges to the Mississippi River. The area is mostly fully developed, with a 2000 Census population of about 740. Land use is shown in Table 3.2 below and on Figure 3.2.

Table 3.1. Lake Magda morphometry.

Parameter	Lake Magda
Surface Area (ac)	10.2
Average Depth (ft)	2 (est)
Maximum Depth (ft)	6.5 (est)
Volume (ac-ft)	22 (est)
Residence Time (years)	0.16 (est)
Littoral Area (ac)	10.2
Watershed (ac)	68.5

Table 3.2. 2000 land use in the Lake Magda watershed.

Land Use Class	Area (acres)	Percent
Single Family Residential	42.6	62%
Water	11.9	17%
Highway	9.4	14%
Park, Recreation, Preserve	4.6	7%
Total Area	68.5	100%

3.2 RECREATIONAL USES

Lake Magda is a developed lake and the watershed and lakeshore is primarily single family homes. There are no public parks or other recreational facilities located on the lake, although there is city-owned open space on the north. There are no known trails, boat launches or public swimming or fishing areas. Homeowners on the lake may periodically use the lake for canoeing, fishing or other limited recreational activities.

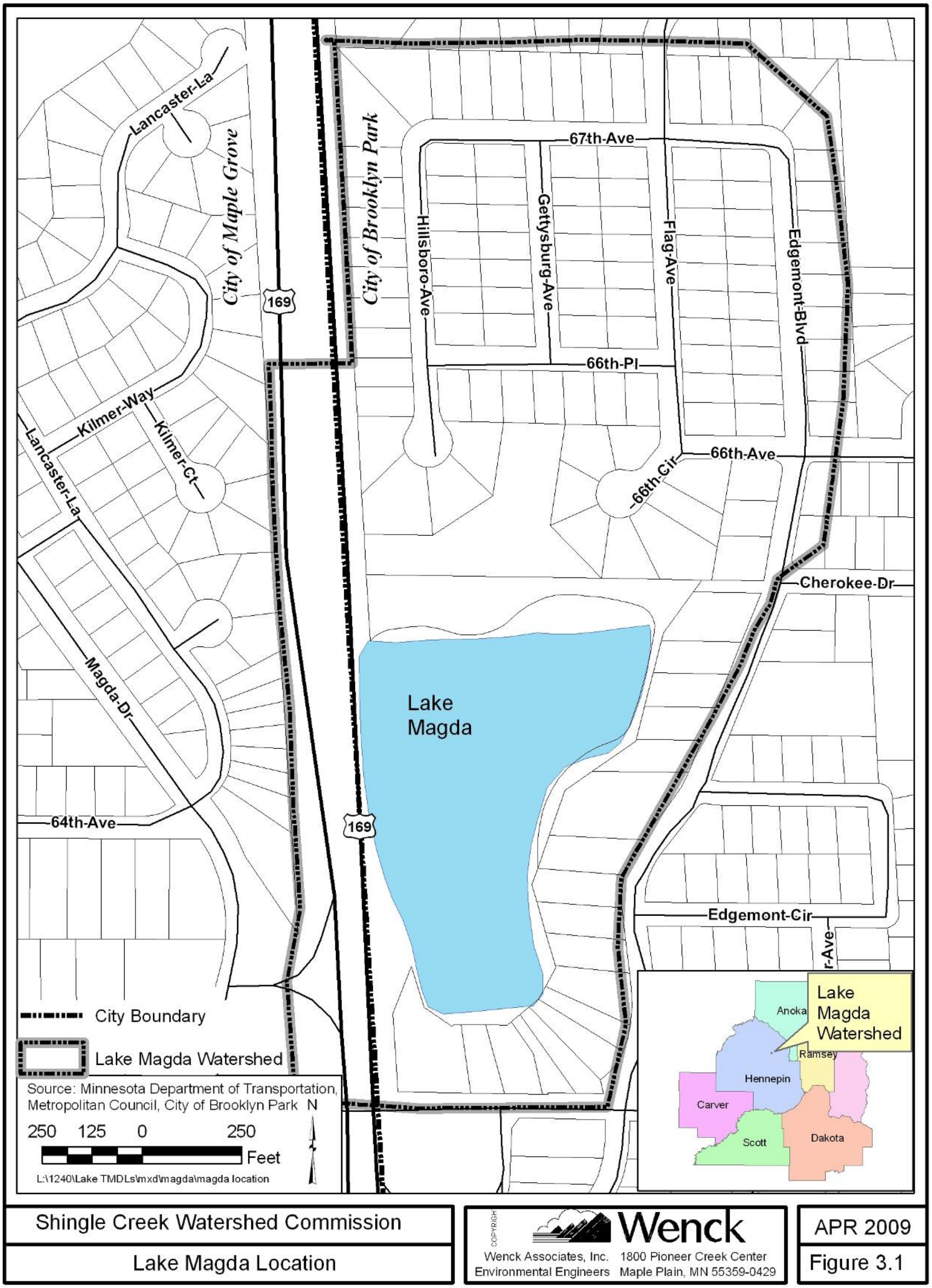

Figure 3.1. Lake Magda location.

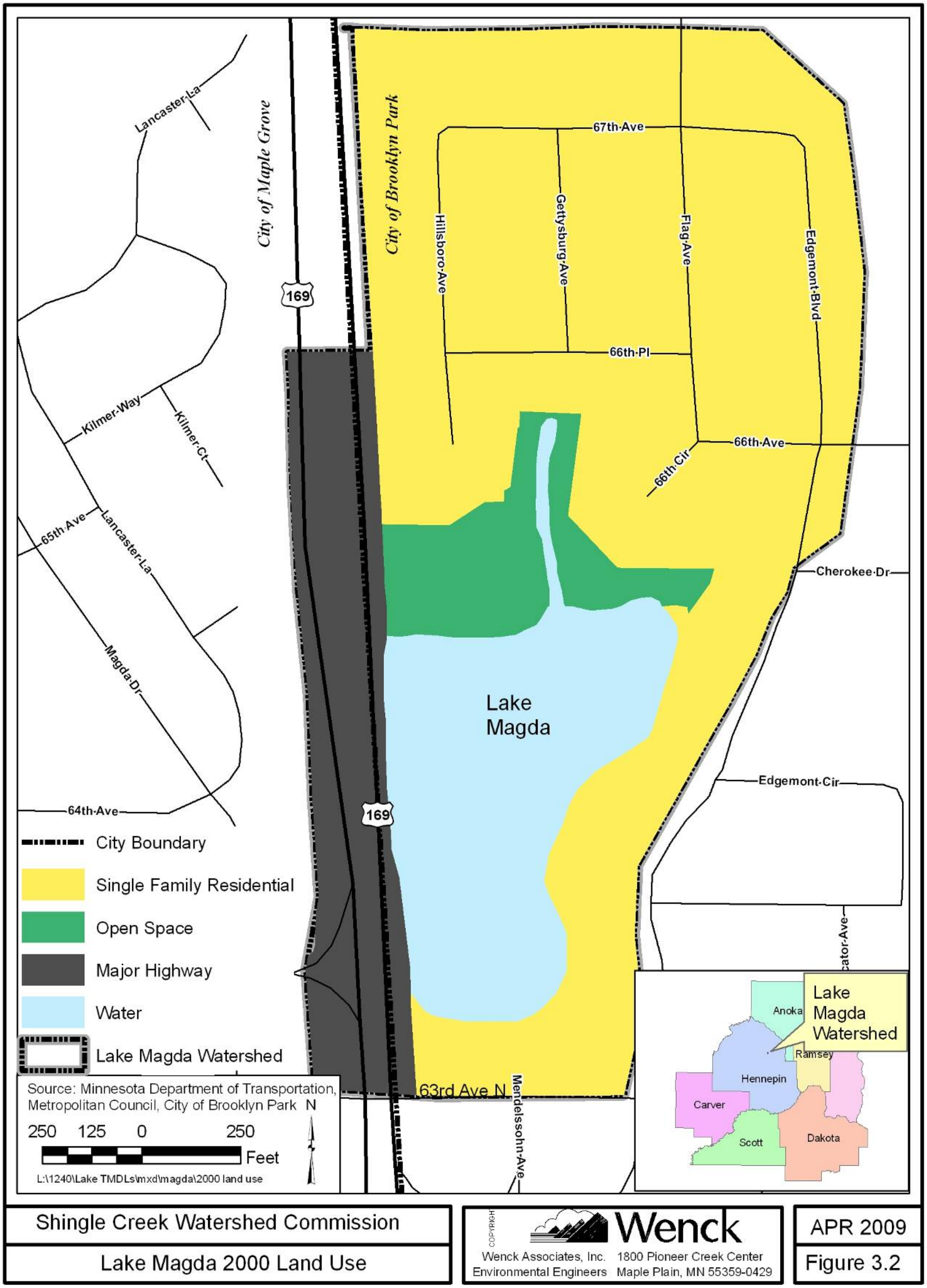

Figure 3.2. Lake Magda 2000 land use.

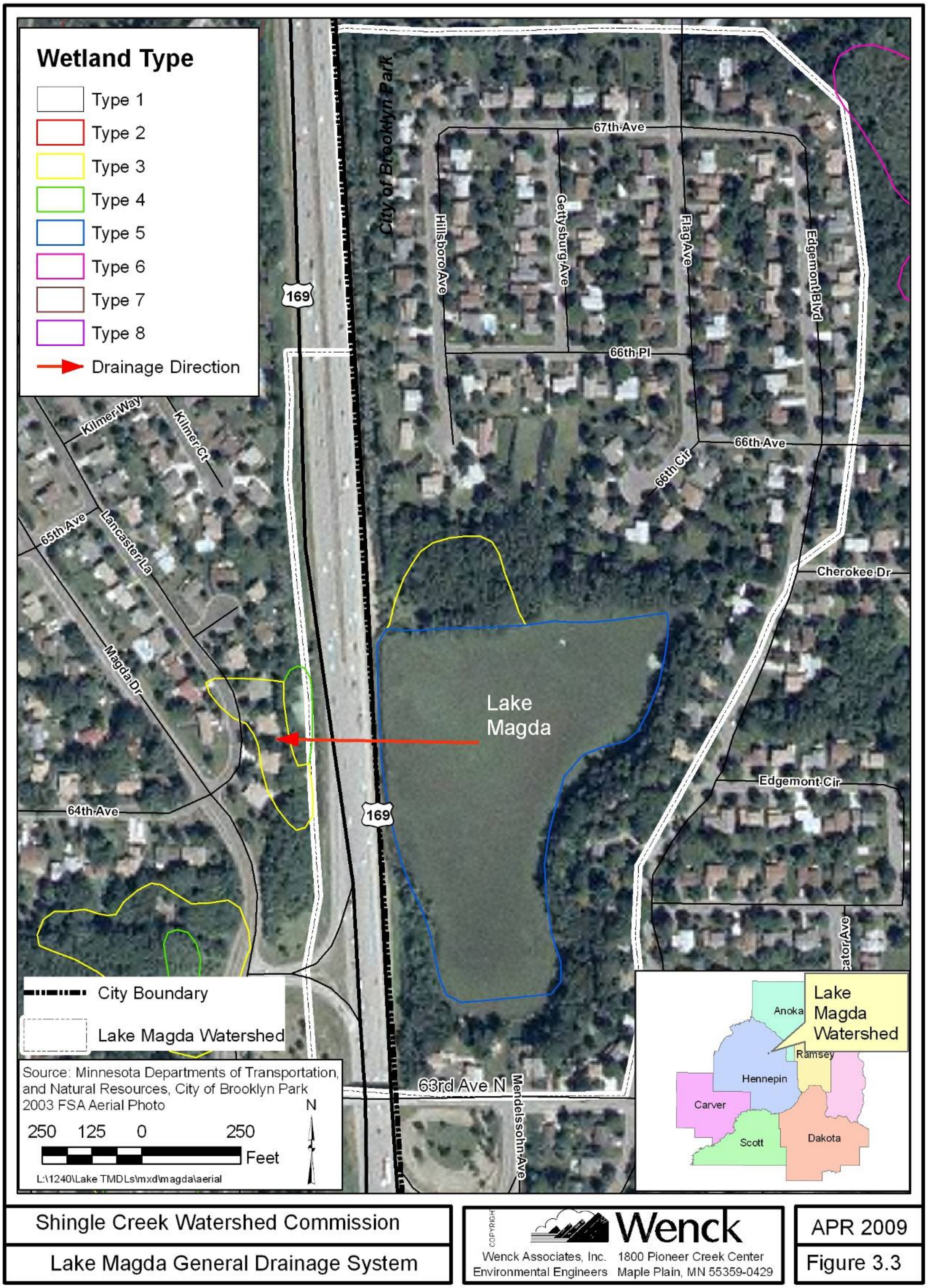

Figure 3.3. Lake Magda general drainage system.

3.3 WATER QUALITY

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

3.3.1 Historic Water Quality

Historic water quality is presented in Figure 3.4, Figure 3.5, and Figure 3.6. Summer average total phosphorus concentration in Lake Magda ranges from 100 µg/L to over 180 µg/L in the years for which data is available. For comparison, the numeric standard for Lake Magda is ≤60 µg/L.

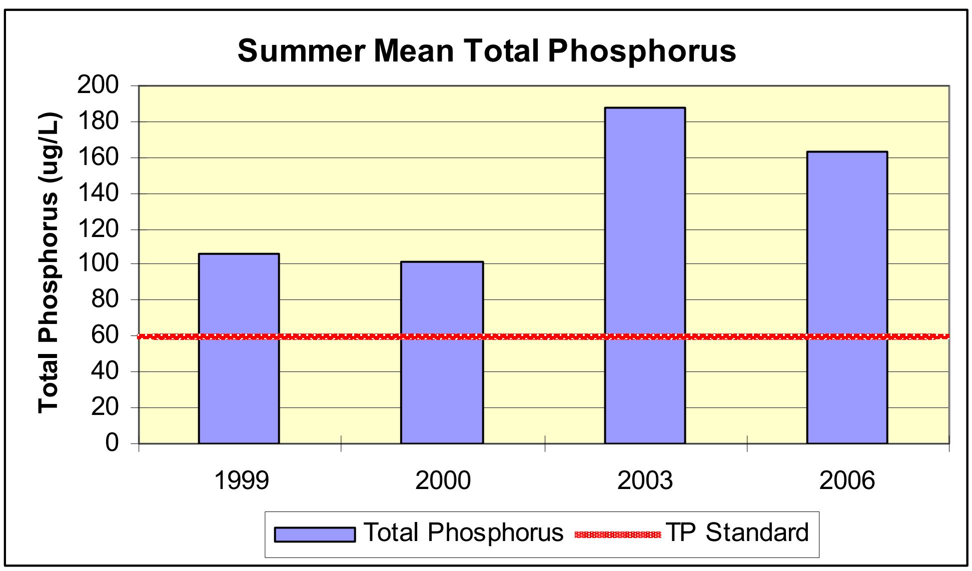

Figure 3.4. Summer (June 1 –September 30) mean total phosphorus concentrations.

A similar trend is observed in chlorophyll-a concentration although the highest concentration is observed in 2006 at over 120 µg/L. The numeric standard for Lake Magda is ≤20 µg/L for chlorophyll-a.

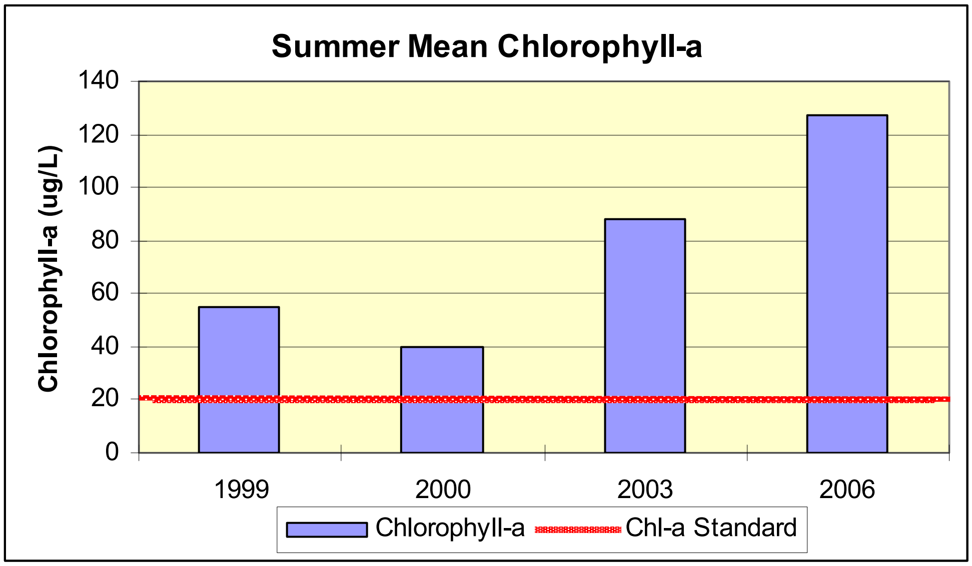

Figure 3.5. Summer (June 1 –September 30) mean chlorophyll-a concentrations.

Water clarity, as measured by Secchi depth, ranges from approximately 0.3 meters to 0.6 meters with the best water clarity observed in 2000 and the worst observed in 2006, coinciding with the large chlorophyll-a concentration observed in that year. The numeric standard for Lake Magda is 1.0 meter of clarity or more measured by Secchi depth.

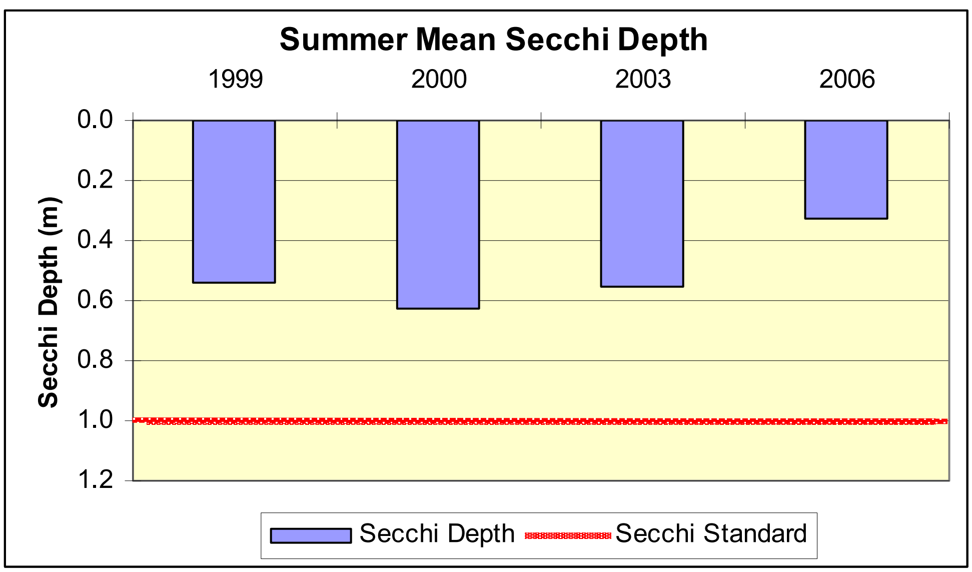

Figure 3.6. Summer (June 1 –September 30) mean Secchi depth (meters).

3.4 FISH POPULATIONS AND FISH HEALTH

3.4.1 Fish Populations

No fish data are available for Lake Magda. Residents report a large population of carp in the lake, but also various minnow and sunfish species.

3.4.2 Fish Kills

Fish kills occur when dissolved oxygen levels are so low that fish begin to die from the lack of oxygen. A fish kill of approximately 1,400 bullheads occurred in 1984.

3.4.3 Carp and Other Rough Fish

Common carp, black bullheads, and other rough fish have both direct and indirect effects on aquatic environments. They uproot aquatic macrophytes during feeding and spawning re-suspending bottom sediments and nutrients. These activities can lead to increased nutrients in the water column ultimately resulting in increased nuisance algal blooms. As noted above, residents report a significant population of carp are present, but no systematic survey has quantified or characterized the fish community.

3.5 AQUATIC PLANTS

3.5.1 Introduction

Aquatic plants are beneficial to lake ecosystems, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, and stabilization of sediments. However, in excess they limit recreational activities such as boating and swimming. Excess nutrients in lakes can lead to aquatic weeds and exotics taking over a lake. Some exotics can lead to special problems in lakes. For example, Eurasian water milfoil can reduce plant biodiversity in a lake because it grows in great densities and out-completes all the other plants. Ultimately, this can lead to a shift in the fish community because these high densities favor panfish over larger game fish. Species such as curly-leaf pondweed can cause very specific problems by changing the dynamics of internal phosphorus loading. All in all, there is a delicate balance between the aquatic plant community in any lake ecosystem.

3.5.2 Littoral Zone

The littoral zone is defined as that portion of the lake that is less than 15 feet in depth and is where the majority of the aquatic plants are found. The littoral zone of the lake also provides the essential spawning habitat for most warmwater fishes. There is limited bathymetry data for Lake Magda, but residents report the lake is shallow and less than 15 feet deep, meaning it is entirely littoral.

3.5.3 Aquatic Plants in Lake Magda

No systematic plant surveys have been conducted on Lake Magda. Residents report that the dominant aquatic species is sago pondweed, with curly-leaf pondweed, coontail and elodea also present.

3.6 SHORELINE HABITAT AND CONDITIONS

The shoreline areas are defined as the areas adjacent to the lake's edge with hydrophytic vegetation and water up to 1.5 feet deep or a water table within 1.5 feet from the surface. Natural shorelines provide water quality treatment, wildlife habitat, and increased biodiversity of plants and aquatic organisms. Natural shoreline areas also provide important habitat to fisheries including spawning areas and refugia as well as aesthetic values.

Vegetated shorelines provide numerous benefits to both lakeshore owners and lake users including improved water quality, increased biodiversity, important habitat for both aquatic and terrestrial animals, and stabilizing erosion resulting in reduced maintenance of the shoreline. Identifying projects where natural shoreline habitats can be restored or protected will enhance the overall lake ecosystem.

No systematic shoreline survey has been conducted, however, by observation the Lake Magda shoreline consists of turf grassed lawns on the east and south shores; wetland vegetation on the north shore, and unmaintained vegetation on the west shore slope abutting TH 169. Because the shoreline can be very steep and hard to maintain, many residents leave their shoreline areas unmowed.

4.0 Modeling Approach and Results

4.1 INTRODUCTION

Understanding the sources and magnitude of nutrient loads to Lake Magda is essential to developing the TMDL. Monitoring data, hydrologic models, and literature values were used to develop a nutrient budget for Lake Magda that estimates total phosphorus load contributions from each source. This budget and monitoring data were used to develop a calibrated lake response model that will be used in Section 5 of this report to establish the Total Maximum Daily Load (TMDL). The following sections describe the potential nutrient sources to Lake Magda, the models and data used to develop the nutrient budget and lake response model, and the validation of the modeling.

4.2 MODEL APPROACH

The model approach and modeling results are described in detail below. In general, two hydrologic models, SWMM (Storm Water Management Model) and P8 (Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds), were used to estimate the annual volume of runoff from the Lake Magda watershed. P8 was also used to estimate the annual nutrient load from the Lake Magda watershed. Literature values were used to estimate atmospheric and internal load. Those values were used to establish the current annual phosphorus budget for Lake Magda, and were input into a lake response model to predict various water quality parameters. Those predictions were compared to actual monitoring data to evaluate model accuracy. The lake response model (BATHTUB) was then used to develop the TMDL, which will be described in Section 4.4 of this report.

4.2.1 Watershed Load

Annual stormwater runoff volume was calculated by modeling the watershed area to the lake using two independent platforms: XP-SWMM and P8. Two platforms were used because the Shingle Creek Watershed Management Commission had previously developed and calibrated its Shingle Creek watershed-wide XP-SWMM model during the development of the *Shingle Creek Chloride TMDL* (Wenck 2007). The P8 model for the Lake Magda watershed was subsequently calibrated to match the Lake Magda watershed runoff volumes developed from the SWMM model (see below). P8 was then used to estimate watershed load.

SWMM Modeling. The Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity from primarily urban areas such as the Shingle Creek watershed. SWMM calculates stormwater runoff by catchment area, and routes it through pipes, channels, and storage/treatment devices, tracking the quantity of runoff generated within each subcatchment. SWMM was first developed in 1971, and is widely used throughout the world (http://www.epa.gov/ednnrmrl/models/swmm/index.htm).

The Shingle Creek watershed XP-SWMM model was derived from subwatershed, pipe, and storage information from cities' local water management plans; profile and cross section data on Shingle Creek; and U. S. Geological Survey (USGS) topographic maps. The Lake Magda watershed is one of 64 subwatersheds in the Shingle Creek XP-SWMM model. Flow data from several stream and pipe locations in the watershed collected in 2002 and 2003 (none of which were located in the Lake Magda watershed) was used to calibrate the SWMM model. The calibration was verified by comparing runoff volume monitored in 2002 at the USGS monitoring station on Shingle Creek at Queen Avenue to model-predicted volumes. The model predicted volume to within 5 percent during the summer season and to within 19 percent in the winter season. The winter results were considered reasonable given the uncertainty of flow records in winter monitoring performed under the ice.

P8 Modeling. For this analysis a separate P8 model was developed for the Lake Magda watershed. P8 (Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds) is a public domain (http://wwwalker.net/p8/), industry standard model developed to assess pollutant loading in urban watersheds such as Shingle Creek. P8 was developed using National Urban Runoff Program (NURP) pollutant loading data.

The P8-predicted annual runoff volume from the Lake Magda watershed was compared to the annual runoff volume predicted for the Lake Magda watershed by the calibrated Shingle Creek XP-SWMM model (Table 4.1). The P8 model calibration factors were adjusted as necessary so the predicted runoff more closely matched the SWMM results.

Table 4.1. Lake Magda watershed XP-SWMM and P8 discharge volume comparison.

Year	Annual Precipitation (in)	SWMM Annual Volume (ac-ft)	P8 Annual Volume (ac-ft)	Percent Difference
1992	35.3	155.0	127.9	-17%
1993	36.7	148.0	151.6	2%
1994	30.2	117.0	114.5	-2%
1995	33.1	131.0	131.5	0%
1996	29.5	110.0	127.3	16%
1997	34.1	146.0	123.6	-15%
1998	31.3	114.0	133.5	17%
1999	30.8	118.0	126.9	8%
2000	34.6	145.0	134.1	-8%
2001	35.4	148.0	159.4	8%
2002	43.3	190.0	183.8	-3%
2003	25.4	106.0	103.6	-2%

4.2.2 Atmospheric Load

Precipitation contains phosphorus that can ultimately end up in a lake from direct input on the lake surface or as a contribution of load to stormwater runoff. The watershed load modeling includes an estimate of deposition on the land, so atmospheric load is typically computed as a deposition rate over the surface area of the lake

A study conducted for the MPCA, “Detailed Assessment of Phosphorus Sources to Minnesota Watersheds” (Barr Engineering, 2004), estimated the atmospheric inputs of phosphorus from deposition for different regions of Minnesota. The rates vary based on the precipitation received in a given year and are categorized as below average (dry), average, or above average (wet). The estimated rates of deposition by precipitation year for the Twin Cities Metro Area are shown in Table 4.2.

Table 4.2. Atmospheric deposition rates per year for the Twin Cities Metro Area.

Type of Precipitation Year	Atmospheric Deposition Rate (kg/km^2)
Dry (<25” precipitation)	24.9
Average (25”-38”)	26.8
Wet (>38” precipitation)	29.0

Source: Barr Engineering 2004.

4.2.3 Internal Phosphorus Load

Internal phosphorus loading from lakes has been demonstrated to be an important aspect of the phosphorus budgets of lakes. This load can be a result of sediment anoxia, or low oxygen conditions, where poorly bound phosphorous is released from the sediments in a form readily available for phytoplankton production. Internal loading can also result from sediment resuspension that may result from rough fish activity, and as noted in section 3.4.1 above, lakeshore residents report a large population of carp in Lake Magda. Additionally, the invasive plant curly leaf pondweed can increase internal loading because it senesces and releases phosphorus during the summer growing season (late June to early July). As noted in section 3.5.3 above, residents report that some curly leaf pondweed is present in Lake Magda.

Measuring or estimating internal loads can be difficult, especially in shallow lakes that may mix many times throughout the year. While Lake Magda is a shallow lake, no data is available to determine its mixing frequency. No actual internal load data is available for Lake Magda.

Internal load can be estimated from the literature, using the anoxic factor approach (Nürnberg 2004), which estimates the period where anoxic conditions exist over the sediments, and uses a sediment phosphorus release rate from literature to estimate internal load. In the case of shallow lakes, an “anoxic factor” can be estimated from lake geomorphology and lake total phosphorus concentrations (Nürnberg 2004). The anoxic factor is expressed in days but is normalized over the area of the lake. For example, if the depth of oxygen depletion (<2 mg/L DO) was 3 meters, then the number of days would be multiplied by the anoxic area at that depth and divided by the entire area of the lake. Under this approach, a release rate is then selected based upon the eutrophic state of the lake. The selected release rates are a range based on previous lake studies (Figure 4.1; Nürnberg 1997).

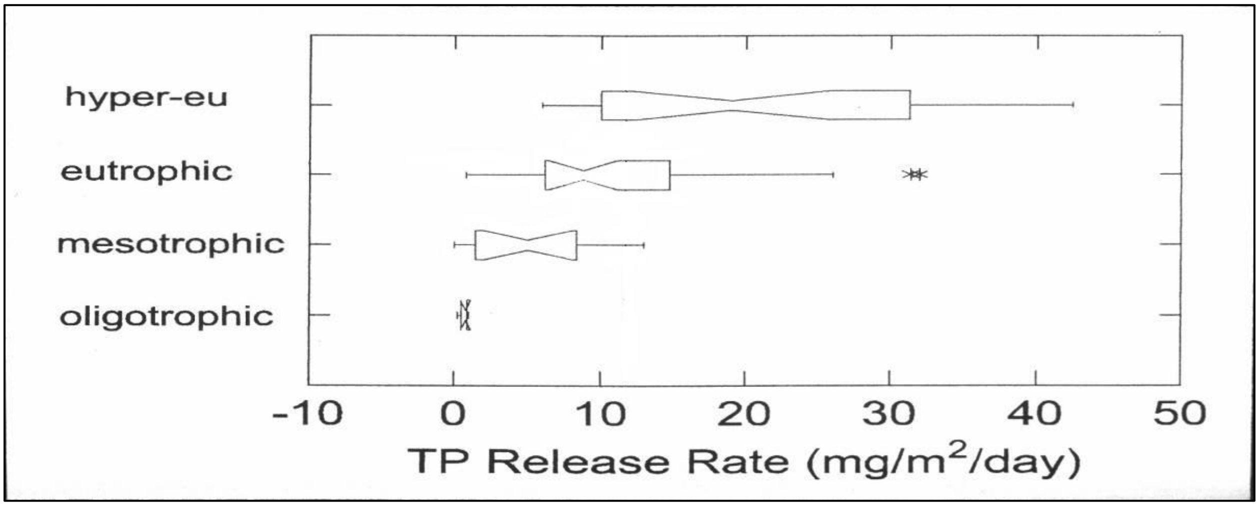

Figure 4.1. Sediment phosphorus release rates by eutrophic condition (Nürnberg 1997).

4.3 CURRENT PHOSPHORUS BUDGET

The current conditions phosphorus budget was developed using the P8 model, the atmospheric deposition load estimation, and the internal load evaluation.

4.3.1 Watershed Modeling Results

Following calibration, the P8 model was run using the current, 1997-2006 period of record rainfall and the NURP 50th percentile particle file to estimate Lake Magda watershed annual pollutant loading. The 50th percentile represents an average urban loading condition. Table 4.3 shows the model-estimated annual volumes and total phosphorus loads for that ten-year period as well as the ten-year average.

Table 4.3. Lake Magda P8 annual volume and total phosphorus (TP) load.

Year	Annual Precipitation (in)	Annual Volume (ac-ft)	Annual TP Load (pounds)	Annual Volume (hm^3)	Annual TP Load (kg)
1997	31.5	123.6	73.0	0.153	33.1
1998	34.9	133.5	83.1	0.165	37.7
1999	33.3	126.9	78.7	0.157	35.7
2000	34.1	134.1	83.3	0.165	37.8
2001	39.8	159.4	91.7	0.197	41.6
2002	46.7	183.8	103.2	0.227	46.8
2003	27.1	103.6	68.1	0.128	30.9
2004	35.1	133.1	82.1	0.164	37.2
2005	39.2	151.1	87.1	0.187	39.5
2006	32.8	127.5	75.7	0.157	34.3
Average	35.5	137.7	82.6	0.170	37.5

4.3.2 Atmospheric Load Modeling Results

The atmospheric load (kg/year) for Lake Magda was calculated by multiplying the lake area by the atmospheric deposition rate. For example, in an average precipitation year the atmospheric load to Lake Magda would be 26.8 kg/km^2-year (from Table 4.3) times the lake surface area (0.0414 km^2), which is 1.1 kg/year.

4.3.3 Internal Load Modeling Results

No dissolved oxygen profile data was available for Lake Magda. Consequently, we predicted the anoxic factor using a relationship with water quality and lake morphology established in Nürnberg 2004. Assuming a release rate of 6 mg/m^2/day, which is about the 25% percentile for eutrophic lakes, the internal load to Lake Magda is calculated to be approximately 14.6 kilograms per year (Table 4.4).

Table 4.4. Results of the internal load assessment using an anoxic factor and release rate for Lake Magda.

Year	Release Rate (mg/m^2/day)[1]	Anoxic Factor (days)	Gross Load (mg/m^2/summer)	Gross Load (kg)
Lake Magda[2]	6	59	354	14.6
	9	59	531	22.0
	12	59	708	29.3

[1]Estimated from Figure 4.1 (Nürnberg 1997).
[2]Anoxic factor predicted based on lake phosphorus concentration and lake morphology.

4.3.4 Current Phosphorus Budget

Phosphorus budgets were developed for 1997-2006 (see Table 1 in Appendix A and the detailed annual loading spreadsheets that follow Table 1). This period was selected because it includes high, average, and low precipitation years, and because it brackets four years when actual water quality data was collected in the lake: 1999, 2000, 2003, and 2006. Table 4.5 presents the current phosphorus input budget as the average annual total phosphorus load from watershed, atmospheric, and internal sources.

Table 4.5. Current total phosphorus input budget for Lake Magda for the period 1997-2006.

Source	Source	Average Annual TP Load (kg/yr)	Average Daily TP Load (kg/day)
Wasteload	Watershed Load	37.5	0.103
Load	Atmospheric Load	1.1	0.003
	Internal Load	14.6	0.040
	TOTAL LOAD	53.2	0.146

4.4 LAKE RESPONSE MODELING AND VALIDATION

The annual and average total phosphorus budgets for Lake Magda were input into a lake response model to estimate the water quality conditions by year. The U.S. Army Corps of Engineers' BATHTUB model predicts eutrophication-related water quality conditions (e.g., phosphorus, nitrogen, chlorophyll- a, and transparency) using empirical relationships previously developed and tested for reservoir and lake applications.

4.4.1 Lake Response Model

Four years were modeled in BATHTUB to validate the assumptions of the model. Several models (subroutines) are available for use within the BATHTUB model. The selection of the subroutines is based on past experience in modeling lakes in Minnesota. The second order decay rate function model was the best fit for the phosphorus model, likely because with its short residence time Lake Magda responds more like a reservoir than a natural lake. The chlorophyll-a response model used was model 1 from the BATHTUB package, which accounts for nitrogen, phosphorus, light, and flushing rate. Secchi depth was predicted using the Secchi vs. Chl-a & Turbidity equation. For more information on these model equations, see the BATHTUB model documentation (http://wwwalker.net/bathtub/, Walker 1999).

The BATHTUB models for each modeled year and the average year are presented in Appendix A, following each year's loading summary spreadsheet. The coefficients generally were left at the default values except for the Secchi/chl-a slope, which was decreased from 0.025 to 0.015 based on the relationship from Minnesota lakes (Heiskary and Wilson 2005). No initial calibration factors were applied.

4.4.2 Lake Response Model Validation

In-lake water quality was measured in Lake Magda in four years between 1997 and 2006: 1999, 2000, 2003, and 2006. Table 4.6 compares the model-predicted mean concentration by parameter to the observed mean concentration. By observation the model overpredicts phosphorus for 1999 and 2000, two years of average precipitation, but predicts chl-a and Secchi depth well for those two years. The model underpredicts total phosphorus and chl-a for 2003 and 2006. The year 2003 was a below-average precipitation year, and the lack of flushing may have exacerbated algae blooms and the growth of nuisance aquatic vegetation. As noted elsewhere, lake residents report the presence of curly-leaf pondweed in the lake, as well as a large population of carp, both of which can increase internal phosphorus load and stimulate algal blooms.

On average the model appears to be a fair representation of lake response in Lake Magda.

Table 4.6. Model fit for Lake Magda.

Year	Variable	Predicted Mean	Observed Mean
1999	Total Phosphorus (µg/L)	132	106
	Chlorophyll-a (µg/L)	54	55
	Secchi Depth (meters)	0.7	0.5
2000	Total Phosphorus (µg/L)	132	101
	Chlorophyll-a (µg/L)	46	40
	Secchi Depth (meters)	0.9	0.6
2003	Total Phosphorus (µg/L)	136	187
	Chlorophyll-a (µg/L)	67	88
	Secchi Depth (meters)	0.6	0.6
2006	Total Phosphorus (µg/L)	129	163
	Chlorophyll-a (µg/L)	69	127
	Secchi Depth (meters)	0.6	0.3

5.0 TMDL Allocation

5.1 TOTAL MAXIMUM DAILY LOAD CALCULATIONS

The numerical TMDL for Lake Magda was calculated as the sum of the Wasteload Allocation, Load Allocation, and the Margin of Safety (MOS) expressed as phosphorus mass per unit time. Nutrient loads in this TMDL are set for phosphorus since this is typically the limiting nutrient for nuisance aquatic algae. This TMDL is written to solve the TMDL equation for a numeric target of 60 µg/L of total phosphorus.

5.1.1 Load Allocations

The Load Allocation (LA) includes all nonpermitted sources, including atmospheric deposition and internal loading. Atmospheric deposition load was calculated as described in section 4.3.2 to be 1.1 kg/yr. As atmospheric load is impossible to control on a local basis, no reduction in that source was assumed for the TMDL.

As described in section 4.3.3, the sediment phosphorus release rate was estimated to be approximately 6 $mg/m^2/day$. The TMDL assumed that at goal the sediment phosphorus release rate would be low, as is found in oligotrophic or the low end of mesotrophic lakes (see figure 6.1). The current anoxic factor and a release rate of 2 $mg/m^2/day$ was used to calculate an internal load of 4.9 kg/yr at the TMDL goal.

5.1.2 Wasteload Allocations

The Wasteload Allocation (WLA) includes permitted discharges such as industrial point and regulated stormwater discharges. There are no known municipal wastewater or industrial wastewater dischargers in the watershed. Stormwater discharges are regulated under the National Pollutant Discharge Elimination System (NPDES), and allocations of nutrient loads are considered wasteloads that must be divided among permit holders. NPDES Phase II permits for small municipal separate storm sewer systems (MS4) have been issued to the member cities in the Shingle Creek watershed as well as Hennepin County and Mn/DOT (Minnesota Department of Transportation) under the Phase II General NPDES Stormwater Permit – MNR040000, however, only the City of Brooklyn Park and Mn/DOT stormwater facilities discharge to Lake Magda. Because there is not enough information available to assign loads to individual permit holders, the Wasteload Allocations are combined in this TMDL as Categorical Wasteload Allocations (WLA) (see Table 5.1) assigned to all permitted dischargers in the contributing lakeshed.

Table 5.1. Basis of wasteload allocation by NPDES permitted facility.

NPDES Permit Number	Allocation
MS400007-Brooklyn Park	Categorical WLA
MS400170-Mn/DOT	Categorical WLA

The pollutant load from construction stormwater is considered to be less than 1 percent of the TMDL and difficult to quantify. Consequently, the WLA includes pollutant loading from construction stormwater sources. Construction stormwater activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install, and maintain all BMPs required under the permit, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

The Load Allocation at goal (see section 5.1.1 above) and the P8 annual runoff by year were entered into a second order decay rate equation in the BATHTUB model to calculate the maximum Wasteload allowable to achieve an in-lake concentration of 60 µg/L TP or less, the applicable standard for Lake Magda. The WLA for the TMDL was calculated by averaging the watershed load at goal for the ten year period 1997-2006. This ten year period brackets the four years for which actual monitoring data is available: 1999, 2000, 2003, and 2006. The result of the modeling and calculations was a WLA of 10.7 kg/year total phosphorus at the TMDL goal. A summary and details by year of these calculations and model inputs are shown in Appendix A, Table 2 and in annual model detail tables.

5.1.3 Margin of Safety

A margin of safety has been incorporated into this TMDL by using a conservative modeling approach to account for an inherently imperfect understanding of the lake system and to ultimately ensure that the nutrient reduction strategy is protective of the water quality standard. The lake response model for total phosphorus used for this TMDL uses the rate of lake sedimentation, or the loss of phosphorus from the water column as a result of settling, to predict total phosphorus concentration. Sedimentation can occur as algae die and settle, as organic material settles, or as algae are grazed by zooplankton. Sedimentation rates in shallow lakes such as Lake Magda can be higher than rates for deep lakes. Shallow lakes differ from deep lakes in that they tend to exist in one of two states: turbid water and clear water. Lake response models assume that even when total phosphorus concentration in the lake is at or better than the state water quality standard the lake will continue to be in that turbid state. However, as nutrient load is reduced and other internal load management activities such as fish community management occur to provide a more balanced lake system, shallow lakes will tend to "flip" to a clear water condition. In that balanced, clear water condition, light penetration allows rooted aquatic vegetation to grow and stabilize the sediments, and zooplankton to thrive and graze on algae at a much higher rate than is experienced in turbid waters. Thus in a clear water state more phosphorus will be removed from the water column through settling than the model would predict.

The TMDL is set to achieve water quality standards while still in a turbid water state. To achieve the beneficial use, the lake must flip to a clear water state which can support the response variables at higher total phosphorus concentrations due to increased zooplankton grazing, reduced sediment resuspension, etc. Therefore, this TMDL is inherently conservative by setting allocations for the turbid water state.

5.1.4 Summary of TMDL Allocations

The load capacity is the Total Maximum Daily Load. The load and wasteload allocations are shown in Table 5.2. A margin of safety is implicit in the TMDL equation and therefore not presented in the tables. A 69 percent reduction in phosphorus load would be required to achieve the stated TP standard of 60 µg/L. The numeric TMDL Goal for Lake Magda was calculated by summing the Wasteload Allocation (10.7 kg/year) and Load Allocation (1.1 kg/year and 4.9 kg/year) which equals 16.7 kg/year total phosphorus (Table 6.2). Then this number was divided by 365.25 days per year (to account for leap year) to convert the annual TMDL (16.7 kg/year) to a daily TMDL (0.045 kg/day). These allocations will guide the development of an implementation plan and necessary reductions.

Table 5.2. TMDL total phosphorus daily and annual loads for Lake Magda portioned among the major sources.

Allocation	Source	Existing TP Load		Total Phosphorus TMDL		Load Reduction
		(kg/day)	(kg/year)	(kg/day)	(kg/year)	(kg/year)
Wasteload	Watershed	0.103	37.5	0.029	10.7	26.8
Load	Atmospheric	0.003	1.1	0.003	1.1	-
	Internal	0.040	14.6	0.013	4.9	9.7
	Total	0.146	53.2	0.045	16.7	36.5

5.2 LAKE RESPONSE VARIABLES

The TMDL presented here is developed to be protective of the aquatic recreation beneficial use in lakes. However there is no loading capacity *per se* for nuisance aquatic plants. Consequently, to understand the impacts of the phosphorus loads to the lake, a water quality response model was utilized to predict the water quality after load reductions were implemented. Utilization of this approach allows for a better understanding of potential lake conditions under numerous loading scenarios. The following sections describe the results from the water quality response modeling.

Using the previously described BATHTUB water quality response model, total phosphorus and chlorophyll-a concentrations were predicted for load reductions in 5% increments. These predicted responses can be used to develop goals for load reductions with an understanding of the overall water quality benefits.

5.2.1 Phosphorus

The modeled response to phosphorus load reductions for the ten year average is presented in Figure 5.1. However, Lake Magda is a shallow basin with a significant potential to internally load phosphorus. Consequently, the actual response measured in the lake will likely be much less pronounced until the internal loading is controlled or biological feedback mechanisms are reestablished in the lake.

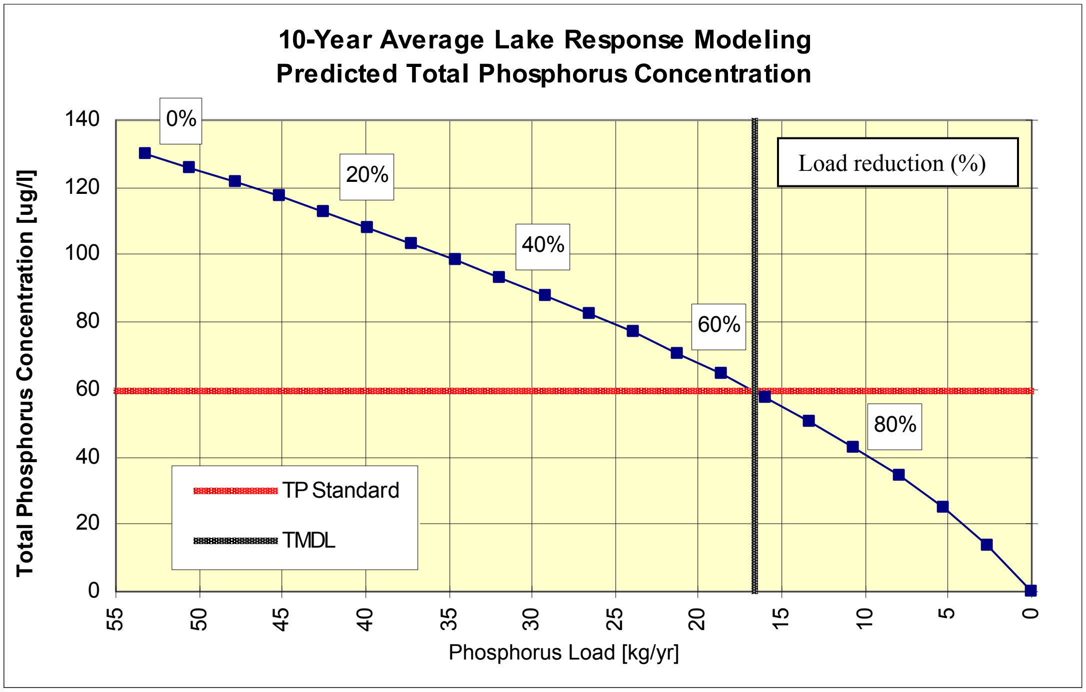

Figure 5.1. In lake total phosphorus concentrations predicted for total phosphorus load reductions applied to all sources.

5.2.2 Chlorophyll-a

The modeled response to chlorophyll-a is presented in Figure 5.2. Although a positive response is predicted, there is a need to reestablish plant and fish communities in Lake Magda to provide biological controls on phytoplankton such as shading by aquatic vegetation and grazing by zooplankton.

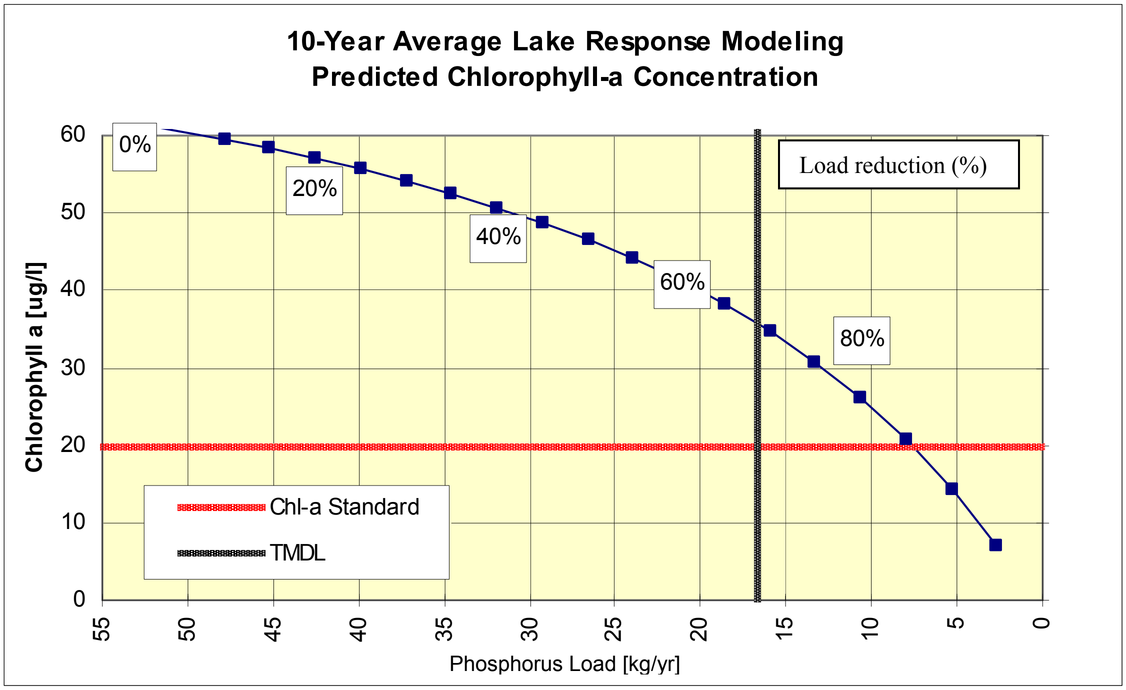

Figure 5.2. In lake chlorophyll-a concentrations predicted for total phosphorus load reductions applied to all sources.

5.2.3 Secchi Depth

Secchi depth response to total phosphorus reductions is presented in Figure 5.3. It is likely that the clarity will meet the state standard if the TP reductions are implemented and the biological health in Lake Magda is restored.

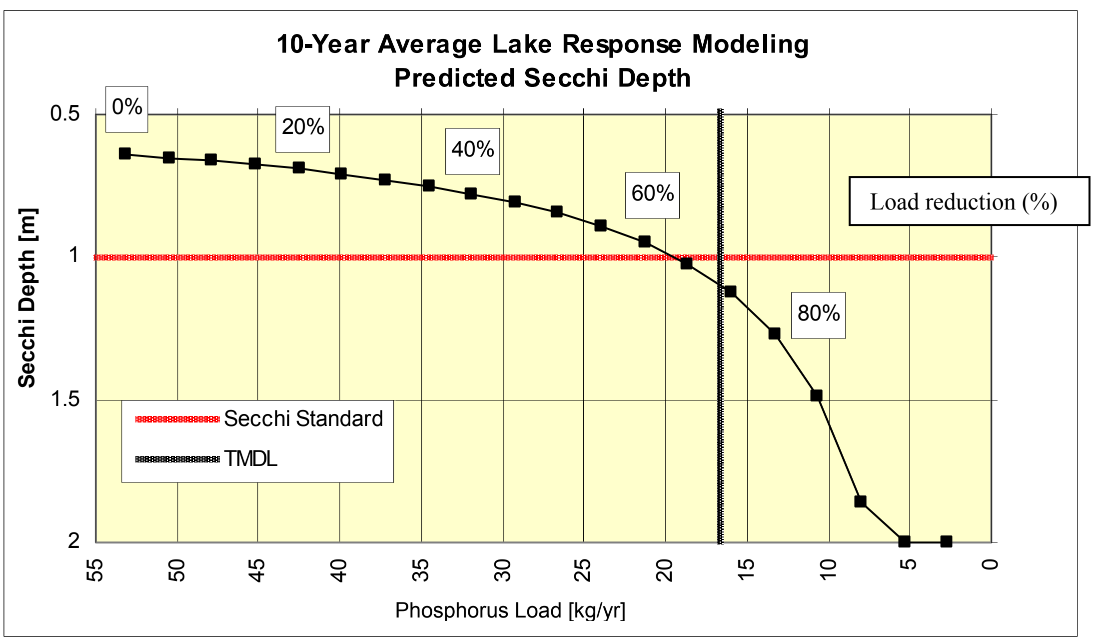

Figure 5.3. Secchi depth predicted for total phosphorus load reductions to all sources.

5.3 SEASONAL AND ANNUAL VARIATION

The daily load reduction targets in this TMDL are calculated from the current phosphorus budget for Lake Magda. The budget is an average of several years of monitoring data, and includes both wet and dry years. BMPs designed to address excess loads to this lake will be designed for these average conditions; however, the performance will be protective of all conditions. For example, a stormwater pond designed for average conditions may not perform at design standards for wet years; however the assimilative capacity of the lake will increase due to increased flushing. Additionally, in dry years the watershed load will be naturally down allowing for a larger proportion of the load to come from internal loading. Consequently, averaging across several modeled years addresses annual variability in lake loading.

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

5.3.1 Critical Condition

The critical condition for this lake is the summer growing season. Minnesota lakes typically demonstrate impacts from excessive nutrients during the summer recreation season (June 1 through September 31) including excessive algal blooms and fish kills. Lake goals have focused on summer-mean total phosphorus, Secchi transparency and chlorophyll-a concentrations. These parameters have been linked to user perception (Heiskary and Wilson 2005). Consequently, the lake response models have focused on the summer growing season as the critical condition. Additionally, this lake tends to have a relatively short residence time and therefore responds to summer growing season loads.

5.4 RESERVE CAPACITY/FUTURE GROWTH

The watershed for this lake is entirely within an MS4 community. The watershed is built out, and all of the development projects that will occur are redevelopment. No new NPDES sources are anticipated in this watershed, therefore no portion of the Wasteload Allocation is being held in reserve.

Future growth will not affect this TMDL. Additionally, the Shingle Creek Watershed Management Commission has rules in place for development and redevelopment that are protective of water quality. Consequently, future development will have to meet watershed requirements that will account for pollution reductions in this TMDL.

6.0 Public Participation

6.1 INTRODUCTION

As a part of the strategy to achieve implementation of the necessary reductions, the Shingle Creek Watershed Management Commission (SCWMC) seeks stakeholder and public engagement and participation regarding their concerns, interests, and questions regarding the development of the TMDL. Specifically, meetings were held for a Technical Advisory Committee representing key stakeholders. Additionally, the SCWMC reviewed the TMDL with the Brooklyn Park City Council and a citizen's advisory committee. Mn/DOT was also sent the draft TMDL and provided comments.

6.2 TECHNICAL ADVISORY COMMITTEE

A Technical Advisory Committee was established so that interested stakeholders could be involved in key decisions during development of the TMDL. Stakeholders represented on the Technical Advisory Committee include local cities, Minnesota Department of Natural Resources (DNR), the Metropolitan Council, the United States Geological Survey (USGS) and the Minnesota Pollution Control Agency. All meetings were open to interested individuals and organizations. Technical Advisory Committee meetings were held on February 10, 2006, March 9, 2006, and June 27, 2007.

6.3 STAKEHOLDER MEETINGS

A stakeholder meeting to which all lakeshore residents were invited was held on March 9, 2009 at Brooklyn Park City Hall.

6.4 PUBLIC MEETINGS

The general TMDL approach and general results of TMDLs were presented to six City Councils in May and July 2006. Meeting notes from Shingle Creek Watershed Management Commission meetings can be found at www.shinglecreek.org/.

The official TMDL public comment period was held from March 22, 2010 through April 21, 2010. Three public comments were received on the Draft TMDL and minor clarifications were made to the draft report.

7.0 Implementation

7.1 IMPLEMENTATION FRAMEWORK

7.1.1 The Shingle Creek Watershed Management Commission

The SCWMC is committed to improving water quality in the Shingle Creek watershed. To this end, the SCWMC completed a Water Quality Plan and adopted it as a Major Plan Amendment to its Watershed Management Plan. A number of activities are detailed in the Management Plan over the next ten years, including developing individual management plans for water resources.

The Shingle Creek Water Quality Plan (WQP):

- Sets forth the Commissions' water quality goals, standards, and methodologies in more detail than the general goals and policies established in the Second Generation Watershed Management Plan.
- Provides philosophical guidance for completing water resource management plans and TMDLs; and
- Provides direction for the ongoing water quality monitoring programs that will be essential to determine if the TMDLs and implementation program are effectively improving water quality.

The Water Quality Plan is composed of four parts:

- A monitoring plan to track water quality changes over time;
- Detailed management plans for each resource to lay out a specific plan of action for meeting water quality goals;
- A capital improvement plan; and
- An education and public outreach plan.

This WQP charts the course the Commission will take to meet its Second Generation Watershed Management Plan goals to protect and improve water quality and meet Commission and State water quality standards. While the Plan lays out a series of activities and projects, implementation will occur as the Commission's and cities' budgets permit. The Commission as part of the Major Plan Amendment process also revised its cost share formula to provide for Commission participation in the cost of TMDL implementation projects. Currently, the Second Generation Watershed Management Plan includes lake and watershed descriptions, monitoring data summaries, and general management objectives for Lake Magda and other lakes in the Shingle Creek Watershed.

The Commission has received significant grant funding from the Minnesota Pollution Control Agency, the Board of Water and Soil Resources, the Metropolitan Council, and the Department of Natural Resources to undertake planning and demonstration projects. The Commission intends to continue to solicit funds and partnerships from these and other sources to supplement the funds provided by the nine cities having land in the Shingle Creek watershed.

The Shingle Creek Watershed Management Commission's Second Generation Watershed Management Plan provides for the development of individual management plans for each of the high priority water resources in the watershed over the next several years. In its Work Plan and Capital Improvement Plan (CIP) the Commission set up a process and budgeted resources to systematically work in partnership with its member cities to develop lake management plans that meet both local and watershed needs, and do so in a consistent manner across the watershed.

7.1.2 Member Cities

Because the Commission is a Joint Powers Organization, it relies on the cities to implement most programs and construct capital improvements. Under the Joint Powers Agreement, cities agree to use their best efforts to carry out directives of the Commission in its exercise of the powers and duties set forth in statute and administrative rule for the protection of water resources. Each city has in place a Local Water Management Plan to address watershed and city goals and objectives; those local plans are periodically updated to reflect resource management plans and adopt or revise strategies for water resource management.

7.2 REDUCTION STRATEGIES

7.2.1 Annual Load Reductions

The focus of implementation will be on reducing the phosphorus loads to the lake through structural and nonstructural Best Management Practices (BMPs). The Total Maximum Daily Loads by source for Lake Magda are shown in Table 7.1 below as daily and annual loads. A *69 percent* annual reduction in total phosphorus load to the lake would be required to consistently meet state standards.

Table 7.1. TMDL total phosphorus daily and annual loads for Lake Magda partitioned among the major sources.

Allocation	Source	Existing TP Load		Total Phosphorus TMDL		Load Reduction
		(kg/day)	(kg/year)	(kg/day)	(kg/year)	(kg/year)
Wasteload	Watershed	0.103	37.5	0.029	10.7	26.8
Load	Atmospheric	0.003	1.1	0.003	1.1	-
	Internal	0.040	14.6	0.013	4.9	9.7
		0.146	53.2	0.045	16.7	36.5

7.2.2 Actions

Restoration options for lakes are numerous with varying rates of success. Consequently, each technology must be evaluated in light of our current understanding of physical and biological processes in that lake. The watershed draining to Lake Magda is small and fully developed, so large-scale Best Management Practice (BMP) opportunities are limited. Following is a description of potential actions for controlling nutrients in the Lake Magda watershed that will be further developed in the Lake Magda Implementation Plan. That Plan will describe in more detail which implementation activities the permitted MS4s (Brooklyn Park and Mn/DOT) will take the lead or participate in. The estimated total cost of implementing these and other potential BMPs ranges from $500,000 to $700,000.

7.2.2.1 External Load Reductions

The Lake Magda watershed is entirely developed. Redevelopment that meets certain thresholds is required to provide pretreatment of stormwater prior to discharge into water resources in the watershed. Small, incremental reductions are also possible through retrofit as redevelopment occurs and through the implementation of Best Management Practices (BMPs) throughout the subwatershed.

Retrofit BMPs. As opportunities arise, retrofit water quality treatment through a variety of Best Management Practices including detention ponds, native plantings, swirl separators, and trash collectors. These small practices are effective in removing debris, leaf litter, and other potential pollutants. Depending on the type of BMP, location, easement requirements, and other factors, costs can range from $5,000 for a trash collector to $250,000 or more for a detention pond. The number of BMPs necessary to achieve the required phosphorus load reduction is unknown and is dependent on the types of opportunities that arise. Additional BMPs may be retrofit when opportunities arise. A significant runoff component to the lake is TH 169 pavement and right of way. Mn/DOT typically retrofits water quality BMPs as feasible when it reconstructs highways; however, there are no reconstruction projects planned for this portion of TH 169 in the near future.

Increase infiltration and filtration in the lakeshed. Encourage the use of rain gardens, native plantings, and reforestation as a means to increase infiltration and evapotranspiration and reduce runoff conveying pollutant loads to the lake. The cost of this strategy varies depending on the BMP, and may range from a single property owner installing an individual rain garden to retrofitting parks and open space with native vegetation rather than mowed turf. The cost of this strategy varies depending on the BMP and may range from $500 for a single property owner installing an individual rain garden to retrofitting parks and open space with native vegetation rather than mowed turf at a cost of $10,000. The Education and Outreach Committee of the Watershed Commission regularly provides education and outreach information to member cities on these topics for publication in city newsletters, neighborhood and block club fliers, and the city's website.

Target street sweeping. Identify key areas and target those areas for more frequent street sweeping. Consider replacing mechanical street sweepers with more efficient regenerative air sweepers. Dustless sweepers cost $150,000-200,000, about twice the cost of traditional broom sweepers. Brooklyn Park should consider how to accomplish this within the context of its overall street sweeping program.

Encourage shoreline restoration. Most property owners maintain a turfed edge to the shoreline, although some property owners maintain an unmowed shoreline or have planted some native buffer. Encourage property owners to restore their shoreline with native plants to reduce erosion and capture direct runoff. Residential property shoreline on Lake Magda totals about 1,500 linear feet. Ideally about 75 percent of the residential shoreline would be native vegetation, with about 25 percent available for lake access. Accomplishing this goal would require restoration of about 1,125 feet of shoreline at a cost of about $33,750 to $56,250.

Conduct education and outreach awareness programs. Educate property owners in the subwatershed about proper fertilizer use, low-impact lawn care practices, and other topics to increase awareness of sources of pollutant loadings to the lakes and encourage the adoption of good individual property management practices.

7.2.2.2 Internal Loads

Several options could be considered to manage internal sources of nutrients. The primary option for the control of internal loading is likely to be biological manipulation. This would include an integrated plan to manage the aquatic vegetation, fish, and zooplankton communities to reduce nutrient loads and maintain a level of water clarity that is desirable both aesthetically and for maintenance of a fishery.

Chemical treatment. Because it is very shallow, Lake Magda is not a good candidate for this type of treatment (i.e. alum treatment to control internal phosphorus loading).

Vegetation management. Aquatic plants should periodically be surveyed to track changes in the plant community and monitor growth and extent of nuisance species. Curly-leaf pondweed is present at non-nuisance levels in the lake. Spread of this invasive species should be monitored. If it should increase to nuisance levels, chemical treatments applied to curly-leaf pondweed for three to five years in a row may be necessary to limit growth of this phosphorus source. The estimated cost of such a treatment should it become necessary is $5,000 annually.

Fishery management. Limited information is available on the fish and zooplankton communities. Surveys should be conducted and data analyzed to determine if biological management may be beneficial to managing water quality. The cost of a fish and zooplankton survey and management plan is about $10,000. The City and Commission should partner with the DNR to monitor and manage the fish population to maintain a beneficial community.

7.3 IMPLEMENTATION STRATEGY

The load allocations in the TMDL represent aggressive goals for nutrient reductions. Consequently, implementation will be conducted using adaptive management principles. Adaptive management is appropriate because it is difficult to predict the lake response that will occur from implementing strategies with the paucity of information available to demonstrate expected reductions. Future technological advances may alter the course of actions detailed here. Continued monitoring and “course corrections” responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL.

Based on this understanding of the appropriate standards for lakes, this TMDL has been established with the intent to implement all the appropriate activities that are not considered greater than extraordinary efforts. If all of the appropriate BMPs and activities have been implemented and the lake still does not meet the current water quality standards, the TMDL will be reevaluated and the Shingle Creek Watershed Management Commission will begin a process with the MPCA to develop more appropriate site-specific standards for the lake. The process will be based on the MPCA's methodology for determining site-specific standards.

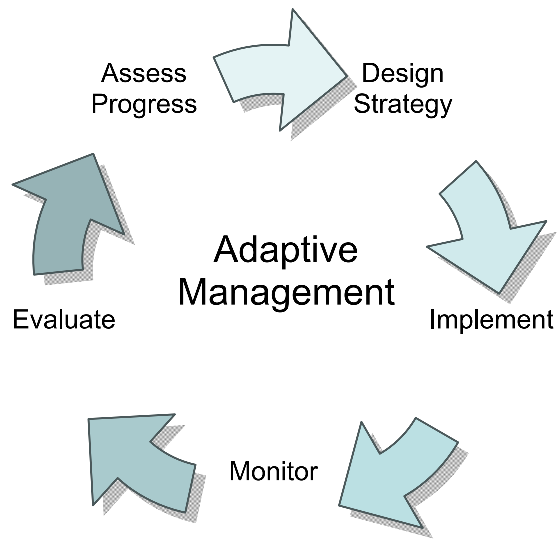

Figure 7.1. Adaptive management.

8.0 Reasonable Assurance

8.1 INTRODUCTION

When establishing a TMDL, reasonable assurances must be provided demonstrating the ability to reach and maintain water quality endpoints. Several factors control reasonable assurance, including a thorough knowledge of the ability to implement BMPs as well as the overall effectiveness of the BMPs. This TMDL establishes aggressive goals for the reduction of phosphorus loads to the lakes. In fact, there are few if any examples where these levels of reductions have been achieved where the sources were primarily nonpoint source in nature, especially in suburban watersheds.

TMDL implementation will be carried out on an iterative basis so that implementation course corrections based on periodic monitoring and reevaluation can adjust the strategy to meet the standard. After the first phase of nutrient reduction efforts, reevaluation will identify those activities that need to be strengthened or other activities that need to be implemented to reach the standards. This type of iterative approach is more cost effective than over engineering to conservatively inflated margins of safety (Walker 2003). Implementation will also address in-lake problems such as invasive plant species (curly-leaf pondweed) and invasive fish (carp and rough fish). These practices go beyond the traditional nutrient controls and provide additional protection for lake water quality.

8.2 THE SHINGLE CREEK WATERSHED MANAGEMENT COMMISSION

The Shingle Creek Watershed Management Commission was formed in 1984 using a Joint Powers Agreement developed under authority conferred to the member communities by Minnesota Statutes 471.59 and 103B.201 through 103B.251. The Metropolitan Surface Water Management Act (Chapter 509, Laws of 1982, Minnesota Statute Section 473.875 to 473.883 as amended) establishes requirements for preparing watershed management plans within the Twin Cities Metropolitan Area.

Minnesota Rules Chapter 8410 requires watershed management plans to address eight management areas and to include specific goals and policies for each. Strategies and policies for each goal were developed to serve as a management framework. To implement these goals, policies, and strategies, the Commission has developed the Capital Improvement Program and Work Plan discussed in detail in the Second Generation Plan (SCWMC 2004). In 2007 the Commission adopted a Water Quality Plan, revised Capital Improvement Program, and Cost Sharing Policy to further progress toward meeting water quality goals. It is expected that the Commission will continuously update the annual Capital Improvement Program (CIP) as a part of its annual budget process.

The philosophy of the Joint Powers Agreement is that the management plan establishes certain common goals and standards for water resources management in the watersheds, agreed to by the nine cities having land in the watershed, and implemented by those cities at both the Commission and local levels. TMDLs developed for water bodies in the watershed will be used as guiding documents for developing appropriate goals, policies, and strategies and ultimately sections of the Capital Improvement Program and Work Plan.

8.3 NPDES MS4 STORMWATER PERMITS

NPDES Phase II stormwater permits are in place for each of the member cities in the Shingle Creek watershed as well as Hennepin County and Mn/DOT. Under the stormwater program, permit holders are required to develop and implement a Stormwater Pollution Prevention Program (SWPPP; MPCA, 2004) that identifies Best Management Practices (BMPs) and measurable goals associated with each of six specified minimum control measures.

Within the Lake Magda watershed, only two MS4s drain to the lake: the City of Brooklyn Park and Mn/DOT. The unique permit numbers assigned under the Phase II General NPDES Stormwater Permit – MNR040000 – are Brooklyn Park: MS400007, and Mn/DOT: MS400170.

There are no known industrial dischargers in the watershed. The pollutant load from construction stormwater is considered to be less than 1 percent of the TMDL and difficult to quantify. Consequently, the WLA includes pollutant loading from construction and industrial stormwater sources.

According to federal regulations, NPDES permit requirements must be consistent with the assumptions and requirements of an approved TMDL and associated Wasteload Allocations (see 122.44(d)(1)(vii)(B)). To meet this regulation, Minnesota's MS4 general permit requires the following:

> "If a USEPA-approved **TMDL(s)** has been developed, you must review the adequacy of your Storm Water Pollution Prevention Program to meet the **TMDL's Waste Load Allocation** set for storm water sources. If the **Storm Water Pollution Prevention Program** is not meeting the applicable requirements, schedules and objectives of the **TMDL**, you must modify your **Storm Water Pollution Prevention Program**, as appropriate, within 18 months after the TMDL is approved."

The TMDL and Implementation Plan will identify specific BMP opportunities sufficient to achieve load reduction. Construction stormwater activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install, and maintain all BMPs required under the permit, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

8.4 MONITORING

8.4.1 Monitoring Implementation of Policies and BMPs

The SCWMC will evaluate progress toward meeting the goals and policies outlined in the Second Generation Plan in its Annual Report. Success will be measured by completion of policies and strategies, or progress toward completion of policies and strategies. The Annual Report will then be presented to the public at the Commission's annual public meeting. The findings of the Annual Report and the comments received from the member cities and the public will then be used to formulate the work plan, budget, CIP and specific measurable goals and objectives for the coming year as well as to propose modifications or additions to the management goals, policies, and strategies. At the end of each five year period the Commission will evaluate the success of BMP implementation in reducing the total phosphorus concentration in Lake Magda, and will reconvene the Technical Advisory Committee to determine if adjustments to the Implementation Plan are necessary.

8.4.2 Follow-up Monitoring

The SCWMC monitors water quality in local lakes through the funding of special studies and citizen volunteer efforts. Additional monitoring is proposed in the Commission's Water Quality Plan in an effort to ensure the quality of data. Schedules of monitoring activities are identified in the Shingle Creek Water Quality Plan (SCWMC 2007) and updated annually. Magda was monitored in 2009, and is next scheduled to be monitored in 2012 and every three years after that. Results of all monitoring will be included in the annual water quality monitoring report.

Lake Magda will be periodically monitored by the Shingle Creek Watershed Management Commission (SWMC) through the CAMP program. The CAMP program is operated by Metropolitan Council Environmental Services (MCES) and is a volunteer monitoring program. Citizen volunteers collect data and samples biweekly.

9.0 Literature Cited

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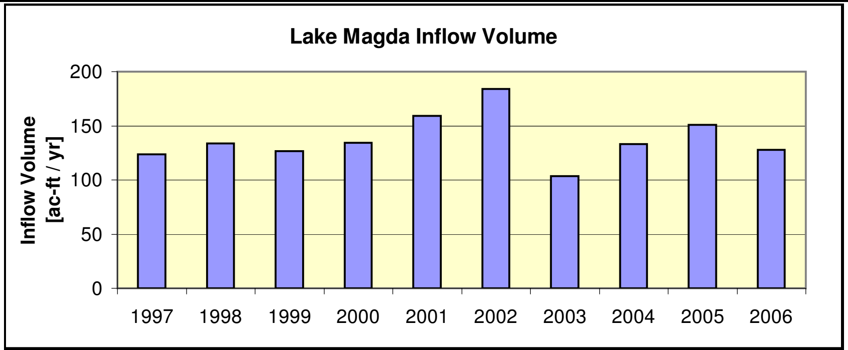
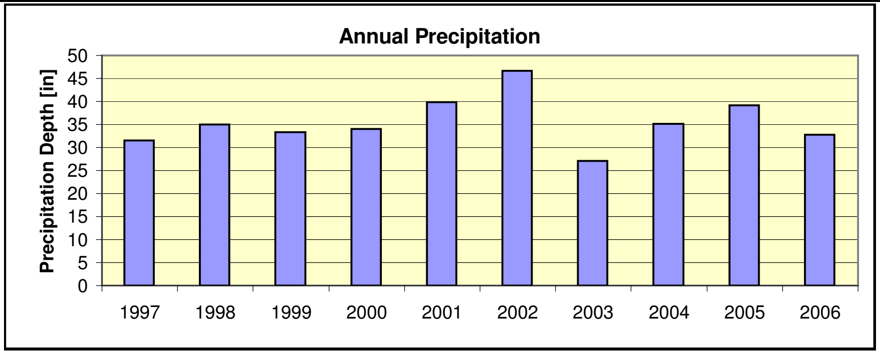
Appendix A

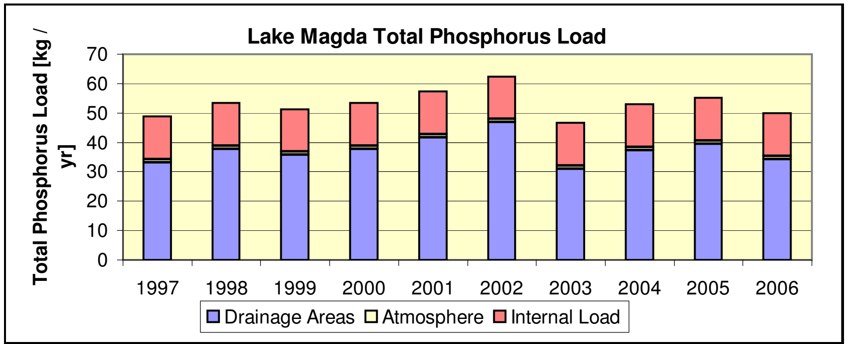
Lake Response Modeling Summary

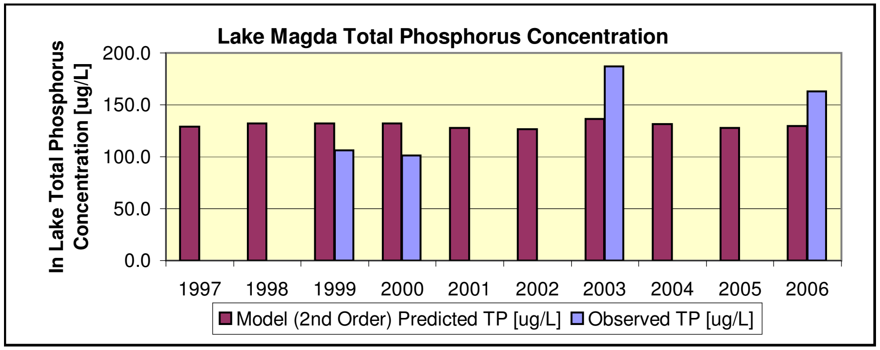
Table 1: Lake Magda Lake Response Modeling Summary: Current Conditions

Magda Lake	**Source**	***1997***	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***Average 1997-2006***	
Precipitation Depth [in]		31.5	34.9	33.3	34.1	39.8	46.7	27.1	35.1	39.2	32.8	Annual	Daily
	Residence Time [yr]	0.18	0.16	0.17	0.16	0.14	0.12	0.21	0.17	0.15	0.17	0.16	
Inflow Volume [ac-ft / yr]	Drainage Areas	123.6	133.5	126.9	134.1	159.4	183.8	103.6	133.1	151.1	127.5	137.7	
	Upstream Lakes	0	0	0	0	0	0	0	0	0	0	0	
	Atmosphere	0	0	0	0	0	0	0	0	0	0	0	
	TOTAL =	**123.6**	**133.5**	**126.9**	**134.1**	**159.4**	**183.8**	**103.6**	**133.1**	**151.1**	**127.5**	**137.7**	
Total Phosphorus Load [kg / yr]	Drainage Areas	33.1	37.7	35.7	37.8	41.6	46.8	30.9	37.2	39.5	34.3	37.5	0.103
	Upstream Lakes	0	0	0	0	0	0	0	0	0	0	-	-
	Atmosphere	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.003
	Internal Load	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	0.040
	TOTAL =	**48.8**	**53.4**	**51.4**	**53.5**	**57.3**	**62.5**	**46.6**	**52.9**	**55.2**	**50.0**	**53.2**	**0.146**
Model Results	Model (2nd Order) Predicted TP [ug/L]	129.2	132.1	132.1	132.1	127.5	126.4	136.1	131.5	127.5	129.4	129.9	
	Observed TP [ug/L]	-	-	106.3	101.3	-	-	187.3	-	-	163.3		
	Predicted Chl-a [ug/L]	58.7	58.9	53.7	46.0	57.2	56.3	67.0	58.8	57.5	68.6	61.6	
	Observed Chl-a [ug/L]	-	-	55.3	40.3	-	-	88.4	-	-	127.4		
	Predicted Secchi Depth [m]	0.67	0.67	0.73	0.85	0.69	0.70	0.59	0.67	0.69	0.58	0.64	
	Observed Secchi Depth [m]	-	-	0.54	0.63	-	-	0.55	-	-	0.33		









1999 Loading Summary for: Lake Magda

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [km²]	Runoff Depth [m/yr]	Discharge [10^6 m³/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1 Watershed	0.25	0.62	0.157	228.0	1.0	35.7
2					1.0	
3					1.0	
4					1.0	
5					1.0	
6					1.0	
7					1.0	
8					1.0	
9					1.0	
10					1.0	
11					1.0	
12					1.0	
13					1.0	
Summation	*0.25*	*0.62*	*0.16*			*35.7*

Inflow from Upstream Lakes

Name	Discharge [10^6 m³/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1		-	1.0	
2		-	1.0	
3		-	1.0	
Summation	*0.00*	-		-

Atmosphere

Lake Area [km²]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m³/yr]	Aerial Loading Rate [kg/km²-yr]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.85	0.85	0.00	26.80	1.0	1.1
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater

Lake Area [km²]	Groundwater Flux [m/yr]	Net Inflow [10^6 m³/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.0	0.00	0	1.0	-

Internal

Lake Area [km²]	Anoxic Factor [days]	Release Rate [mg/m²-day]	Calibration Factor [--]	Load [kg/yr]
0.0414	59.0	6.0	1.0	14.6

Net Discharge [10^6 m³/yr] =	**0.16**	**Net Load [kg/yr] =**	**51.4**

NOTES

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

1999 Lake Response Modeling for: Lake Magda

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \left[-1 + (1 + 4KA1P_iT)^{-5}\right] \Big/ (2KA1T)$		as f(W,Q,V,Fot) from BATHTUB 2nd Order Decay		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
$A1 = 0.056\,Fot^{-1}Qs \Big/ (Qs + 13.3)$		b =	0.458	[--]
		W (total P load = inflow + atm.) =	51	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0271	[10^6 m^3]
$Qs = Max(Z/T, 4)$		Fot=	0.4	[--]
		Qs=	11.54	[m/yr]
		T = V/Q =	0.17	[yr]
		P_i = W/Q =	329	[ug/l]
Model Predicted In-Lake [TP]			**132.1**	**[ug/l]**
Observed In-Lake [TP]			**106.3**	**[ug/l]**
CHLOROPHYLL-A CONCENTRATION				
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4		
		CB (Calibration factor) =	1.00	[--]
Model Predicted In-Lake [Chl-a]			**37.0**	**[ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times a)]}$	as f(TP, N, Flushing), Walker 1999, Model 1		
		CB (Calibration factor) =	1.00	
$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$		P (Total Phosphorus) =	106	[ug/l]
		N (Total Nitrogen) =	2,450	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	96.2	[ug/l]
$X_{pn} = \left[P^{-2} + \left(\dfrac{N-150}{12}\right)^{-2}\right]^{-0.5}$		X_{pn} (Composite nutrient conc.)=	92.9	[ug/l]
		G (Kinematic factor) =	0.32	[--]
		F_s (Flushing Rate) =	5.77	[$year^{-1}$]
$G = Z_{mix}(0.14 + 0.0039F_s)$		Z_{mix} (Mixing Depth) =	2.00	[m]
$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\text{Chl}a]$		a (Non algal turbidity) =	0.02	[m^{-1}]
		S (Secchi Depth) =	0.73	[m]
		Maximum lake depth =	2.00	[m]
Model Predicted In-Lake [Chl-a]			**53.7**	**[ug/l]**
Observed In-Lake [Chl-a]			**55.3**	**[ug/l]**
SECCHI DEPTH				
	$SD = \dfrac{CS}{(a + 0.015 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.02	[m^{-1}]
Model Predicted In-Lake SD			**0.73**	**[m]**
Observed In-Lake SD			**0.54**	**[m]**
PHOSPHORUS SEDIMENTATION RATE				
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$			
		P_{sed} (phosphorus sedimentation) =	**18**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	W-P_{sed} =		**33**	**[kg/yr]**

2000 Loading Summary for: Lake Magda

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1 Watershed	0.25	0.65	0.165	228.4	1.0	37.8
2					1.0	
3					1.0	
4					1.0	
5					1.0	
6					1.0	
7					1.0	
8					1.0	
9					1.0	
10					1.0	
11					1.0	
12					1.0	
13					1.0	
Summation	*0.25*	*0.65*	*0.165*			*37.8*

Inflow from Upstream Lakes

Name	Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1		-	1.0	
2		-	1.0	
3		-	1.0	
Summation	*0.00*	-		-

Atmosphere

Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.87	0.87	0.00	26.80	1.0	1.1
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater

Lake Area [km^2]	Groundwater Flux [m/yr]	Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.0	0.00	0	1.0	-

Internal

Lake Area [km^2]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.0414	59.0	6.0	1.0	14.6

Net Discharge [10^6 m^3/yr] =	**0.17**	**Net Load [kg/yr] =**	**53.5**

NOTES

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

2000 Lake Response Modeling for: Lake Magda

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \left[-1+(1+4KA1P_iT)^{-5}\right] / (2KA1T)$	as f(W,Q,V,	Fot=	0.6	[--]
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
$A1 = 0.056 Fot^{-1} Qs / (Qs+13.3)$		b =	0.458	[--]
		W (total P load = inflow + atm.) =	54	[kg/yr]
		Q (lake outflow) =	0.165	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0271	[10^6 m^3]
$Qs = Max(Z/T, 4)$		Fot=	0.4	[--]
		Qs=	12.19	[m/yr]
		T = V/Q =	0.16	[yr]
		P_i = W/Q =	324	[ug/l]
Model Predicted In-Lake [TP]			**132.1**	**[ug/l]**
Observed In-Lake [TP]			**101.3**	**[ug/l]**
CHLOROPHYLL-A CONCENTRATION				
$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4			
		CB (Calibration factor) =	1.00	[--]
Model Predicted In-Lake [Chl-a]			**37.0**	**[ug/l]**
$[\mathrm{Chl}a] = \dfrac{CB \times B_x}{[(1+0.025 \times B_x \times G)(1+G \times a)]}$	as f(TP, N, Flushing), Walker 1999, Model 1			
		CB (Calibration factor) =	1.00	
$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$		P (Total Phosphorus) =	101	[ug/l]
		N (Total Nitrogen) =	1,563	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	74.6	[ug/l]
$X_{pn} = \left[P^{-2} + \left(\dfrac{N-150}{12}\right)^{-2}\right]^{-0.5}$		X_{pn} (Composite nutrient conc.)=	76.8	[ug/l]
		G (Kinematic factor) =	0.33	[--]
		F_s (Flushing Rate) =	6.09	[$year^{-1}$]
$G = Z_{mix}(0.14 + 0.0039 F_s)$		Z_{mix} (Mixing Depth) =	2.00	[m]
$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$		a (Non algal turbidity) =	0.02	[m^{-1}]
		S (Secchi Depth) =	0.85	[m]
		Maximum lake depth =	2.00	[m]
Model Predicted In-Lake [Chl-a]			**46.0**	**[ug/l]**
Observed In-Lake [Chl-a]			**40.3**	**[ug/l]**
SECCHI DEPTH				
$SD = \dfrac{CS}{(a + 0.015 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)			
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.02	[m^{-1}]
Model Predicted In-Lake SD			**0.85**	**[m]**
Observed In-Lake SD			**0.63**	**[m]**
PHOSPHORUS SEDIMENTATION RATE				
$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$				
		P_{sed} (phosphorus sedimentation) =	**19**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	W-P_{sed} =		**35**	**[kg/yr]**

2003 Loading Summary for: Lake Magda

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[km^2]	[m/yr]	[10^6 m^3/yr]	[ug/L]	[--]	[kg/yr]
1	Watershed	0.25	0.51	0.128	241.9	1.0	30.9
2						1.0	
3						1.0	
4						1.0	
5						1.0	
6						1.0	
7						1.0	
8						1.0	
9						1.0	
10						1.0	
11						1.0	
12						1.0	
13						1.0	
	Summation	*0.25*	*0.51*	*0.13*			*30.9*

Inflow from Upstream Lakes					
	Name	Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1			-	1.0	
2			-	1.0	
3			-	1.0	
	Summation	*0.00*	-		-

Atmosphere						
Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.69	0.69	0.00	26.80	1.0	1.1
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater						
Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.0		0.00	0	1.0	-

Internal						
Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.0414	59.0			6.0	1.0	14.6
		Net Discharge [10^6 m^3/yr] =	**0.13**		**Net Load [kg/yr] =**	**46.6**

NOTES

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

2003 Lake Response Modeling for: Lake Magda

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \left[-1 + (1 + 4KA1P_iT)^{-5}\right] / (2KA1T)$	as f(W,Q,V,Fot) from BATHTUB 2nd Order Decay		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
	$A1 = 0.056\,Fot^{-1}Qs / (Qs + 13.3)$	b =	0.458	[--]
		W (total P load = inflow + atm.) =	47	[kg/yr]
		Q (lake outflow) =	0.1278	$[10^6\ m^3/yr]$
		V (modeled lake volume) =	0.0271	$[10^6\ m^3]$
	$Qs = Max(Z/T, 4)$	Fot=	0.4	[--]
		Qs=	9.42	[m/yr]
		T = V/Q =	0.21	[yr]
		P_i = W/Q =	365	[ug/l]
Model Predicted In-Lake [TP]			**136.1**	**[ug/l]**
Observed In-Lake [TP]			**187.3**	**[ug/l]**
CHLOROPHYLL-A CONCENTRATION				
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4		
		CB (Calibration factor) =	1.00	[--]
Model Predicted In-Lake [Chl-a]			**38.1**	**[ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times a)]}$	as f(TP, N, Flushing), Walker 1999, Model 1		
		CB (Calibration factor) =	1.00	
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	187	[ug/l]
		N (Total Nitrogen) =	2,200	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	144.5	[ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	126.2	[ug/l]
		G (Kinematic factor) =	0.32	[--]
		F_s (Flushing Rate) =	4.71	$[year^{-1}]$
	$G = Z_{mix}(0.14 + 0.0039F_s)$	Z_{mix} (Mixing Depth) =	2.00	[m]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.02	$[m^{-1}]$
		S (Secchi Depth) =	0.59	[m]
		Maximum lake depth =	2.00	[m]
Model Predicted In-Lake [Chl-a]			**67.0**	**[ug/l]**
Observed In-Lake [Chl-a]			**88.4**	**[ug/l]**
SECCHI DEPTH				
	$SD = \dfrac{CS}{(a + 0.015 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.02	$[m^{-1}]$
Model Predicted In-Lake SD			**0.59**	**[m]**
Observed In-Lake SD			**0.55**	**[m]**
PHOSPHORUS SEDIMENTATION RATE				
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$			
		P_{sed} (phosphorus sedimentation) =	**18**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	$W - P_{sed}$ =		**28**	**[kg/yr]**

2006 Loading Summary for: Lake Magda

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1 Watershed	0.25	0.62	0.157	218.1	1.0	34.3
2					1.0	
3					1.0	
4					1.0	
5					1.0	
6					1.0	
7					1.0	
8					1.0	
9					1.0	
10					1.0	
11					1.0	
12					1.0	
13					1.0	
Summation	*0.25*	*0.62*	*0.16*			*34.3*

Inflow from Upstream Lakes				
Name	Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1		-	1.0	
2		-	1.0	
3		-	1.0	
Summation	*0.00*	-		-

Atmosphere						
Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.83	0.83	0.00	26.80	1.0	1.1
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater					
Lake Area [km^2]	Groundwater Flux [m/yr]	Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.0	0.00	0	1.0	-

Internal				
Lake Area [km^2]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.0414	59.0	6.0	1.0	14.6

Net Discharge [10^6 m^3/yr] =	**0.16**	**Net Load [kg/yr] =**	**50.0**

NOTES

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

2006 Lake Response Modeling for: Lake Magda

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \left[-1+\left(1+4KA1P_iT\right)^{-5}\right] / \left(2KA1T\right)$	as f(W,Q,V,Fot) from BATHTUB 2nd Order Decay		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
	$A1 = 0.056 Fot^{-1} Qs / \left(Qs + 13.3\right)$	b =	0.458	[--]
		W (total P load = inflow + atm.) =	50	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
	$Qs = Max(Z/T, 4)$	V (modeled lake volume) =	0.0271	[10^6 m^3]
		Fot=	0.4	[--]
		Qs=	11.59	[m/yr]
		T = V/Q =	0.17	[yr]
		P_i = W/Q =	318	[ug/l]
Model Predicted In-Lake [TP]			**129.4**	**[ug/l]**
Observed In-Lake [TP]			**163.3**	**[ug/l]**
CHLOROPHYLL-A CONCENTRATION				
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4		
		CB (Calibration factor) =	1.00	[--]
Model Predicted In-Lake [Chl-a]			**36.2**	**[ug/l]**
	$[\text{Chl}a] = \frac{CB \times B_x}{\left[\left(1+0.025 \times B_x \times G\right)\left(1+G \times \text{a}\right)\right]}$	as f(TP, N, Flushing), Walker 1999, Model 1		
		CB (Calibration factor) =	1.00	
	$B_x = \frac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	163	[ug/l]
		N (Total Nitrogen) =	3,000	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	157.3	[ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	134.5	[ug/l]
		G (Kinematic factor) =	0.33	[--]
		F_s (Flushing Rate) =	5.80	[$year^{-1}$]
	$G = Z_{mix}\left(0.14 + 0.0039 F_s\right)$	Z_{mix} (Mixing Depth) =	2.00	[m]
	$F_s = \frac{Q}{V}$; $a = \frac{1}{SD} - 0.015 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.02	[m^{-1}]
		S (Secchi Depth) =	0.58	[m]
		Maximum lake depth =	2.00	[m]
Model Predicted In-Lake [Chl-a]			**68.6**	**[ug/l]**
Observed In-Lake [Chl-a]			**127.4**	**[ug/l]**
SECCHI DEPTH				
	$SD = \frac{CS}{\left(\text{a} + 0.015 \times [\text{Chl}a]\right)}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.02	[m^{-1}]
Model Predicted In-Lake SD			**0.58**	**[m]**
Observed In-Lake SD			**0.33**	**[m]**
PHOSPHORUS SEDIMENTATION RATE				
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$			
		P_{sed} (phosphorus sedimentation) =	**18**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	W-P_{sed} =		**32**	**[kg/yr]**

1997- 2006 Average Loading Summary for Lake Magda

	Water Budgets			Phosphorus Loading		

Inflow from Drainage Areas

Name	Drainage Area [km²]	Runoff Depth [m/yr]	Discharge [10^6 m³/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1 Watershed	0.25		0.170		1.0	37.5
2					1.0	
3					1.0	
4					1.0	
5					1.0	
6					1.0	
7					1.0	
8					1.0	
9					1.0	
10					1.0	
11					1.0	
12					1.0	
13					1.0	
Summation	*0.25*	*0.00*	*0.17*			*37.5*

Inflow from Upstream Lakes

Name	Discharge [10^6 m³/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1		-	1.0	
2		-	1.0	
3		-	1.0	
Summation	*0.00*	-		*-*

Atmosphere

Lake Area [km²]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m³/yr]	Aerial Loading Rate [kg/km²-yr]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.83	0.83	0.00	26.80	1.0	1.1
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater

Lake Area [km²]	Groundwater Flux [m/yr]	Net Inflow [10^6 m³/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.0	0.00	0	1.0	-

Internal

Lake Area [km²]	Anoxic Factor [days]	Release Rate [mg/m²-day]	Calibration Factor [--]	Load [kg/yr]
0.0414	59.0	6.0	1.0	14.6

Net Discharge [10^6 m³/yr] =	**0.17**	**Net Load [kg/yr] =**	**53.2**

NOTES

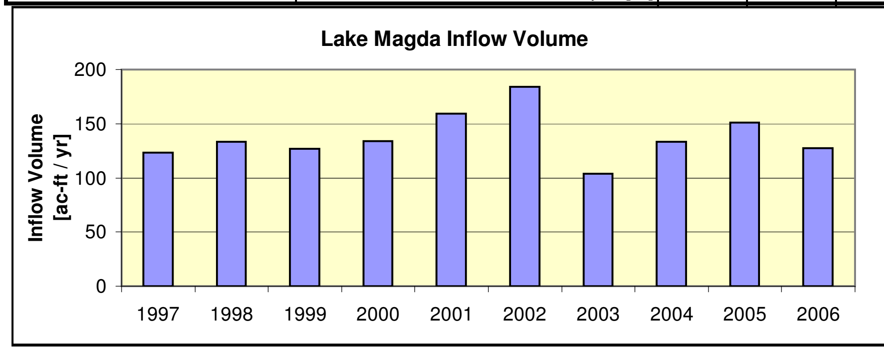
1 Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

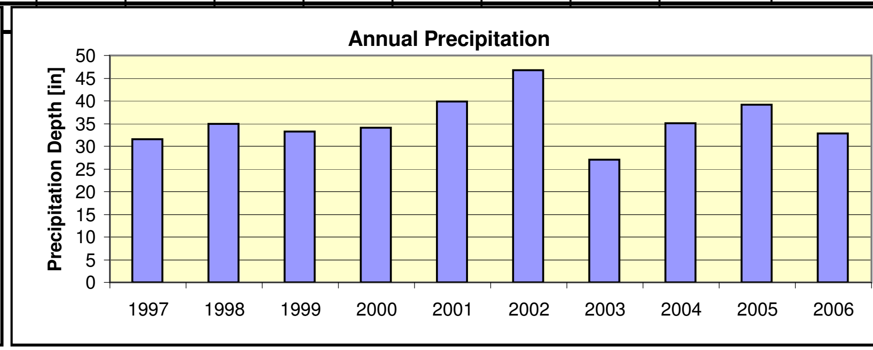
1997- 2006 Average Lake Response Modeling for Lake Magda

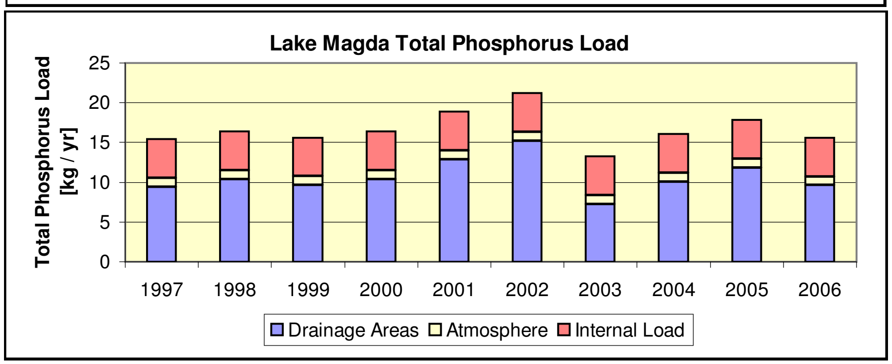
Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \left[-1+\left(1+4KA1P_iT\right)^{-5}\right] / \left(2KA1T\right)$	as f(W,Q,V,Fot) from BATHTUB 2nd Order Decay		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
	$A1 = 0.056 Fot^{-1} Qs / \left(Qs + 13.3\right)$	b =	0.458	[--]
		W (total P load = inflow + atm.) =	53	[kg/yr]
		Q (lake outflow) =	0.170	[10^6 m^3/yr]
	$Qs = Max(Z/T, 4)$	V (modeled lake volume) =	0.0271	[10^6 m^3]
		Fot=	0.4	[--]
		Qs=	12.52	[m/yr]
		T = V/Q =	0.16	[yr]
		P_i = W/Q =	313	[ug/l]
Model Predicted In-Lake [TP]			**129.9**	**[ug/l]**
Observed In-Lake [TP]				**[ug/l]**
CHLOROPHYLL-A CONCENTRATION				
	$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4		
		CB (Calibration factor) =	1.00	[--]
Model Predicted In-Lake [Chl-a]			**36.4**	**[ug/l]**
	$[\mathrm{Chl}a] = \frac{CB \times B_x}{\left[(1+0.025 \times B_x \times G)(1+G \times \mathrm{a})\right]}$	as f(TP, N, Flushing), Walker 1999, Model 1		
		CB (Calibration factor) =	1.00	
	$B_x = \frac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	130	[ug/l]
		N (Total Nitrogen) =	3,000	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	126.2	[ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	114.0	[ug/l]
		G (Kinematic factor) =	0.33	[--]
		F_s (Flushing Rate) =	6.26	[$year^{-1}$]
	$G = Z_{mix}\left(0.14 + 0.0039 F_s\right)$	Z_{mix} (Mixing Depth) =	2.00	[m]
	$F_s = \frac{Q}{V}$ $a = \frac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	0.02	[m^{-1}]
		S (Secchi Depth) =	0.64	[m]
		Maximum lake depth =	2.00	[m]
Model Predicted In-Lake [Chl-a]			**61.6**	**[ug/l]**
Observed In-Lake [Chl-a]				**[ug/l]**
SECCHI DEPTH				
	$SD = \frac{CS}{\left(\mathrm{a} + 0.015 \times [\mathrm{Chl}a]\right)}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.02	[m^{-1}]
Model Predicted In-Lake SD			**0.64**	**[m]**
Observed In-Lake SD				**[m]**
PHOSPHORUS SEDIMENTATION RATE				
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$			
		P_{sed} (phosphorus sedimentation) =	**18**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	$W - P_{sed}$ =		**35**	**[kg/yr]**

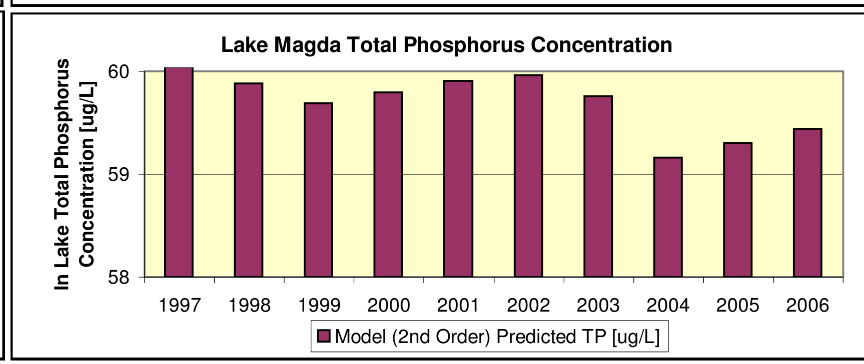
Table 2: Lake Magda Response Modeling Summary: At Goal (60 ug/L TP)

Magda Lake	Source	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*TMDL*	
Precipitation Depth [in]		31.5	34.9	33.3	34.1	39.8	46.7	27.1	35.1	39.2	32.8	Annual	Daily
	Residence Time [yr]	0.18	0.16	0.17	0.16	0.14	0.12	0.21	0.17	0.15	0.17	0.16	
Inflow Volume [ac-ft / yr]	Drainage Areas	123.6	133.5	126.9	134.1	159.4	183.8	103.6	133.1	151.1	127.5	137.7	
	Upstream Lakes	0	0	0	0	0	0	0	0	0	0	0	
	Atmosphere	0	0	0	0	0	0	0	0	0	0	0	
	TOTAL =	**123.6**	**133.5**	**126.9**	**134.1**	**159.4**	**183.8**	**103.6**	**133.1**	**151.1**	**127.5**	**137.7**	
Total Phosphorus Load [kg / yr]	Drainage Areas	9.4	10.4	9.6	10.4	12.9	15.2	7.3	10.0	11.8	9.6	10.7	0.029
	Upstream Lakes	0	0	0	0	0	0	0	0	0	0	0.0	0.000
	Atmosphere	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.003
	Internal Load	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	0.013
	TOTAL =	**15.4**	**16.4**	**15.6**	**16.4**	**18.9**	**21.2**	**13.3**	**16.0**	**17.8**	**15.6**	**16.7**	**0.045**
Model Results	Model (2nd Order) Predicted TP [ug/L]	60.0	59.9	59.7	59.8	59.9	60.0	59.8	59.2	59.3	59.4	59.6	
	Observed TP [ug/L]	-	-	-	-	-	-	-	-	-	-		
	Predicted Chl-a [ug/L]	35.5	35.3	35.4	33.2	35.0	34.7	35.4	34.9	34.8	35.8	35.8	
	Observed Chl-a [ug/L]	-	-	-	-	-	-	-	-	-	-		
	Predicted Secchi Depth [m]	1.10	1.11	1.10	1.18	1.12	1.13	1.11	1.12	1.13	1.09	1.09	
	Observed Secchi Depth [m]	-	-	-	-	-	-	-	-	-	-		









1999 Loading Summary for: Lake Magda at Goal

Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

Name	Drainage Area [km²]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1 Watershed	0.25	0.62	0.157	61.6	0.27	9.6
2					1.0	
3					1.0	
4					1.0	
5					1.0	
6					1.0	
7					1.0	
8					1.0	
9					1.0	
10					1.0	
11					1.0	
12					1.0	
13					1.0	
Summation	*0.25*	*0.62*	*0.16*	*61.6*		*9.6*

Inflow from Upstream Lakes

Name	Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1		-	1.0	
2		-	1.0	
3		-	1.0	
Summation	*0.00*	-		-

Atmosphere

Lake Area [km²]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km²-yr]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.85	0.85	0.00	26.80	1.0	1.1

Dry-year total P deposition =	24.9
Average-year total P deposition =	26.8
Wet-year total P deposition =	29.0
(Barr Engineering 2004)	

Groundwater

Lake Area [km²]	Groundwater Flux [m/yr]	Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.0	0.00	0	1.0	-

Internal

Lake Area [km²]	Anoxic Factor [days]	Release Rate [mg/m²-day]	Calibration Factor [--]	Load [kg/yr]
0.0414	59.0	2.0	1.0	4.9

Net Discharge [10^6 m^3/yr] =	**0.16**	**Net Load [kg/yr] =**	**15.6**

NOTES

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

1999 Lake Response Modeling for: Lake Magda at Goal

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \left[-1+(1+4KA1P_iT)^{.5}\right] / (2KA1T)$	as f(W,Q,V,Fot) from BATHTUB 2nd Order Decay	
		C_P =	1.00 [--]
	$A1 = 0.056\,Fot^{-1}Qs / (Qs+13.3)$	C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	16 [kg/yr]
	$Qs = Max(Z/T, 4)$	Q (lake outflow) =	0.1565 [$10^6\ m^3$/yr]
		V (modeled lake volume) =	0.0271 [$10^6\ m^3$]
		Fot=	0.4 [--]
		Qs=	11.54 [m/yr]
		T = V/Q =	0.17 [yr]
		P_i = W/Q =	100 [ug/l]
Model Predicted In-Lake [TP]			**59.7 [ug/l]**
Observed In-Lake [TP]			**106.3 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**16.7 [ug/l]**
	$[\mathrm{Chl}a] = \dfrac{CB \times B_x}{[(1+0.025 \times B_x \times G)(1+G \times \mathrm{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	60 [ug/l]
		N (Total Nitrogen) =	2,450 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	50.2 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	57.0 [ug/l]
		G (Kinematic factor) =	0.32 [--]
		F_s (Flushing Rate) =	5.77 [$year^{-1}$]
	$G = Z_{mix}(0.14 + 0.0039F_s)$	Z_{mix} (Mixing Depth) =	2.00 [m]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	0.02 [m^{-1}]
		S (Secchi Depth) =	1.10 [m]
		Maximum lake depth =	2.00 [m]
Model Predicted In-Lake [Chl-a]			**35.4 [ug/l]**
Observed In-Lake [Chl-a]			**55.3 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\mathrm{a} + 0.015 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.02 [m^{-1}]
Model Predicted In-Lake SD			**1.10 [m]**
Observed In-Lake SD			**0.54 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**5 [kg/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**11 [kg/yr]**

2000 Loading Summary for: Lake Magda at Goal

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	Watershed	0.25	0.65	0.165	62.8	0.28	10.4
2						1.0	
3						1.0	
4						1.0	
5						1.0	
6						1.0	
7						1.0	
8						1.0	
9						1.0	
10						1.0	
11						1.0	
12						1.0	
13						1.0	
	Summation	*0.25*	*0.65*	*0.17*	*62.8*		*10.4*

Inflow from Upstream Lakes

	Name	Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1			-	1.0	
2			-	1.0	
3			-	1.0	
	Summation	*0.00*	-		-

Atmosphere

Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.87	0.87	0.00	26.80	1.0	1.1

Dry-year total P deposition =	24.9
Average-year total P deposition =	26.8
Wet-year total P deposition =	29.0
(Barr Engineering 2004)	

Groundwater

Lake Area [km^2]	Groundwater Flux [m/yr]	Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.0	0.00	0	1.0	-

Internal

Lake Area [km^2]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.0414	59.0	2.0	1.0	4.9

Net Discharge [10^6 m^3/yr] = 0.17 | **Net Load [kg/yr] = 16.4**

NOTES

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

2000 Lake Response Modeling for: Lake Magda at Goal

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \left[-1 + (1 + 4KA1P_iT)^{.5}\right] / (2KA1T)$	as f(W,Q,V,Fot) from BATHTUB 2nd Order Decay	
	$A1 = 0.056 Fot^{-1} Qs / (Qs + 13.3)$	C_P =	1.00 [--]
	$Qs = Max(Z/T, 4)$	C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	16 [kg/yr]
		Q (lake outflow) =	0.1654 [10^6 m^3/yr]
		V (modeled lake volume) =	0.0271 [10^6 m^3]
		Fot=	0.4 [--]
		Qs=	12.19 [m/yr]
		T = V/Q =	0.16 [yr]
		P_i = W/Q =	99 [ug/l]
Model Predicted In-Lake [TP]			**59.8 [ug/l]**
Observed In-Lake [TP]			**101.3 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**16.7 [ug/l]**
	$[\mathrm{Chl}a] = \frac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \mathrm{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \frac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	60 [ug/l]
		N (Total Nitrogen) =	1,563 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	45.9 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	53.3 [ug/l]
		G (Kinematic factor) =	0.33 [--]
		F_s (Flushing Rate) =	6.09 [$year^{-1}$]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	2.00 [m]
	$F_s = \frac{Q}{V}$; $a = \frac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	0.02 [m^{-1}]
		S (Secchi Depth) =	1.18 [m]
		Maximum lake depth =	2.00 [m]
Model Predicted In-Lake [Chl-a]			**33.2 [ug/l]**
Observed In-Lake [Chl-a]			**40.3 [ug/l]**
SECCHI DEPTH			
	$SD = \frac{CS}{(\mathrm{a} + 0.015 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.02 [m^{-1}]
Model Predicted In-Lake SD			**1.18 [m]**
Observed In-Lake SD			**0.63 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**5 [kg/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**11 [kg/yr]**

2003 Loading Summary for: Lake Magda at Goal

Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1 Watershed	0.25	0.51	0.128	56.8	0.24	7.3
2					1.0	
3					1.0	
4					1.0	
5					1.0	
6					1.0	
7					1.0	
8					1.0	
9					1.0	
10					1.0	
11					1.0	
12					1.0	
13					1.0	
Summation	*0.25*	*0.51*	*0.13*	*56.8*		*7.3*

Inflow from Upstream Lakes

Name	Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1		-	1.0	
2		-	1.0	
3		-	1.0	
Summation	*0.00*	-		-

Atmosphere

Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.69	0.69	0.00	26.80	1.0	1.1

Dry-year total P deposition =	24.9
Average-year total P deposition =	26.8
Wet-year total P deposition =	29.0
(Barr Engineering 2004)	

Groundwater

Lake Area [km^2]	Groundwater Flux [m/yr]	Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.0	0.00	0	1.0	-

Internal

Lake Area [km^2]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.0414	59.0	2.0	1.0	4.9

Net Discharge [10^6 m^3/yr] =	**0.13**	**Net Load [kg/yr] =**	**13.3**

NOTES

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

2003 Lake Response Modeling for: Lake Magda at Goal

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \left[-1+(1+4KA1P_iT)^{.5}\right] / (2KA1T)$	as f(W,Q,V,Fot) from BATHTUB 2nd Order Decay		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
	$A1 = 0.056\,Fot^{-1}Qs / (Qs+13.3)$	b =	0.458	[--]
		W (total P load = inflow + atm.) =	13	[kg/yr]
		Q (lake outflow) =	0.1278	$[10^6\ m^3/yr]$
	$Qs = Max(Z/T, 4)$	V (modeled lake volume) =	0.0271	$[10^6\ m^3]$
		Fot=	0.4	[--]
		Qs=	9.42	[m/yr]
		T = V/Q =	0.21	[yr]
		P_i = W/Q =	104	[ug/l]
Model Predicted In-Lake [TP]			**59.8**	**[ug/l]**
Observed In-Lake [TP]			**187.3**	**[ug/l]**
CHLOROPHYLL-A CONCENTRATION				
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4		
		CB (Calibration factor) =	1.00	[--]
Model Predicted In-Lake [Chl-a]			**16.7**	**[ug/l]**
	$[\text{Chl}a] = \frac{CB \times B_x}{[(1+0.025 \times B_x \times G)(1+G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1		
		CB (Calibration factor) =	1.00	
	$B_x = \frac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	60	[ug/l]
		N (Total Nitrogen) =	2,200	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	49.5	[ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	56.4	[ug/l]
		G (Kinematic factor) =	0.32	[--]
		F_s (Flushing Rate) =	4.71	$[\text{year}^{-1}]$
	$G = Z_{mix}(0.14 + 0.0039F_s)$	Z_{mix} (Mixing Depth) =	2.00	[m]
	$F_s = \frac{Q}{V}$; $a = \frac{1}{SD} - 0.015 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.02	$[m^{-1}]$
		S (Secchi Depth) =	1.11	[m]
		Maximum lake depth =	2.00	[m]
Model Predicted In-Lake [Chl-a]			**35.4**	**[ug/l]**
Observed In-Lake [Chl-a]			**88.4**	**[ug/l]**
SECCHI DEPTH				
	$SD = \frac{CS}{(\text{a} + 0.015 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.02	$[m^{-1}]$
Model Predicted In-Lake SD			**1.11**	**[m]**
Observed In-Lake SD			**0.55**	**[m]**
PHOSPHORUS SEDIMENTATION RATE				
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$			
		P_{sed} (phosphorus sedimentation) =	**4**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	W-P_{sed} =		**9**	**[kg/yr]**

2006 Loading Summary for: Lake Magda at Goal

Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

Name	Drainage Area [km²]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1 Watershed	0.25	0.62	0.157	61.1	0.28	9.6
2					1.0	
3					1.0	
4					1.0	
5					1.0	
6					1.0	
7					1.0	
8					1.0	
9					1.0	
10					1.0	
11					1.0	
12					1.0	
13					1.0	
Summation	*0.25*	*0.62*	*0.16*	*61.1*		*9.6*

Inflow from Upstream Lakes

Name	Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1		-	1.0	
2		-	1.0	
3		-	1.0	
Summation	*0.00*	-		-

Atmosphere

Lake Area [km²]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km²-yr]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.83	0.83	0.00	26.80	1.0	1.1
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater

Lake Area [km²]	Groundwater Flux [m/yr]	Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.0	0.00	0	1.0	-

Internal

Lake Area [km²]	Anoxic Factor [days]	Release Rate [mg/m²-day]	Calibration Factor [--]	Load [kg/yr]
0.0414	59.0	2.0	1.0	4.9

Net Discharge [10^6 m^3/yr] =	**0.16**	**Net Load [kg/yr] =**	**15.6**

NOTES

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

2006 Lake Response Modeling for: Lake Magda at Goal

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \left[-1+(1+4KA1P_iT)^{.5}\right] / (2KA1T)$	as f(W,Q,V,Fot) from BATHTUB 2nd Order Decay	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
	$A1 = 0.056\,Fot^{-1}Qs / (Qs+13.3)$	b =	0.458 [--]
		W (total P load = inflow + atm.) =	16 [kg/yr]
		Q (lake outflow) =	0.1573 [10^6 m^3/yr]
	$Qs = Max(Z/T, 4)$	V (modeled lake volume) =	0.0271 [10^6 m^3]
		Fot=	0.4 [--]
		Qs=	11.59 [m/yr]
		T = V/Q =	0.17 [yr]
		P_i = W/Q =	99 [ug/l]
Model Predicted In-Lake [TP]			**59.4 [ug/l]**
Observed In-Lake [TP]			**163.3 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**16.6 [ug/l]**
	$[\mathrm{Chl}a] = \frac{CB \times B_x}{[(1+0.025 \times B_x \times G)(1+G \times a)]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \frac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	59 [ug/l]
		N (Total Nitrogen) =	3,000 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	51.0 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	57.7 [ug/l]
		G (Kinematic factor) =	0.33 [--]
		F_s (Flushing Rate) =	5.80 [$year^{-1}$]
	$G = Z_{mix}(0.14 + 0.0039F_s)$	Z_{mix} (Mixing Depth) =	2.00 [m]
	$F_s = \frac{Q}{V}$; $a = \frac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	0.02 [m^{-1}]
		S (Secchi Depth) =	1.09 [m]
		Maximum lake depth =	2.00 [m]
Model Predicted In-Lake [Chl-a]			**35.8 [ug/l]**
Observed In-Lake [Chl-a]			**127.4 [ug/l]**
SECCHI DEPTH			
	$SD = \frac{CS}{(a + 0.015 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.02 [m^{-1}]
Model Predicted In-Lake SD			**1.09 [m]**
Observed In-Lake SD			**0.33 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**5 [kg/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**11 [kg/yr]**

TMDL Loading Summary for: Lake Magda at Goal

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1 Watershed	0.25	0.67	0.170	62.8	1.00	10.7
2					1.0	
3					1.0	
4					1.0	
5					1.0	
6					1.0	
7					1.0	
8					1.0	
9					1.0	
10					1.0	
11					1.0	
12					1.0	
13					1.0	
Summation	*0.25*	*0.67*	*0.17*	*62.8*		*10.7*

Inflow from Upstream Lakes						
Name			Discharge [10^6 m^3/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1				-	1.0	
2				-	1.0	
3				-	1.0	
Summation			*0.00*	-		-

Atmosphere						
Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.83	0.83	0.00	26.80	1.0	1.1
			Dry-year total P deposition =	24.9		
			Average-year total P deposition =	26.8		
			Wet-year total P deposition =	29.0		
			(Barr Engineering 2004)			

Groundwater						
Lake Area [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.0414	0.0		0.00	0	1.0	-

Internal						
Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.0414	59.0			2.0	1.0	4.9
			Net Discharge [10^6 m^3/yr] = 0.17			**Net Load [kg/yr] = 16.7**

NOTES

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

TMDL Lake Response Modeling for: Lake Magda at Goal

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \left[-1+\left(1+4KA1P_iT\right)^{-5}\right] / \left(2KA1T\right)$	as f(W,Q,V,Fot) from BATHTUB 2nd Order Decay		
		C_P =	1.00	[--]
	$A1 = 0.056 Fot^{-1} Qs / \left(Qs+13.3\right)$	C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	17	[kg/yr]
	$Qs = Max(Z/T, 4)$	Q (lake outflow) =	0.1698	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0271	[10^6 m^3]
		Fot=	0.4	[--]
		Qs=	12.51	[m/yr]
		T = V/Q =	0.16	[yr]
		P_i = W/Q =	98	[ug/l]
Model Predicted In-Lake [TP]			**59.6**	**[ug/l]**
Observed In-Lake [TP]			**-**	**[ug/l]**
CHLOROPHYLL-A CONCENTRATION				
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4		
		CB (Calibration factor) =	1.00	[--]
Model Predicted In-Lake [Chl-a]			**16.7**	**[ug/l]**
	$[\text{Chl}a] = \frac{CB \times B_x}{\left[\left(1+0.025\times B_x \times G\right)\left(1+G\times a\right)\right]}$	as f(TP, N, Flushing), Walker 1999, Model 1		
		CB (Calibration factor) =	1.00	
	$B_x = \frac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	60	[ug/l]
		N (Total Nitrogen) =	3,000	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	51.2	[ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	57.8	[ug/l]
		G (Kinematic factor) =	0.33	[--]
		F_s (Flushing Rate) =	6.26	[$year^{-1}$]
	$G = Z_{mix}\left(0.14+0.0039F_s\right)$	Z_{mix} (Mixing Depth) =	2.00	[m]
	$F_s = \frac{Q}{V}$; $a = \frac{1}{SD} - 0.015\times[\text{Chl}a]$	a (Non algal turbidity) =	0.02	[m^{-1}]
		S (Secchi Depth) =	1.09	[m]
		Maximum lake depth =	2.00	[m]
Model Predicted In-Lake [Chl-a]			**35.8**	**[ug/l]**
Observed In-Lake [Chl-a]			**-**	**[ug/l]**
SECCHI DEPTH				
	$SD = \frac{CS}{\left(a+0.015\times[\text{Chl}a]\right)}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.02	[m^{-1}]
Model Predicted In-Lake SD			**1.09**	**[m]**
Observed In-Lake SD			**-**	**[m]**
PHOSPHORUS SEDIMENTATION RATE				
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$			
		P_{sed} (phosphorus sedimentation) =	**5**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	W-P_{sed} =		**12**	**[kg/yr]**

Appendix B

Water Quality Monitoring

1.0 Water Quality Monitoring

1.1 INTRODUCTION

Lake water quality monitoring has been conducted on thirteen lakes in the Shingle Creek watershed since 1990 as a part of the CAMP program. Additionally, some Cities have conducted monitoring on lakes on their own or as a partnership with the Three Rivers Park District. This section presents water quality monitoring data for Lake Magda to characterize current conditions and diagnose key problems degrading current water quality.

1.2 PREVIOUS STUDIES AND MONITORING ON LAKE MAGDA

1.2.1 Citizen Assisted Monitoring Program (CAMP)

The Citizen Assisted Monitoring Program (CAMP) is operated by Metropolitan Council Environmental Services, which provides coordination and data analysis for the almost 200 lakes monitored annually in the Metro area. Citizen volunteers collect data and samples biweekly. Lake Magda has been monitored periodically since 1999.

1.3 MONITORING PARAMETERS

The following sections generally discuss the parameters that are typically monitored and the value of that data in understanding lake processes.

1.3.1 Temperature and Dissolved Oxygen

Understanding lake stratification is important to the development of both the nutrient budget for a lake as well as ecosystem management strategies. Lakes that are dimictic (mix from top to bottom in the spring and fall) can have very different nutrient budgets than lakes that are completely mixed all year. Typically, temperature drives the stratification of a lake because water density changes with water temperature. However, the larger impact usually lies with the dissolved oxygen profile. As cooler, denser water is trapped at the bottom of a lake, it can become devoid of oxygen affecting both aquatic organisms and the sediment biogeochemistry.

1.3.2 Phosphorus and Nitrogen

Lake algal production is typically limited by nutrient availability, specifically phosphorus and nitrogen. Minnesota lakes are almost exclusively limited by phosphorus; however excessive phosphorus concentrations can lead to nitrogen limiting conditions. Phosphorus and nitrogen are measured to determine the availability of the nutrients for algal production. Dissolved and orthophosphorus are the most readily available forms of phosphorus while total phosphorus is a measure of all the phosphorus, bound and unbound. Nitrate is the most readily available form of nitrogen for algal production and Total Kjeldahl nitrogen is a measure of all nitrogen in the water column.

1.3.3 Chlorophyll-a and Secchi Depth

Algal biomass can be measured directly by developing cell-by-cell counts and volumes. However, this is time intensive and often expensive. Chlorophyll-a has been shown to be a good estimator of algal biomass and is inexpensive and easy to analyze.

Secchi depth is also a predictor of algal production by measuring the clarity of lake water. This is accomplished by lowering a round disc shaded black and white over the shady side of the boat and recording the depth at which the disc is no longer visible.

1.4 LAKE MONITORING RESULTS

Following is a discussion of the lake monitoring results for Lake Magda. The discussion is focused on specific monitoring years to present nutrient cycling dynamics in the lakes.

1.4.1 Historical Data

Spring and summer average water quality for Lake Magda is presented in Table 1.1 and Table 1.2 respectively. Data suggests that severe algal bloom conditions persist year round.

Table 1.1. Spring average (January 1 through May 31) water quality conditions for Lake Magda.

	Total Phosphorus (µg/L)		Chlorophyll-a (µg/L)		Secchi Depth (m)	
Year	N	Mean	N	Mean	N	Mean
1999	4	92	4	59	4	0.6
2000	3	160	3	62	3	0.5
2003	2	82	2	24	3	1.0
2006	2	106	3	21	3	0.8
Average		111		44		0.7

N = number of samples

Table 1.2. Summer average (June 1 through September 30) water quality conditions for Lake Magda.

	Total Phosphorus (µg/L)		Chlorophyll-a (µg/L)		Secchi Depth (m)	
Year	N	Mean	N	Mean	N	Mean
1999	8	106	8	55	8	0.5
2000	8	101	8	40	8	0.6
2003	7	187	8	88	8	0.6
2006	8	160	8	127	8	0.33
Average		137		78		0.5
Standard	60 or less		20 or less		1.0 or greater	

N = number of samples

1.4.2 Temperature and Dissolved Oxygen

No temperature or dissolved oxygen profiles are available for Lake Magda, and no data is available to determine the mixing pattern in the lake. However, given that it is a shallow lake, it likely mixes completely several times a year due to wind action.

1.4.3 Phosphorus

Total phosphorus concentration generally increased throughout the summer in 2003, with maximum concentration generally occurring in August or early September, as can be seen in Figure 1.2. Lake Magda showed a different pattern in 2000 than in 2003, as shown in Figure 1.1.

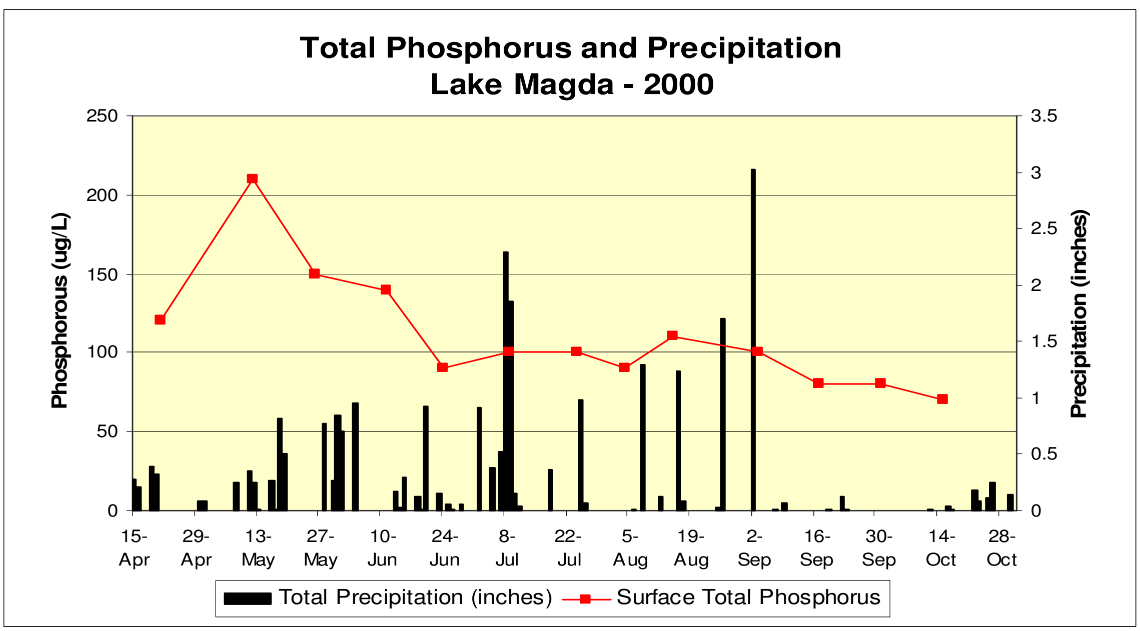


Figure 1.1. Surface total phosphorus concentrations and total precipitation for Lake Magda in 2000.

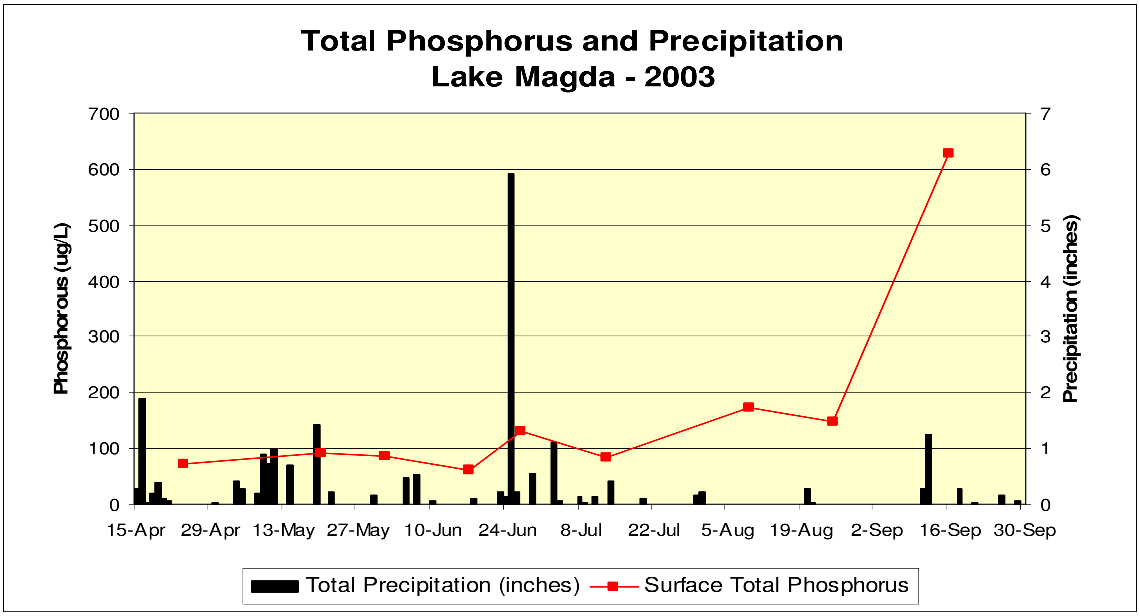


Figure 1.2. Surface total phosphorus concentrations and total precipitation for Lake Magda in 2003.

1.4.4 Chlorophyll-a

Chlorophyll-a concentrations generally track with TP concentrations increasing through the spring and early summer (Figure 1.3 and Figure 1.4). Dissolved phosphorus concentrations remain low throughout the year with the algae utilizing the readily available forms of phosphorus. If the lake becomes nitrogen limited we would expect to see some increases in phosphorus without an algal response.

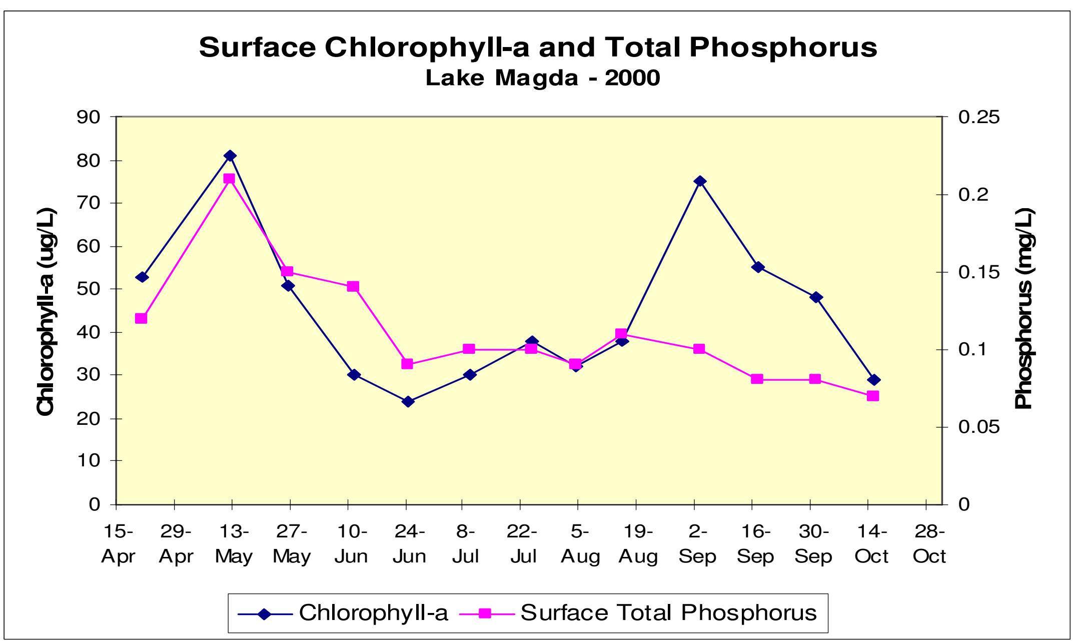


Figure 1.3. Chlorophyll-a and phosphorus concentrations in the surface waters of Lake Magda in 2000.

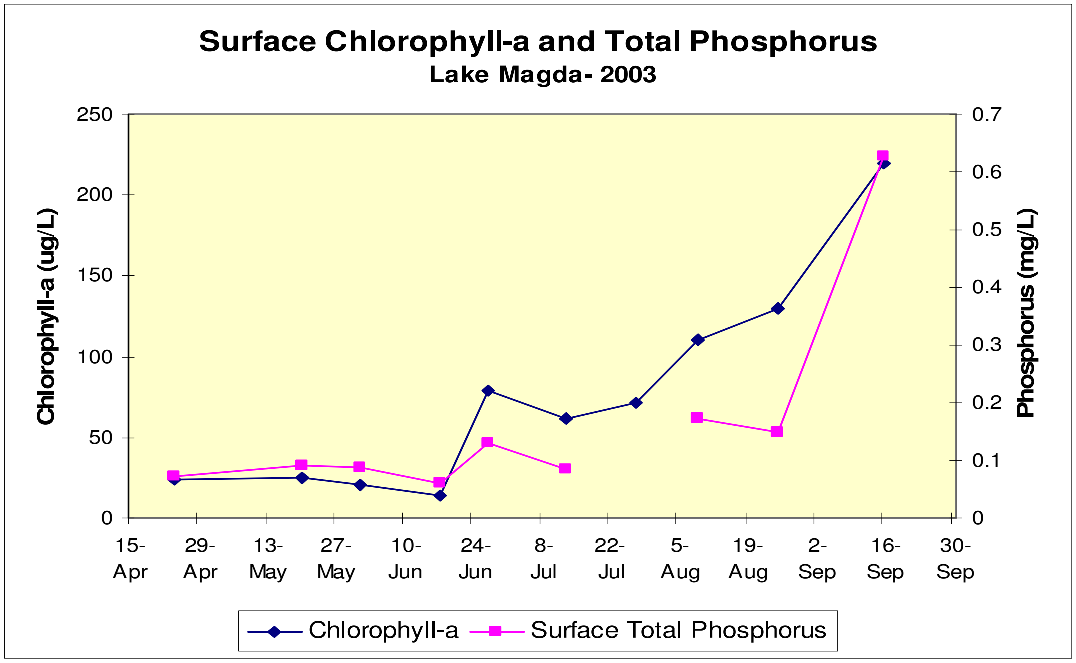


Figure 1.4. Chlorophyll-a and phosphorus concentrations in the surface waters of Lake Magda in 2003.

1.5 CONCLUSIONS

Monitoring data indicate that Lake Magda is a biologically productive system in which water quality exceeds the shallow lake standards for total phosphorus (≤60µg/L), chlorophyll-a (≤20µg/L), and Secchi depth (≥1.0 meters) in all monitored years.