Meadow Lake Nutrient TMDL

FINAL

Prepared for

Shingle Creek Watershed Management Commission

Minnesota Pollution Control Agency

January 2010

Wenck

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Meadow Lake Nutrient TMDL

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Prepared for:

SHINGLE CREEK WATERSHED MANAGEMENT COMMISSION

MINNESOTA POLLUTION CONTROL AGENCY

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TMDL Summary

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EPA/MPCA Required Elements	**Summary**	**TMDL Page #**
Location	City of New Hope in Hennepin County, Minnesota, in the Upper Mississippi River Basin.	3-1
303(d) Listing Information	Meadow 27-0057 Meadow Lake 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. This TMDL was prioritized to start in 2007 and be completed by 2008.	1-1
Applicable Water Quality Standards/ Numeric Targets	Criteria set forth in Minn. R. 7050.0150 (3) and (5). For Meadow Lake, the numeric target is a total phosphorus concentration of 60 µg/L or less.	2-1 – 2-2
Loading Capacity (expressed as daily load)	The loading capacity is the total maximum daily load. The critical condition for these lakes is the summer growing season. The loading capacity is set forth in Table 6.1. **Total maximum daily total phosphorus load (kg/day)** Meadow Lake: 0.044	6-1 – 6-3
Wasteload Allocation	Portion of the loading capacity allocated to existing and future point sources. **Source** / **Permit #** / **WLA (kg/day)** Permitted Stormwater: Meadow Lake / MS400039 City of New Hope / 0.025	6-1 – 6-3
Load Allocation	The portion of the loading capacity allocated to existing and future nonpoint sources. **Source** / **Load Allocation (kg/day)** Atmospheric Load / 0.003 Internal Load / 0.016	6-1 – 6-3
Margin of Safety	The margin of safety is implicit in this TMDL due to the conservative assumptions of the model and the proposed iterative nutrient reduction strategy with monitoring.	6-2
Seasonal Variation	Seasonal variation is accounted for by developing targets for the summer critical period when the frequency and severity of nuisance algal growth is greatest. Although the critical period is the summer, lakes are not sensitive to short-term changes but rather respond to long term changes in annual load.	6-5 – 6-6

TMDL Summary (Cont.)

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 Management 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 9
Monitoring	The Shingle Creek Watershed Management Commission periodically monitors this lake and will continue to do so through the implementation period.	9-3
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 8
Public Participation	Public Comment period: September 28, 2009 – October 28, 2009 Meetings: See Section 7 Comments received: Four comments were received on the Draft TMDL Report.	Section 7

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses a nutrient impairment in Meadow Lake (27-0057). The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients.

Meadow Lake is located in the City of New Hope, Hennepin County, Minnesota, in the Shingle Creek watershed. It is a neighborhood lake that primarily provides aesthetic values and some canoe and paddle boating opportunities. The drainage area to the lake is 103 acres of fully developed urban and suburban land. The drainage area is entirely in the City of New Hope. Meadow Lake outlets by storm sewer to Bass Creek. Bass 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 82 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 Meadow Lake.

1.0 Introduction

1.1 PURPOSE

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

This TMDL provides waste load allocations (WLAs) and load allocations (LAs) for Meadow Lake. 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

Meadow Lake (DNR Lake # 27-0057) was first placed on the State of Minnesota's 303(d) list of impaired waters in 2002 and identified for impairment of aquatic recreation. Meadow Lake is a neighborhood lake located in the City of New Hope. There is a small city park adjacent to the lake. The primary lake use is its aesthetic value, although the lakeshore residents do use it for paddle boating.

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

Meadow Lake is a small, shallow lake classified as a class 2B water for which aquatic life and recreation are the protected beneficial uses. The MPCA first included Meadow Lake 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 2007 and completed by 2008. 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)) were narrative standards prohibiting the increase of undesirable aquatic plants or algae. In accordance with Minnesota Rules 7050.0150(5), to evaluate whether a waterbody was 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), Meadow Lake is now considered a shallow lake with a numeric target of ≤60 µg/L. 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, Meadow Lake 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	Shallow Lake Standards[1]
Total phosphorus concentration (µg/L)	≤60
Chlorophyll-a concentration (µg/L)	≤20
Secchi disk transparency (meters)	≥1

[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).

2.1.2 Analysis of Impairment

Meadow Lake 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 191 µg/L to 266 µg/L. Chlorophyll-a (chl-a) concentration has ranged from 91 µg/L to 192 µg/L, while the Secchi depth is typically around 0.3 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 New Hope (Figure 3.1). Meadow Lake is a small lake in a fully developed suburban residential watershed, with a park and municipal golf course abutting the lake on the east. Lake morphometry is shown in Table 3.1. There are six storm sewer outfalls into the lake. Meadow Lake outlets into storm sewer that discharges to Bass Creek. A small pond on the golf course designated P1.1A, which was a shallow bay of the lake before it was disconnected from the lake, is connected hydraulically to Meadow Lake by an equalizer pipe, but most of the golf course drains east to storm sewer that discharges to Twin Lake (Figure 3.2). Pond P1.1A overflows into another golf course pond, P3.2, which discharges east to Twin Lake. The area is mostly fully developed, with a 2000 Census population of about 2,300. Land use is shown in Table 3.2 below and on Figure 3.3. In 2006 the City of New Hope reconstructed streets in this area and added a number of stormwater treatment features, including swirl separators at some outfalls and a large boulevard rain garden.

Table 3.1. Meadow Lake morphometry.

Parameter	Meadow Lake	Parameter	Meadow Lake
Surface Area (ac)	11.8	Watershed (ac)	103
Littoral Area (ac)	11.8	Volume (ac-ft)	17.1
Average Depth (ft)	1.45	Residence Time (years)	0.12
Maximum Depth (ft)	3.6		

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

Land Use Class	Area (acres)	Percent
Single Family Residential	75.5	73
Water	13.4	13
Institutional	11.9	12
Park, Rec, Preserve, Golf	2.0	2
Multi-Family Residential	0.6	<1
Total Area	103.4	100

Source: Metropolitan Council, derived from city Comprehensive Plans.

3.2 RECREATIONAL USES

A small park and a municipal golf course abut the lake to the east. No boat launches are available, and the lake is not used for fishing or swimming. Shore fishing and canoe launching is possible at Meadow Lake Park. Meadow Lake Elementary School is located in the northwest corner of the watershed. School grounds include ballfields, playgrounds, and basketball courts.

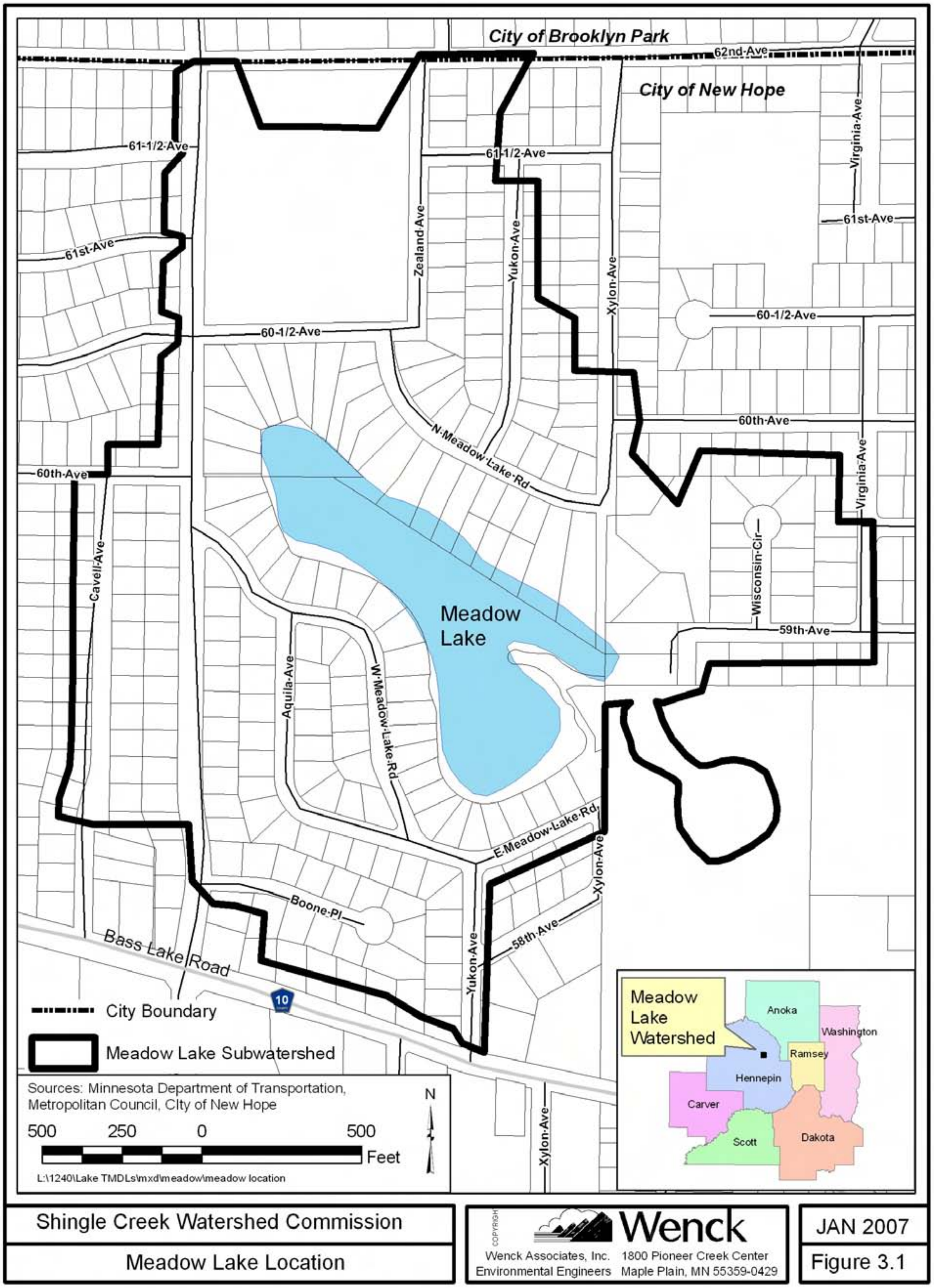

Figure 3.1. Meadow Lake location

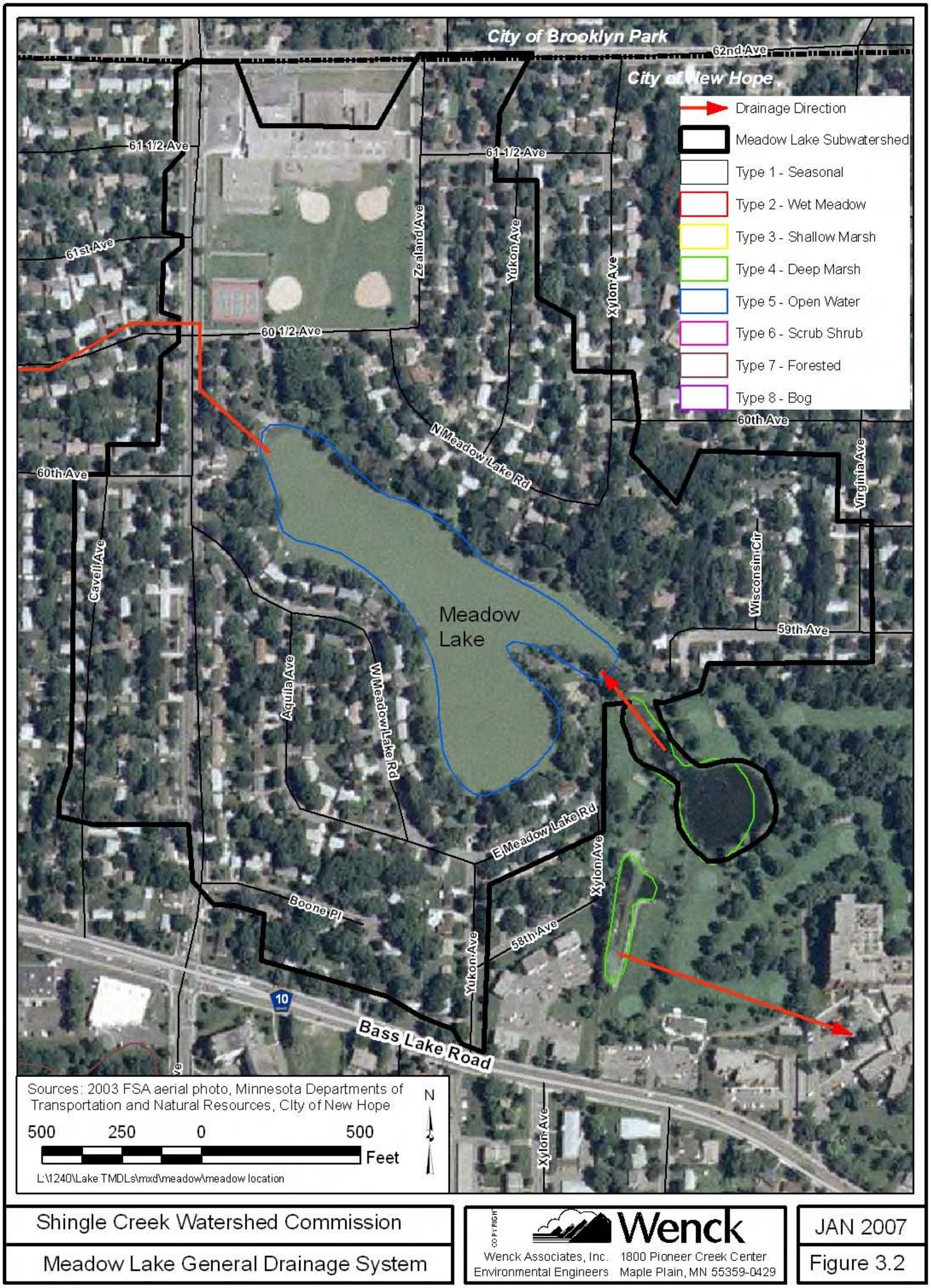

Figure 3.2. Meadow Lake general drainage system.

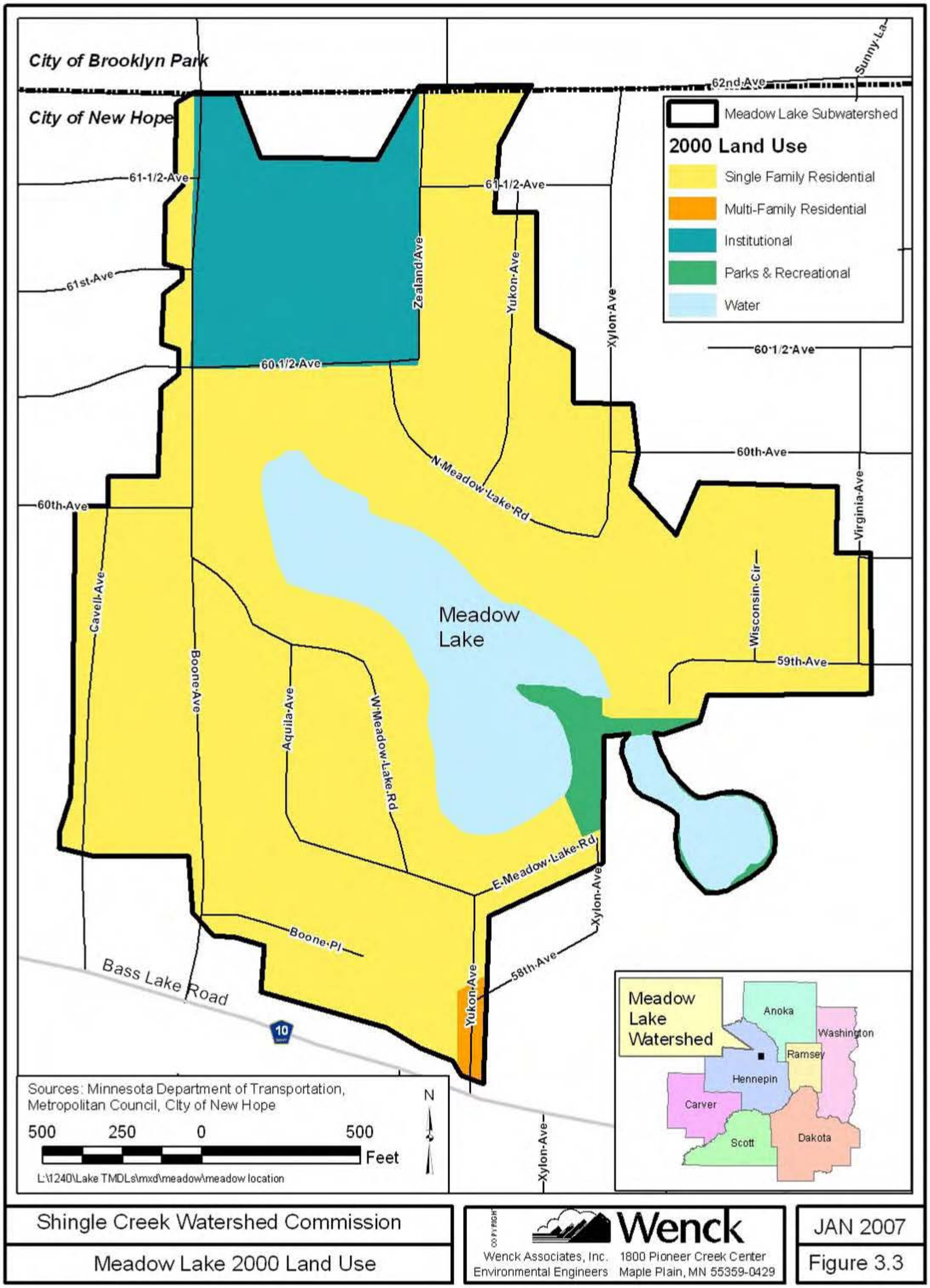

Figure 3.3. Meadow Lake 2000 land use.

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. However, 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 fewer 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 Meadow Lake ranges from approximately 200 µg/L to over 250 µg/L in the years in which measurements were taken. For comparison, the numeric standard for Meadow Lake is 60 µg/L or lower.

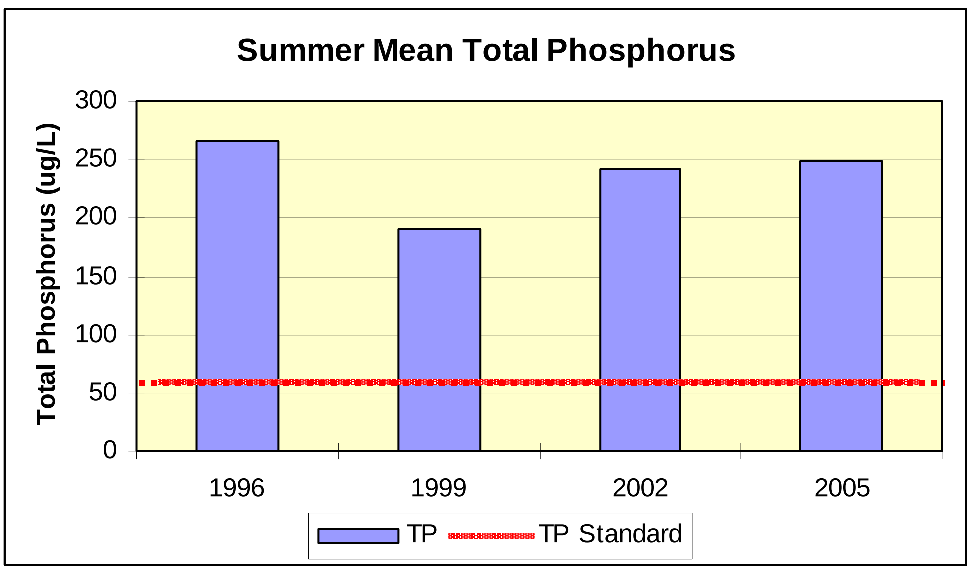

Figure 3.4. Summer (June 1 –September 30) mean total phosphorus concentrations.

More variability is observed in chlorophyll-a concentration than total phosphorus concentration. Chlorophyll-a concentration ranges from approximately 70 µg/L to nearly 200 µg/L with the highest concentration occurring in 2002. In 2005, the chlorophyll-a concentration was approximately 68 µg/L. The numeric standard for Meadow Lake is 20 µg/L or lower for chlorophyll-a.

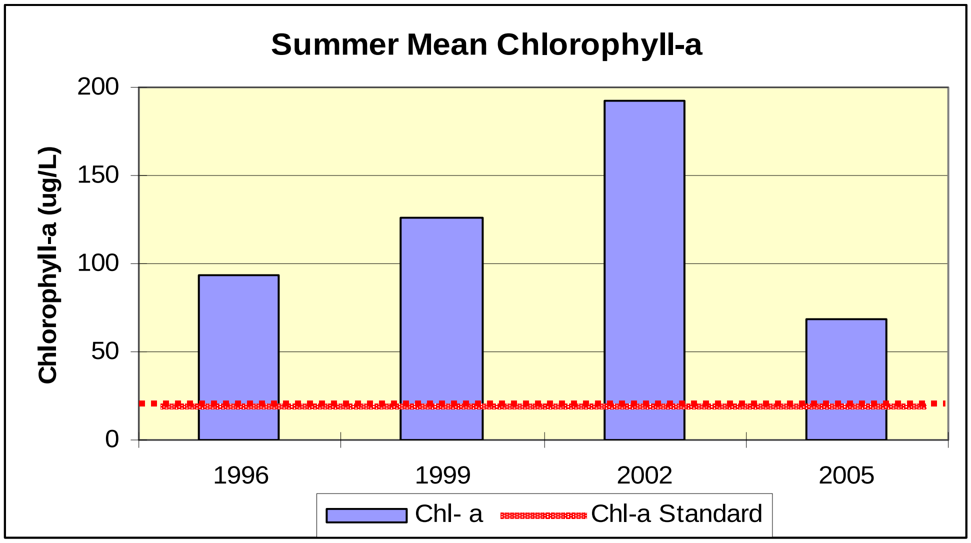

Figure 3.5. Summer (June 1 –September 30) mean chlorophyll-a concentrations.

Water clarity, as measured by Secchi depth, ranges from approximately 0.3 meters to 0.45 meters. The worst clarity occurred in 2002 which coincides with the high chlorophyll-a concentration observed in that year. In 2005, the water clarity was the best of the years in which measurements were taken at nearly 0.45 meters. The numeric standard for Meadow Lake is 1.0 meter of clarity or more as measured by Secchi depth.

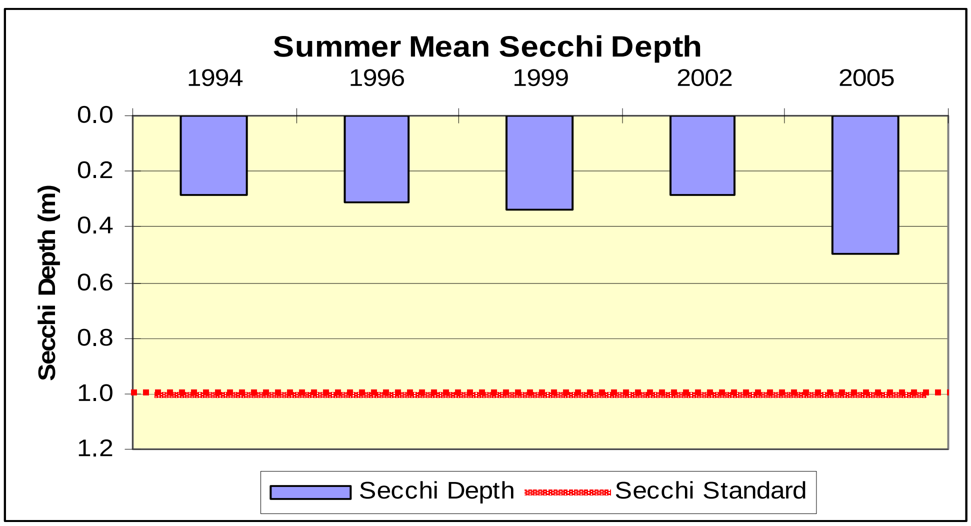

Figure 3.6. Summer (June 1 –September 30) mean Secchi depth (meters).

3.4 FISH POPULATIONS AND FISH HEALTH

3.4.1 Fish Populations

No Minnesota Department of Natural Resources fish survey data are available for Meadow Lake. In 2008 University of St. Thomas researchers conducted a preliminary fish survey and found an abundance of fathead minnows. The researchers will be undertaking a three-year study of shallow lakes in the region and have selected Meadow Lake as a site for further research.

3.4.2 Carp and Other Rough Fish

Common carp, black bullheads, and other rough fish have not been found to date in Meadow Lake, but if they are present, can 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. The fathead minnows found in abundance in Meadow Lake are also bottom feeders, disturbing sediment as they feed.

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-competes 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. The maximum depth of Meadow Lake is about 3.5 feet, so it is entirely littoral.

3.5.3 Aquatic Plants in Meadow Lake

A plant survey conducted on Meadow Lake for a wetland functions and values assessment in 2007 found that the lake was about 90% vegetated with dense submergent vegetation growing almost to the surface over most of the lake. The vegetation was made up almost entirely of leafy pondweed and flatstem pondweed with some coontail and water celery. Meadow Lake has in the past been invaded with nuisance levels of filamentous waternet.

3.5.4 Curly-Leaf Pondweed

Curly-leaf pondweed (*Potamogeton crispus*) is an exotic that can easily take over a lake's aquatic macrophyte community. Curly-leaf pondweed provides a unique problem in that it is believed to significantly affect the in-lake production of phosphorus, contributing to the eutrophication problem. Curly-leaf pondweed grows under the ice, but dies back relatively early, releasing nutrients to the water column in summer possibly leading to algal blooms. Curly-leaf pondweed can also out-compete more desirable native plant species. Curly-leaf pondweed is present in Meadow Lake at non-nuisance levels.

Lakeshore residents have in the past observed a large curly-leaf pondweed community in the lake. In 2006 the City of New Hope conducted a partial drawdown of the lake to dredge accumulated sediment at the storm sewer outfalls. The following year residents noted a significant reduction in the presence of curly-leaf pondweed.

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. By observation the Meadow Lake shoreline is almost entirely turf grassed lawns and trees. Some shoreline has been planted with native vegetation and most of the shoreline is kept unmowed.

4.0 Nutrient Source Assessment

4.1 INTRODUCTION

Understanding the sources of nutrients to the lakes is a key component to developing the TMDL for Meadow Lake. To that end, a phosphorus budget that sets forth the current phosphorus load contributions from each potential source was developed using modeling and collected data described below. Following is a brief description of the budget components and how those values were developed.

4.2 ATMOSPHERIC LOAD

Atmospheric inputs of phosphorus from wet and dry deposition are estimated using rates set forth in the MPCA report “Detailed Assessment of Phosphorus Sources to Minnesota Watersheds” (Barr Engineering, 2004), and are based on annual precipitation. The values used for dry (< 25 inches), average, and wet precipitation years (>38 inches) for atmospheric deposition are 24.9, 26.8, and 29.0 kg/km^2-year, respectively. The atmospheric load (kg/year) for Meadow Lake was calculated by multiplying the lake area (km^2) by the atmospheric deposition rate (kg/km^2-year). For example, in an average precipitation year the atmospheric load to Meadow Lake would be 26.8 kg/km^2-year times the lake surface area (0.04039 km^2), which is 1.1 kg/year. The watershed is small enough that it is unlikely that there are significant geographic differences in rainfall intensity and amounts across the watershed.

4.3 TRIBUTARY OR WATERSHED LOAD

Watershed load was calculated by modeling the watershed area to the lake using two independent platforms: SWMM and P8. SWMM was used to develop watershed hydraulics and runoff volumes through calibration to collected data. The P8 model was subsequently calibrated to match the watershed runoff volumes developed from the SWMM model. Watershed loads were calculated using P8 for the subwatershed.

4.3.1 SWMM Modeling

The Environmental Protection Agency’s (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 and quality from primarily urban areas. SWMM calculates stormwater runoff by catchment area, and routes it through pipes, channels, and storage/ treatment devices, tracking the quantity and quality 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 Management Commission developed its watershed-wide XP-SWMM model during the development of the *Shingle Creek Chloride TMDL* (Wenck 2007). This calibrated model was used to predict annual runoff volumes for Meadow Lake's watershed. The 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. Flow data from several stream and pipe locations in the watershed collected in 2002 and 2003 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. More details on the calibration of the XP-SWMM model can be found in the *Shingle Creek Chloride TMDL* report (http://www.pca.state.mn.us/water/tmdl/tmdl-approved.html).

4.3.2 P8 Modeling

Watershed loads were estimated using the P8 model for urban watersheds (Walker 1990). 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. P8 was developed using National Urban Runoff Program (NURP) data and provides loading estimates based on data collected as a part of the NURP program. The NURP 50th percentile particle file was used to estimate watershed pollutant loading.

The P8 model for the Meadow Lake watershed was calibrated to match annual runoff volumes predicted by the calibrated XP-SWMM model. XP-SWMM and P8 runoff volumes are included in Appendix A. The P8 model was compared to in-lake data to validate the runoff calculations. Some of the lake load is a result of internal loading, which has been estimated separately. The P8 results give a relative sense of watershed nutrient dynamics and provide a tool for future evaluation of watershed BMPs.

4.4 INTERNAL PHOSPHORUS LOADS

Internal phosphorus loading from lakes has been demonstrated to be an important aspect of the phosphorus budgets of lakes. However, measuring or estimating internal loads can be difficult, especially in shallow lakes that may mix many times throughout the year. Because it is so shallow, Meadow Lake most likely mixes several times a year from wind action. No data is available to document mixing frequency.

Internal load was estimated from an anoxic factor (Nürnberg 2004), which estimates the period where anoxic conditions exist over the sediments, and a sediment phosphorus release rate. In the case of shallow lakes, anoxic factor can be estimated from lake geomorphology and lake TP 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 0.5 meters then the number of days was multiplied by the anoxic area at that depth and divided by the entire area of the lake. A release rate was then selected based upon the eutrophic state of the lake. The selected release rates were a range based on previous lake studies that compiled and averaged data from a number of lakes (Figure 4.1; Nürnberg 1997).

No dissolved oxygen profile data is available for Meadow Lake. Consequently, the anoxic factor was predicted using a relationship with water quality and lake morphology (Nürnberg 2004). Using the lower end of loading in hypereutrophic lakes, the internal load to Meadow Lake using a lake area of 0.05 km^2 is approximately 34 kilograms per year. As discussed later in this report, the maximum total phosphorus load the lake can assimilate and still meet State water quality standards is about 15 kilograms per year. Consequently, the internal load has the potential to cause Meadow Lake to exceed the State standard even without any external loading.

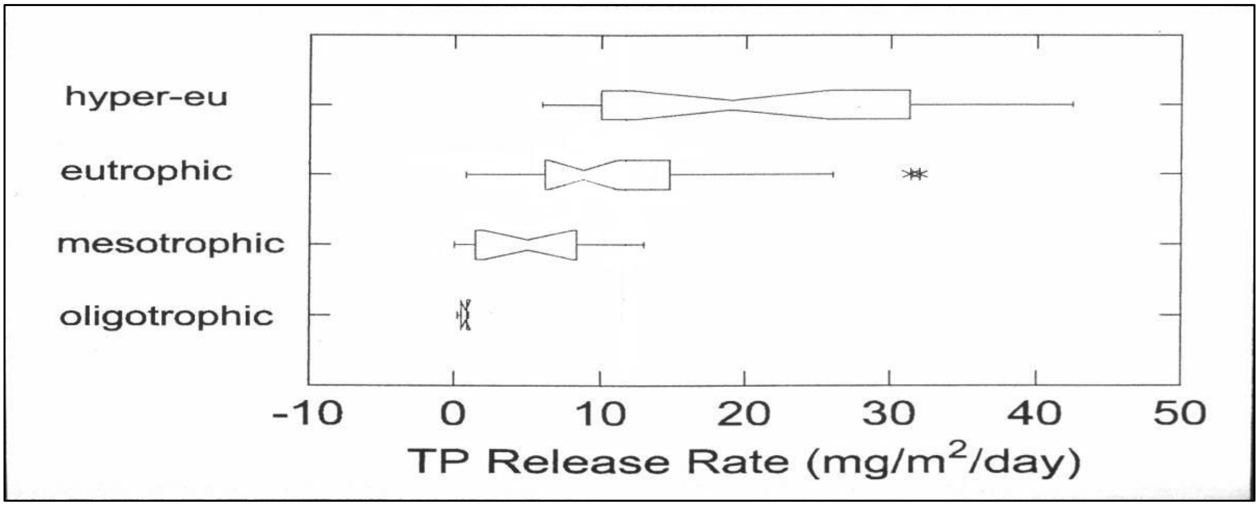

Figure 4.1. Sediment phosphorus release rates by eutrophic condition. (Nürnberg 1997).

Table 4.1. Results of the internal load assessment using an anoxic factor and release rate for Meadow Lake.

	Release Rate ($mg/m^2/day$)[1]	Anoxic Factor (days)	Gross Load (mg/m^2/summer)	Gross Load (kg/yr)
Meadow Lake[2]	6.0	70	420	17
	9.0	70	630	25
	12.0	70	840	34

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

4.5 CURRENT PHOSPHORUS BUDGET

The current conditions phosphorus budget was developed using the P8 model results (Section 4.3), the internal load evaluation (Section 4.4) and equations extracted from the BATHTUB model. 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 applications. The Canfield-Bachmann natural lake model, which was developed for northern temperate lakes, was selected from the suite of BATHTUB relationships to model lake phosphorus concentration response. Other models from the suite were used to predict chlorophyll-a and transparency.

Phosphorus budgets were developed for the fifteen year period 1992-2007 (see the summary in Table 1 and detailed annual models in Appendix A). Table 4.2 presents the average annual total phosphorus load by source for the period 1996-2005. 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: 1996, 1999, 2002, and 2005.

Table 4.2. Current total phosphorus budget for Meadow Lake for the period 1996-2005.

Source	Source	Average Annual TP Load (kg/yr)	Average Daily TP Load (kg/day)
Wasteload	Watershed Load	52.6	0.144
Load	Atmospheric Load	1.1	0.003
	Internal Load	33.9	0.093
	TOTAL LOAD	87.6	0.240

5.0 Linking Water Quality Targets and Sources

5.1 INTRODUCTION

A detailed nutrient budget can be a useful tool for identifying management options and their potential effects on water quality. Additionally, lake response models can be developed to understand how different lake variables respond to changes in nutrient loads. Through this knowledge, managers can make educated decisions about how to allocate restoration dollars and efforts as well as understand the resultant effect of such efforts.

5.2 SELECTION OF MODELS AND TOOLS

A BATHTUB lake response model was developed using the nutrient budget presented in Section 4. Four years were modeled 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 and is focused on subroutines that were developed based on data from natural lakes. The Canfield-Bachmann natural lake model was chosen for the phosphorus model. 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 default "Secchi vs. Chl-a & Turbidity" equation. For more information on these model equations, see the BATHTUB model documentation (Walker 1999). Model coefficients are also available in the model for calibration or adjustment based on known cycling characteristics. The coefficients 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 (MPCA 2004). No initial calibration factors were applied to any of the lakes.

5.3 FIT OF THE MODEL

In-lake water quality was measured in Meadow Lake in four years between 1992 and 2007: 1996, 1999, 2002, and 2005. The model predicts phosphorus to within five percent in all years except 1999 in which the model over-predicts measured values by approximately 35% as shown in Table 5.1. Chlorophyll-a is over-predicted in 1996 and 2005 but under-predicted in 1999 and 2002. Secchi depth is predicted to within less than a tenth of a meter in all years in which measurements were taken.

Table 5.1. Model fit for Meadow Lake.

Year	Variable	Predicted Mean	Observed Mean
1996	Total Phosphorus (µg/L)	257	266
	Chlorophyll-a (µg/L)	110	93
	Secchi Depth (meters)	0.35	0.31
1999	Total Phosphorus (µg/L)	258	191
	Chlorophyll-a (µg/L)	106	126
	Secchi Depth (meters)	0.36	0.34
2002	Total Phosphorus (µg/L)	237	242
	Chlorophyll-a (µg/L)	108	192
	Secchi Depth (meters)	0.36	0.28
2005	Total Phosphorus (µg/L)	244	257
	Chlorophyll-a (µg/L)	106	91
	Secchi Depth (meters)	0.39	0.44

6.0 TMDL Allocation

6.1 TOTAL MAXIMUM DAILY LOAD CALCULATIONS

The numerical TMDL for Meadow Lake 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.

6.1.1 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 4.2 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 4.4, the sediment phosphorus release rate was estimated to be approximately 12 $mg/m^2/day$. 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 2.0 $mg/m^2/day$ were used to calculate an internal load of 5.7 kg/yr at the TMDL goal.

6.1.2 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 dischargers in the watershed. Stormwater discharges are regulated under the National Pollutant Discharge Elimination System (NPDES). The City of New Hope holds an NPDES Phase II permit under the Minnesota Phase II General Stormwater Permit MNR040000 for stormwater discharging to Meadow Lake. The unique NPDES permit number assigned to New Hope is MS400039.

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 6.1.1 above) and the P8 annual runoff by year were entered into the Canfield-Bachmann equation to calculate the maximum Wasteload allowable to achieve an in-lake concentration of 60 µg/L TP, the applicable standard for Meadow Lake. The WLA for the TMDL was calculated by averaging the watershed load at goal for the ten year period 1996-2005. This ten year period brackets the four years for which actual monitoring data is available: 1996, 1999, 2002, and 2005. The ten year average WLA is 9.0 kg/year. A summary and details by year of these calculations and model inputs are shown in Table 2 and annual model output in Appendix A.

6.1.3 Margin of Safety

A margin of safety has been incorporated into this TMDL by using conservative assumptions. These were utilized 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.

Conservative modeling assumptions include:

1. Applying sedimentation rates from the Canfield-Bachmann model that under-predicts the sedimentation rate for shallow lakes (and ultimately over-predicts in-lake phosphorus concentrations). The sedimentation rate refers to the loss of phosphorus from the water column as a result of settling. This can occur as algae die and settle, as organic material settles, or as algae are grazed by zooplankton. Zooplankton grazing plays a large role in algal and subsequent phosphorus sedimentation in shallow lakes. However, the Canfield-Bachmann equation does not account for the expected higher sedimentation rates expected in healthy shallow lake systems. Consequently, the model-predicted phosphorus concentrations will be higher than expected because it does not account for the additional loss of phosphorus from the water column from that zooplankton grazing.
2. The Canfield-Bachmann model was used to match data by only adjusting the loads and not applying calibration factors. The sedimentation rates used in the model are conservatively low for Minnesota lakes, providing an additional margin of safety.
3. Lake response model results were compared to four years of monitoring data. Model performance in these four years was within five percent for total phosphorus and within acceptable limits for the other parameters without changing the default sedimentation factors implicit in the Canfield-Bachmann empirical model. Consequently, a large margin of safety is not necessary for this TMDL.

6.1.4 Summary of TMDL Allocations

The load capacity is the Total Maximum Daily Load. The load and wasteload allocations are shown in Table 6.1. A margin of safety is implicit in the TMDL equation and therefore not presented in the tables. An 82 percent reduction in phosphorus load would be required to achieve the stated TP standard of 60 µg/L. The watershed, internal, and atmospheric loads were divided by 365.25 days per year (to account for leap year) to convert the annual TMDL to a daily TMDL.

Table 6.1. TMDL total phosphorus daily and annual loads for Meadow Lake 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	0.144	52.6	0.025	9.0	43.6
Load	Atmospheric	0.003	1.1	0.003	1.1	-
	Internal	0.093	33.9	0.016	5.7	28.2
		0.240	87.6	0.044	15.8	71.8

These allocations will guide the development of an implementation plan and necessary reductions.

6.2 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 and Secchi depth 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.

6.2.1 Phosphorus

The modeled response to phosphorus load reductions for 2003 is presented in Figure 6.1 as an average year because the precipitation in 2003 (27.1 inches) is similar to the 30-year normal (28.3 inches). However, Meadow Lake is a shallow basin with a significant potential to internally load phosphorus. Consequently, the measured response will likely be much less pronounced until the internal loading is controlled or biological feedback mechanisms are reestablished in the lake.

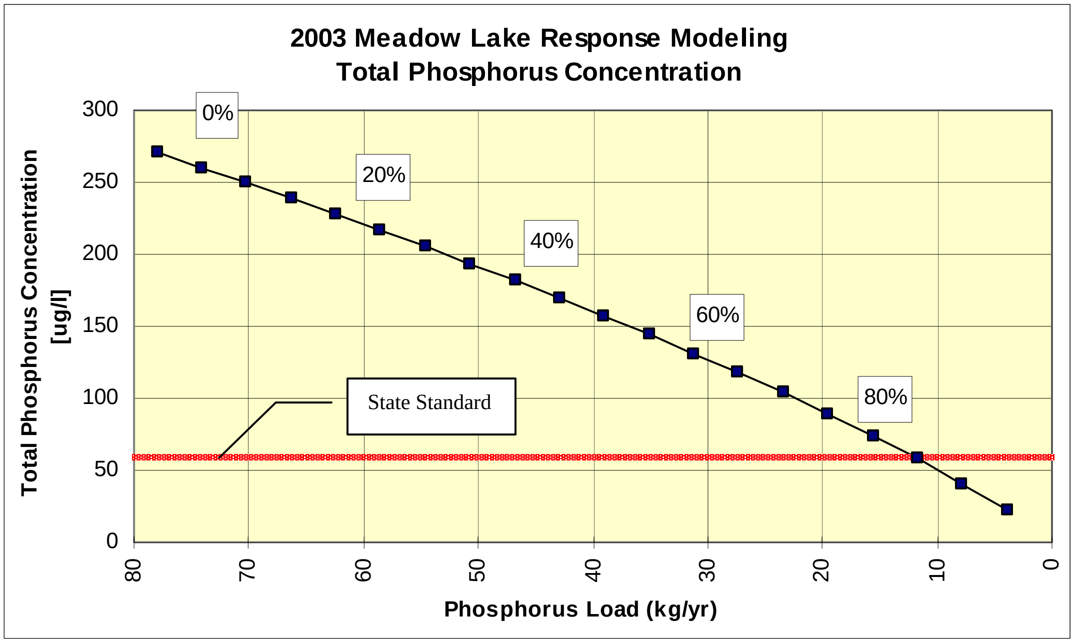

Figure 6.1. In-lake total phosphorus concentrations predicted for total phosphorus load reductions applied to all sources.

6.2.2 Chlorophyll-a

The modeled response to chlorophyll-a is presented in Figure 6.2. Although a positive response is predicted, there is a need to reestablish plant and fish communities in Meadow Lake to provide biological controls on phytoplankton such as shading by aquatic vegetation and grazing by zooplankton.

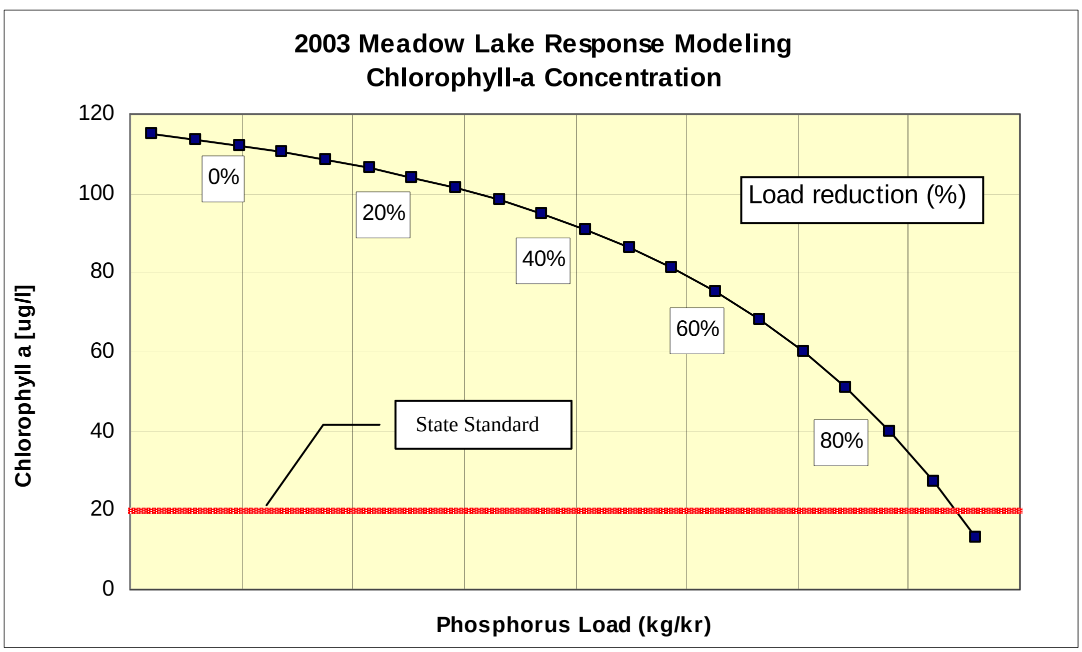

Figure 6.2. In-lake chlorophyll-a concentrations predicted for total phosphorus load reductions applied to all basins.

6.2.3 Secchi Depth

Secchi depth response to total phosphorus reductions is presented in Figure 6.3. It is likely that the clarity will meet the State standard if the TP reductions are implemented and the biological health in Meadow Lake is restored.

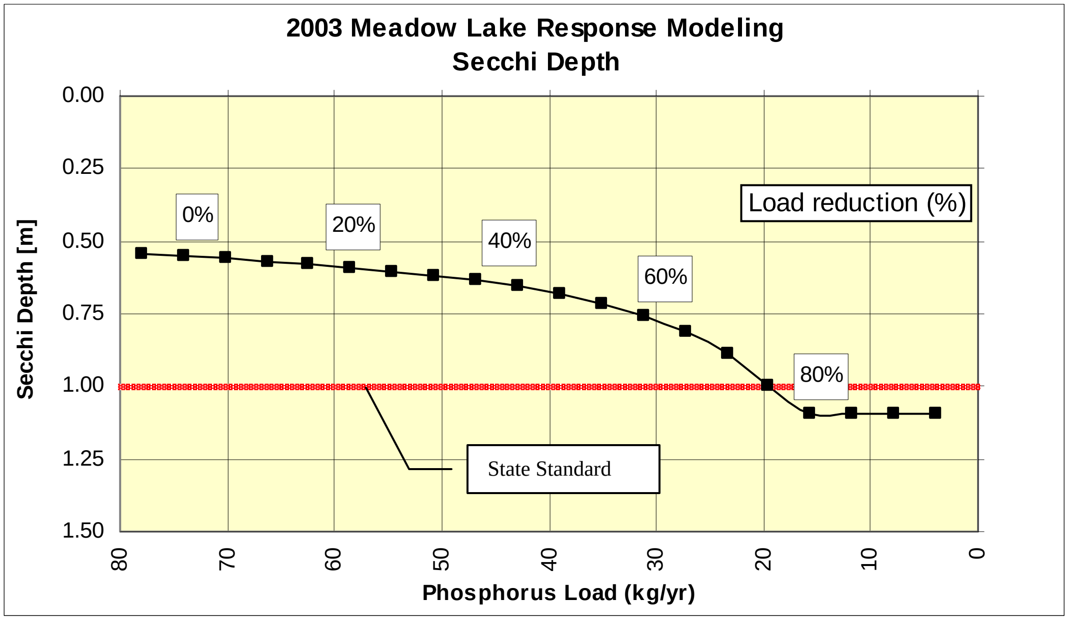

Figure 6.3. Secchi depth predicted for total phosphorus load reductions to all sources.

6.3 SEASONAL AND ANNUAL VARIATION

The daily load reduction targets in this TMDL are calculated from the current phosphorus budget. 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 the lakes 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.

6.3.1 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 30) 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, these lakes tend to have relatively short residence times and therefore respond to summer growing season loads.

6.4 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 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. Development and redevelopment projects are required to provide stormwater rate control, stormwater runoff water quality treatment, and volume management practices to infiltrate the first 0.5” of runoff from new impervious surfaces.

7.0 Public Participation

7.1 INTRODUCTION

As a part of the strategy to achieve implementation of the necessary allocations, 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 City Councils and citizens advisory committees at meetings to which lake association members were invited.

7.2 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.

7.3 STAKEHOLDER MEETINGS

A stakeholder meeting to which all residents living in the lake's watershed were invited was held on March 5, 2009 at New Hope City Hall. The TMDL and draft Implementation Plan were reviewed with the Meadow Lake Association at its annual meeting on May 2, 2009.

7.4 PUBLIC MEETINGS AND PUBLIC NOTICE

The general TMDL approach and results of the TMDL were presented to six City Councils in May and July 2006. Additional public comments were taken as part of the official TMDL public notice period from September 28, 2009 through October 28, 2009. Several comment letters were received during the public notice period and minor clarifications were made to the TMDL in response to these comments. Meeting notes from Shingle Creek Watershed Management Commission meetings can be found at www.shinglecreek.org/.

8.0 Implementation

8.1 IMPLEMENTATION FRAMEWORK

8.1.1 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 Meadow Lake 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.

8.1.2 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.

8.2 REDUCTION STRATEGIES

8.2.1 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 Meadow Lake are shown in Table 8.1 below as daily and annual loads. An *82 percent* annual reduction in total phosphorus load to the lake would be required to consistently meet state standards.

Table 8.1. TMDL total phosphorus daily and annual loads for Meadow Lake 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	0.144	52.6	0.025	9.0	43.6
Load	Atmospheric	0.003	1.1	0.003	1.1	-
	Internal	0.093	33.9	0.016	5.7	28.2
		0.240	87.6	0.044	15.8	71.8

8.2.2 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 Meadow Lake is small and fully developed, so large-scale Best Management Practices (BMP) opportunities are limited. Following is a description of potential actions for controlling nutrients in the Meadow Lake watershed that will be further developed in the Meadow Lake Implementation Plan. The estimated total cost of implementing these and other potential BMPs ranges from $500,000 to $1,000,000.

8.2.2.1 External Load Reductions

The Meadow Lake watershed is small and entirely developed, with some infill development and redevelopment opportunities. Small, incremental reductions are possible through retrofit as redevelopment occurs and through the implementation of Best Management Practices (BMPs) throughout the subwatershed.

Maximize load reduction through redevelopment. As redevelopment occurs, areas with little or no treatment will be required to meet current water quality standards. It may be possible to "upsize" water quality treatment BMPs to increase treatment efficiency beyond the minimum required by city and commission requirements to maximize the amount of load reduction achieved. Incorporating BMPs to bring a redevelopment site to Watershed Commission treatment standards would be at the developer's cost. The public cost of "upsizing" would be dependant on the specific BMPs, negotiations with developers, etc., but could range from $10,000 to $500,000 each.

Retrofit BMPs. As opportunities arise, retrofit water quality treatment through a variety of Best Management Practices including detention ponds, native plantings, sump manholes, 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 sump manhole 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 dependant on the types of opportunities that arise. New Hope City streets in much of the watershed were reconstructed in 2006, and some stormwater BMPs were retrofit as part of that project. Swirl separators were installed upstream of some outfalls, and a large rain garden was installed to treat street runoff. Implementation activities to improve the water quality of the runoff from the municipal golf course's pond to Meadow Lake should also be considered. Additional BMPs may be retrofit when opportunities arise.

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. New Hope 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. New Hope should consider demonstration projects in the city park on Meadow Lake and other lakes in city parks and open spaces. Residential property shoreline on Meadow Lake totals about 3,500 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 2,625 feet of shoreline at a cost of about $78,750 to $131,250.

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 Meadow Lake and encourage the adoption of good individual property management practices. Meadow Lake has an active lake association.

8.2.2.2 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, Meadow Lake is not a good candidate for an alum or other chemical treatment.

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. Chemical treatments applied 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 communities and no information is available for 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.

Drawdown. Meadow Lake may be a good candidate for a water level drawdown. A drawdown would expose and consolidate the lake sediments and provide an opportunity for the native seed bank to reestablish a more beneficial aquatic vegetation community. A partial drawdown was completed in 2006 as part of an outfall dredging project. Lake residents indicate that the year following that partial drawdown aquatic vegetation was noticeably improved. However, Meadow Lake discharges by storm sewer directly to Bass Creek and Shingle Creek with no interim treatment. A full drawdown should be conducted with care to avoid unintended downstream impacts to those Impaired Waters. The estimated cost of a full drawdown is $150,000.

8.3 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. It is expected that it may take 10-20 years to implement BMPs and load-reduction activities. 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.

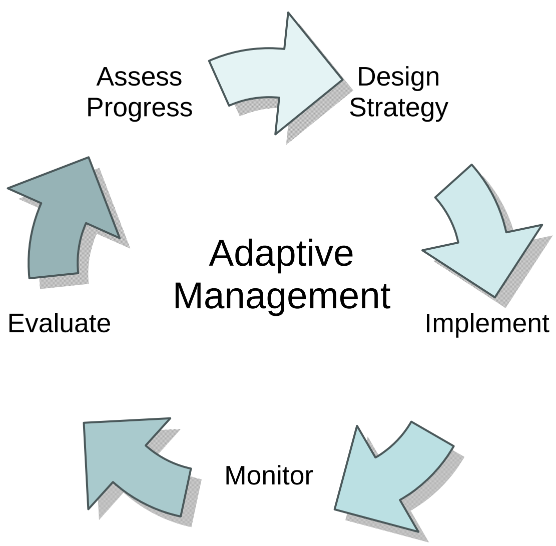

Figure 8.1. Adaptive management.

9.0 Reasonable Assurance

9.1 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 stormwater 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.

9.2 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 Commissions have 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.

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.

9.3 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 Meadow Lake watershed, only one MS4 drains to the lake: the City of New Hope. The unique permit number assigned to New Hope under the Phase II General NPDES Stormwater Permit – MNR040000 – is MS400039.

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 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 Implementation Plan will identify specific BMP opportunities sufficient to achieve a load reduction and the City's SWPPP will be modified accordingly as a product of this plan. 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.

9.4 MONITORING

9.4.1 Monitoring Implementation of Policies and BMPs

The SCWMC will evaluate progress toward meeting the goals and policies outlined in the Second Generation Plan and the Water Quality Plan. Success will be measured by completion of policies and strategies, or progress toward completion of policies and strategies. The Commission’s Annual Report is 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 are 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 Meadow Lake, and will reconvene the Technical Advisory Committee to determine if adjustments to the Implementation Plan are necessary.

9.4.2 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). Results of all monitoring will be included in the annual water quality monitoring report.

Meadow Lake will be periodically monitored by the Shingle Creek Watershed Management Commission (SWMC) through the Citizen Assisted Monitoring Program (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.

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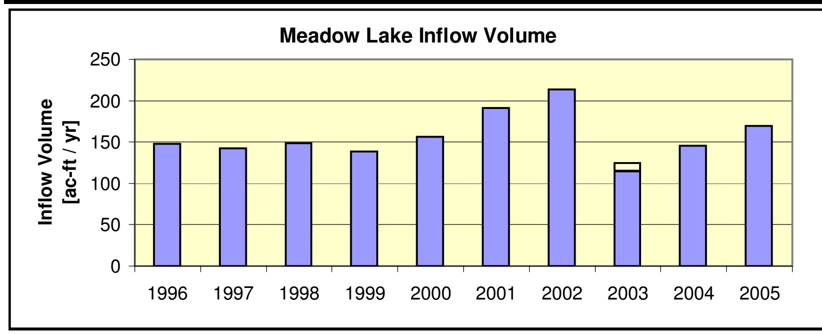
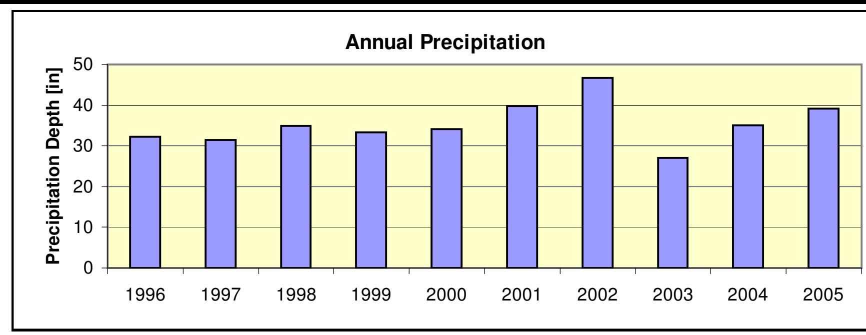
Appendix A

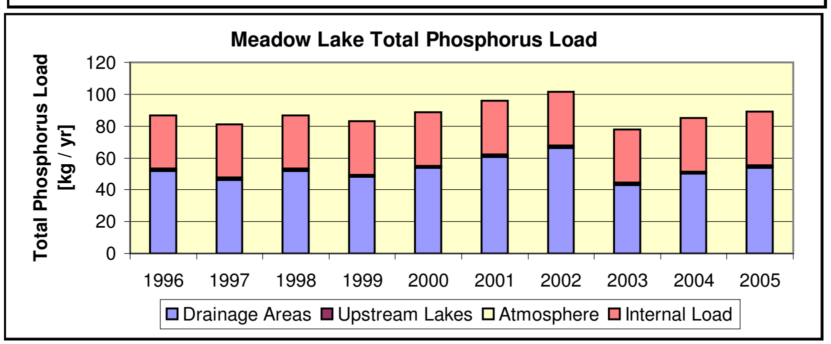
Lake Response Modeling Summary

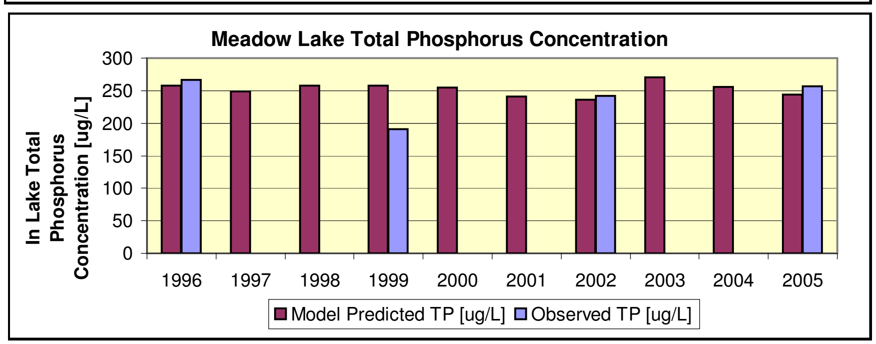
Table 1: Meadow Lake Response Modeling Summary: Current Conditions

Meadow Lake	**Source**	***1996***	***1997***	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***Average 1996-2005***	
Precipitation Depth [in]		32.3	31.5	34.9	33.3	34.1	39.8	46.7	27.1	35.1	39.2	Annual	Daily
	Residence Time [yr]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1		
Inflow Volume [ac-ft / yr]	Drainage Areas	148	143	148	139	156	191	213	114	146	170		
	Upstream Lakes	0	0	0	0	0	0	0	0	0	0		
	Atmosphere	0	0	0	0	0	0	0	10	0	0		
	TOTAL =	**148**	**143**	**148**	**139**	**156**	**191**	**213**	**124**	**146**	**170**		
Total Phosphorus Load [kg / yr]	Drainage Areas	51.7	46.1	51.8	48.0	53.7	60.6	66.4	43.0	50.0	53.9	52.6	0.144
	Upstream Lakes	0	0	0	0	0	0	0	0	0	0	-	-
	Atmosphere	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.1	1.1	1.2	1.1	0.003
	Internal Load	33.9	33.9	33.9	33.9	33.9	33.9	33.9	33.9	33.9	33.9	33.9	0.093
	TOTAL =	**86.7**	**81.1**	**86.8**	**83.0**	**88.7**	**95.7**	**101.5**	**78.0**	**85.0**	**89.0**	**87.6**	**0.240**
Model Results	Model Predicted TP [ug/L]	257	249	257	258	254	241	237	271	255	244	252	
	Observed TP [ug/L]	266	-	-	191	-	-	242	-	-	257	-	
	Phosphorus Sedimentation [lb]	88	82	88	86	88	86	87	88	86	84		
	TOTAL OUTFLOW [lb] =	***104***	***97***	***104***	***97***	***108***	***125***	***137***	***84***	***101***	***112***		
Internal Load Factors:	*Release Rate [mg/m^2-day]*	*12*	*12*	*12*	*12*	*12*	*12*	*12*	*12*	*12*	*12*		
	Anoxic factor [day]	*70*	*70*	*70*	*70*	*70*	*70*	*70*	*70*	*70*	*70*		









1996 Loading Summary for: Meadow Lake

Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1 Watershed	0.42	0.44	0.182	283.6	1.0	51.7
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	*0.42*	*0.44*	*0.18*	*283.6*		*51.7*

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]
0.04	0.82	0.82	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]
0.04	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]
0.04	70.0	12.0	1.0	33.9

Net Discharge [10^6 m^3/yr] =	**0.18**	**Net Load [kg/yr] =**	**86.7**

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.

1996 Lake Response Modeling for: Meadow Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	87	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0211	[10^6 m^3]
		T = V/Q =	0.12	[yr]
		P_i = W/Q =	476	[ug/l]
Model Predicted In-Lake [TP]			**257.5**	**[ug/l]**
Observed In-Lake [TP]			**266.3**	**[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]			**72.1**	**[ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1		
		CB (Calibration factor) =	1.00	
$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$		P (Total Phosphorus) =	257	[ug/l]
		N (Total Nitrogen) =	3,313	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	238.9	[ug/l]
$X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$		X_{pn} (Composite nutrient conc.)=	184.2	[ug/l]
		G (Kinematic factor) =	0.19	[--]
		F_s (Flushing Rate) =	8.65	[$year^{-1}$]
$G = Z_{mix}(0.14 + 0.0039 F_s)$		Z_{mix} (Mixing Depth) =	1.09	[m]
$F_s = \dfrac{Q}{V}$	$a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.10	[m^{-1}]
		S (Secchi Depth) =	0.35	[m]
		Maximum lake depth =	1.09	[m]
Model Predicted In-Lake [Chl-a]			**109.9**	**[ug/l]**
Observed In-Lake [Chl-a]			**93.2**	**[ug/l]**
SECCHI DEPTH				
	$SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.10	[m^{-1}]
Model Predicted In-Lake SD			**0.35**	**[m]**
Observed In-Lake SD			**0.31**	**[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) =	**40**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	W-P_{sed} =		**47**	**[kg/yr]**

1999 Loading Summary for: Meadow Lake

Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1 Watershed	0.42	0.41	0.171	280.7	1.0	48.0
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	*0.42*	*0.41*	*0.17*	*280.7*		*48.0*

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]
0.04	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 [km^2]	Groundwater Flux [m/yr]	Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.04	0.0	0.00	0	1.0	-

Internal

Lake Area [km^2]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.04	70.0	12.0	1.0	33.9

Net Discharge [10^6 m^3/yr] =	**0.17**	**Net Load [kg/yr] =**	**83.0**

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.

1999 Lake Response Modeling for: Meadow Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	83	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0211	[10^6 m^3]
		T = V/Q =	0.12	[yr]
		P_i = W/Q =	486	[ug/l]
Model Predicted In-Lake [TP]			**257.5**	**[ug/l]**
Observed In-Lake [TP]			**191.3**	**[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]			**72.1**	**[ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1		
		CB (Calibration factor) =	1.00	
$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$		P (Total Phosphorus) =	258	[ug/l]
		N (Total Nitrogen) =	2,950	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	219.7	[ug/l]
$X_{pn} = \left[P^{-2} + \left(\frac{N - 150}{12}\right)^{-2}\right]^{-0.5}$		X_{pn} (Composite nutrient conc.)=	172.9	[ug/l]
		G (Kinematic factor) =	0.19	[--]
		F_s (Flushing Rate) =	8.10	[$year^{-1}$]
$G = Z_{mix}(0.14 + 0.0039 F_s)$		Z_{mix} (Mixing Depth) =	1.09	[m]
$F_s = \dfrac{Q}{V}$	$a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.10	[m^{-1}]
		S (Secchi Depth) =	0.36	[m]
		Maximum lake depth =	1.09	[m]
Model Predicted In-Lake [Chl-a]			**106.3**	**[ug/l]**
Observed In-Lake [Chl-a]			**125.6**	**[ug/l]**
SECCHI DEPTH				
	$SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.10	[m^{-1}]
Model Predicted In-Lake SD			**0.36**	**[m]**
Observed In-Lake SD			**0.34**	**[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) =	**39**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	W-P_{sed} =		**44**	**[kg/yr]**

2002 Loading Summary for: Meadow Lake

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	0.42	0.63	0.263	252.3	1.0	66.4
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	*0.42*	*0.63*	*0.26*	*252.3*		*66.4*

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 [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]
0.04	1.19	1.19	0.00	29.00	1.0	1.2
			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]
0.04	0.0	0.00	0	1.0	-

Internal

Lake Area [km²]	Anoxic Factor [days]	Release Rate [mg/m²-day]	Calibration Factor [--]	Load [kg/yr]
0.04	70.0	12.0	1.0	33.9

Net Discharge [10^6 m^3/yr] =	**0.26**	**Net Load [kg/yr] =**	**101.5**

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.

2002 Lake Response Modeling for: Meadow Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	102	[kg/yr]
		Q (lake outflow) =	0.3	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0211	[10^6 m^3]
		T = V/Q =	0.08	[yr]
		P_i = W/Q =	386	[ug/l]
Model Predicted In-Lake [TP]			**236.5**	**[ug/l]**
Observed In-Lake [TP]			**242.0**	**[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]			**66.2**	**[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) =	237	[ug/l]
		N (Total Nitrogen) =	4,100	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	252.7	[ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	192.1	[ug/l]
		G (Kinematic factor) =	0.21	[--]
		F_s (Flushing Rate) =	12.48	[year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	1.09	[m]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.025 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	0.10	[m^{-1}]
		S (Secchi Depth) =	0.36	[m]
		Maximum lake depth =	1.09	[m]
Model Predicted In-Lake [Chl-a]			**107.6**	**[ug/l]**
Observed In-Lake [Chl-a]			**192.0**	**[ug/l]**
SECCHI DEPTH				
	$SD = \dfrac{CS}{(\mathrm{a} + 0.025 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.10	[m^{-1}]
Model Predicted In-Lake SD			**0.36**	**[m]**
Observed In-Lake SD			**0.28**	**[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) =	**39**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	W-P_{sed} =		**62**	**[kg/yr]**

2005 Loading Summary for: Meadow Lake

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1 Watershed	0.42	0.50	0.209	257.7	1.0	53.9
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	*0.42*	*0.50*	*0.21*	*257.7*		*53.9*

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]
0.04	0.99	0.99	0.00	29.00	1.0	1.2
		Dry-year total P deposition =		24.9		
		Average-year total P deposition =		26.8		
		Wet-year total P deposition =		29.0		
		(Barr Engineering 2004)				

Groundwater

Lake Area [km^2]	Groundwater Flux [m/yr]	Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.04	0.0	0.00	0	1.0	-

Internal

Lake Area [km^2]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.04	70.0	12.0	1.0	33.9

Net Discharge [10^6 m^3/yr] = 0.21 | **Net Load [kg/yr] = 89.0**

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.

2005 Lake Response Modeling for: Meadow Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	89	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0211	[10^6 m^3]
		T = V/Q =	0.10	[yr]
		P_i = W/Q =	425	[ug/l]
Model Predicted In-Lake [TP]			**243.5**	**[ug/l]**
Observed In-Lake [TP]			**256.8**	**[ug/l]**
CHLOROPHYLL-A CONCENTRATION				
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4		
		CB (Calibration factor) =	1.00	[--]
Model Predicted In-Lake [Chl-a]			**68.2**	**[ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1		
		CB (Calibration factor) =	1.00	
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	244	[ug/l]
		N (Total Nitrogen) =	3,233	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	226.2	[ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	176.8	[ug/l]
		G (Kinematic factor) =	0.19	[--]
		F_s (Flushing Rate) =	9.92	[year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	1.09	[m]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.10	[m^{-1}]
		S (Secchi Depth) =	0.37	[m]
		Maximum lake depth =	1.09	[m]
Model Predicted In-Lake [Chl-a]			**105.5**	**[ug/l]**
Observed In-Lake [Chl-a]			**90.7**	**[ug/l]**
SECCHI DEPTH				
	$SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.10	[m^{-1}]
Model Predicted In-Lake SD			**0.37**	**[m]**
Observed In-Lake SD			**0.44**	**[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) =	**38**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	W-P_{sed} =		**51**	**[kg/yr]**

TP Budget Loading Summary for: Meadow Lake

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [km^2]	Runoff Depth [m/yr]	Discharge [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	Watershed	0.42	0.46	0.192	273.4	1.0	52.6
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	*0.42*	*0.46*	*0.19*	*273.4*		*52.6*

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 [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.04	0.87	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]
0.04	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]
0.04	70.0	12.0	1.0	33.9

Net Discharge [10^6 m^3/yr] =	**0.19**	**Net Load [kg/yr] =**	**87.6**

NOTES

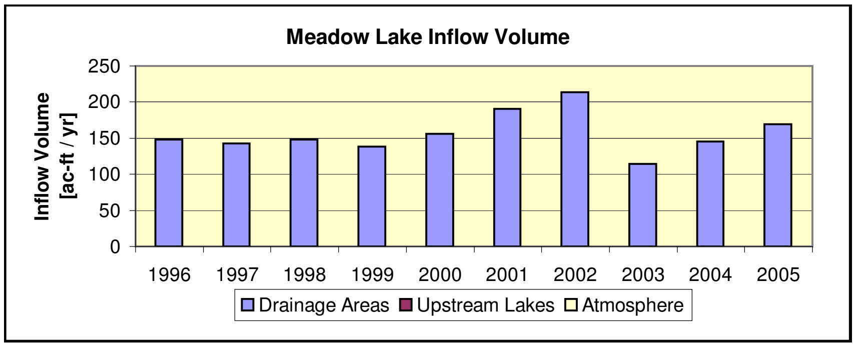
[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

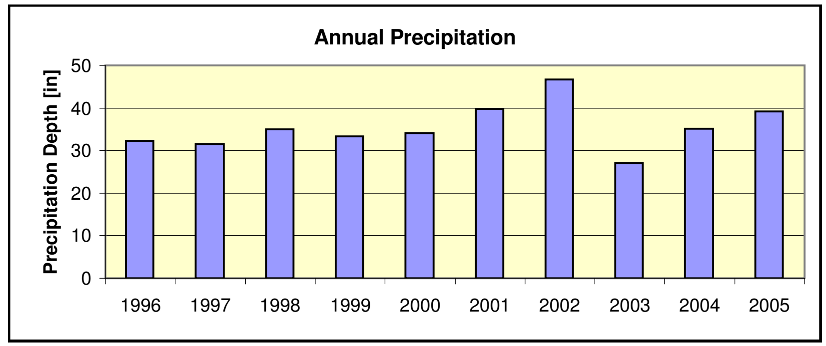
TP Budget Lake Response Modeling for: Meadow Lake

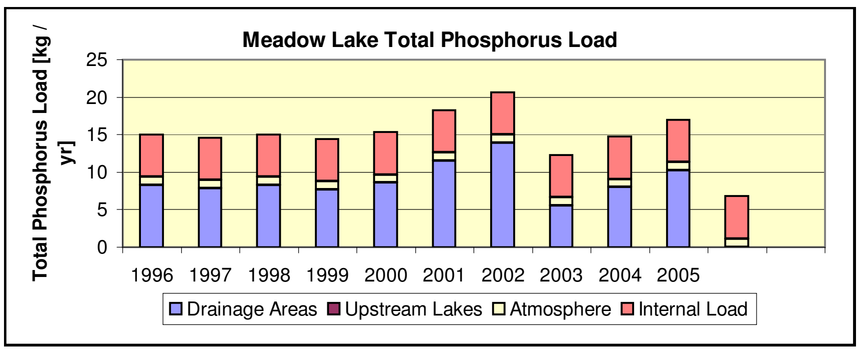
Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	88	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	0.0211	[10^6 m^3]
		T = V/Q =	0.11	[yr]
		P_i = W/Q =	455	[ug/l]
Model Predicted In-Lake [TP]			**252.0**	**[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]			**70.6**	**[ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1		
		CB (Calibration factor) =	1.00	
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	252	[ug/l]
		N (Total Nitrogen) =	3,361	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	237.7	[ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	183.5	[ug/l]
		G (Kinematic factor) =	0.19	[--]
		F_s (Flushing Rate) =	9.12	[$year^{-1}$]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	1.09	[m]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.10	[m^{-1}]
		S (Secchi Depth) =	0.35	[m]
		Maximum lake depth =	1.09	[m]
Model Predicted In-Lake [Chl-a]			**109.0**	**[ug/l]**
Observed In-Lake [Chl-a]			**-**	**[ug/l]**
SECCHI DEPTH				
	$SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.10	[m^{-1}]
Model Predicted In-Lake SD			**0.35**	**[m]**
Observed In-Lake SD			**-**	**[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) =	**39**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	W-P_{sed} =		**48**	**[kg/yr]**

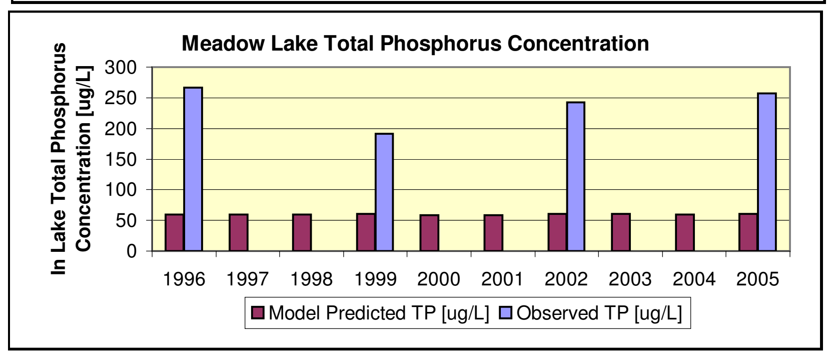
Table 2: Meadow Lake Response Modeling Summary: At Goal (60 ug/L TP)

Meadow Lake	**Source**	***1996***	***1997***	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***Average 1996-2005***	
Precipitation Depth [in]		32.3	31.5	34.9	33.3	34.1	39.8	46.7	27.1	35.1	39.2	Annual	Daily
	Residence Time [yr]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1		
Inflow Volume [ac-ft / yr]	Drainage Areas	148	143	148	139	156	191	213	114	146	170		
	Upstream Lakes	0	0	0	0	0	0	0	0	0	0		
	Atmosphere	0	0	0	0	0	0	0	0	0	0		
	TOTAL =	**148**	**143**	**148**	**139**	**156**	**191**	**213**	**114**	**146**	**170**	**157**	
Total Phosphorus Load [kg / yr]	Drainage Areas	8.3	7.8	8.3	7.7	8.6	11.5	13.9	5.6	8.0	10.2	9.0	0.025
	Upstream Lakes	-	-	-	-	-	-	-	-	-	-	-	-
	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	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	0.016
	TOTAL =	**15.0**	**14.6**	**15.0**	**14.4**	**15.3**	**18.3**	**20.7**	**12.3**	**14.7**	**17.0**	**15.8**	**0.044**
Model Results	Model Predicted TP [ug/L]	60	60	60	60	58	59	60	60	59	60	60	
	Observed TP [ug/L]	266	-	-	191	-	-	242	-	-	257		
	Phosphorus Sedimentation [lb]	9	9	9	9	9	10	11	8	9	10		
	TOTAL OUTFLOW [lb] =	***24***	***23***	***24***	***23***	***25***	***30***	***35***	***19***	***24***	***28***		
Internal Load Factors:	*Release Rate [mg/m^2 -day]*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*
	Anoxic factor [day]	*70*	*70*	*70*	*70*	*70*	*70*	*70*	*70*	*70*	*70*	*70*	*70*









1996 Loading Summary for: Meadow Lake 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	0.42	0.44	0.182	45.4	0.16	8.3
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	*0.42*	*0.44*	*0.18*	*45.4*		*8.3*

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]
0.04	0.82	0.82	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]
0.04	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]
0.04	70.0	2.0	1.0	5.7

Net Discharge [10^6 m^3/yr] =	**0.18**	**Net Load [kg/yr] =**	**15.0**

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.

1996 Lake Response Modeling for: Meadow Lake at Goal

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	15	[kg/yr]
		Q (lake outflow) =	0.2	[106 m3/yr]
		V (modeled lake volume) =	0.0211	[106 m3]
		T = V/Q =	0.12	[yr]
		P_i = W/Q =	82	[ug/l]
Model Predicted In-Lake [TP]			**59.7**	**[ug/l]**
Observed In-Lake [TP]			**266.3**	**[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]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1		
		CB (Calibration factor) =	1.00	
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	60	[ug/l]
		N (Total Nitrogen) =	3,313	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	51.6	[ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	58.2	[ug/l]
		G (Kinematic factor) =	0.19	[--]
		F_s (Flushing Rate) =	8.65	[year-1]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	1.09	[m]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.10	[m-1]
		S (Secchi Depth) =	0.89	[m]
		Maximum lake depth =	1.09	[m]
Model Predicted In-Lake [Chl-a]			**40.7**	**[ug/l]**
Observed In-Lake [Chl-a]			**93.2**	**[ug/l]**
SECCHI DEPTH				
	$SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.10	[m-1]
Model Predicted In-Lake SD			**0.89**	**[m]**
Observed In-Lake SD			**0.31**	**[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) =	**4**	**[kg/yr]**
PHOSPHORUS OUTFLOW LOAD				
	W-P_{sed} =		**11**	**[kg/yr]**

1999 Loading Summary for: Meadow Lake 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	0.42	0.41	0.171	44.9	0.16	7.7
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	*0.42*	*0.41*	*0.17*	*44.9*		*7.7*
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]
0.04	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 [km^2]	Groundwater Flux [m/yr]		Net Inflow [10^6 m^3/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.04	0.0		0.00	0	1.0	-
Internal						
Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.04	70.0			2.0	1.0	5.7
			Net Discharge [10^6 m^3/yr] = 0.17		**Net Load [kg/yr] =**	**14.4**

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: Meadow Lake at Goal

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	14	[kg/yr]
		Q (lake outflow) =	0.2	[106 m3/yr]
		V (modeled lake volume) =	0.0211	[106 m3]
		T = V/Q =	0.12	[yr]
		P_i = W/Q =	84	[ug/l]
Model Predicted In-Lake [TP]			**60.4**	**[ug/l]**
Observed In-Lake [TP]			**191.3**	**[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]			**16.9**	**[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) =	2,950	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	51.9	[ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	58.4	[ug/l]
		G (Kinematic factor) =	0.19	[--]
		F_s (Flushing Rate) =	8.10	[year-1]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	1.09	[m]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.025 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	0.10	[m-1]
		S (Secchi Depth) =	0.89	[m]
		Maximum lake depth =	1.09	[m]
Model Predicted In-Lake [Chl-a]			**41.0**	**[ug/l]**
Observed In-Lake [Chl-a]			**125.6**	**[ug/l]**
SECCHI DEPTH				
	$SD = \dfrac{CS}{(\mathrm{a} + 0.025 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.10	[m-1]
Model Predicted In-Lake SD			**0.89**	**[m]**
Observed In-Lake SD			**0.34**	**[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} =		**10**	**[kg/yr]**

2002 Loading Summary for: Meadow Lake 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	0.42	0.63	0.263	53.0	0.21	13.9
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	*0.42*	*0.63*	*0.26*	*53.0*		*13.9*

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*	-		*0.0*

Atmosphere

Lake Area [km^2]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10^6 m^3/yr]	Aerial Loading Rate [kg/km^2-yr]	Calibration Factor [--]	Load [kg/yr]
0.04	1.19	1.19	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]
0.04	0.0	0.00	0	1.0	0.0

Internal

Lake Area [km^2]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [kg/yr]
0.04	70.0	2.0	1.0	5.7

Net Discharge [10^6 m^3/yr] =	**0.26**	**Net Load [kg/yr] =**	**20.7**

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.

2002 Lake Response Modeling for: Meadow Lake at Goal

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	21 [kg/yr]
		Q (lake outflow) =	0.3 [10^6 m^3/yr]
		V (modeled lake volume) =	0.0211 [10^6 m^3]
		T = V/Q =	0.08 [yr]
		P_i = W/Q =	79 [ug/l]
Model Predicted In-Lake [TP]			**60.3 [ug/l]**
Observed In-Lake [TP]			**242.0 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**16.9 [ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{\ 1.33}}{4.31}$	P (Total Phosphorus) =	60 [ug/l]
		N (Total Nitrogen) =	4,100 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	52.9 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	59.3 [ug/l]
		G (Kinematic factor) =	0.21 [--]
		F_s (Flushing Rate) =	12.48 [$year^{-1}$]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	1.09 [m]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.10 [m^{-1}]
		S (Secchi Depth) =	0.89 [m]
		Maximum lake depth =	1.09 [m]
Model Predicted In-Lake [Chl-a]			**40.7 [ug/l]**
Observed In-Lake [Chl-a]			**192.0 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.10 [m^{-1}]
Model Predicted In-Lake SD			**0.89 [m]**
Observed In-Lake SD			**0.28 [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} =		**16 [kg/yr]**

2005 Loading Summary for: Meadow Lake at Goal

Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

Name	Drainage Area [km²]	Runoff Depth [m/yr]	Discharge [10⁶ m³/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1 Watershed	0.42	0.50	0.209	49.0	0.19	10.2
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	*0.42*	*0.50*	*0.21*	*49.0*		*10.2*

Inflow from Upstream Lakes

Name	Discharge [10⁶ m³/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1		-	1.0	
2		-	1.0	
3		-	1.0	
Summation	*0.00*	-		*0.0*

Atmosphere

Lake Area [km²]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10⁶ m³/yr]	Aerial Loading Rate [kg/km²-yr]	Calibration Factor [--]	Load [kg/yr]
0.04	0.99	0.99	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 [10⁶ m³/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.04	0.0	0.00	0	1.0	0.0

Internal

Lake Area [km²]	Anoxic Factor [days]	Release Rate [mg/m²-day]	Calibration Factor [--]	Load [kg/yr]
0.04	70.0	2.0	1.0	5.7

Net Discharge [10⁶ m³/yr] =	**0.21**	**Net Load [kg/yr] =**	**17.0**

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.

2005 Lake Response Modeling for: Meadow Lake at Goal

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	17 [kg/yr]
		Q (lake outflow) =	0.2 [10^6 m^3/yr]
		V (modeled lake volume) =	0.0211 [10^6 m^3]
		T = V/Q =	0.10 [yr]
		P_i = W/Q =	81 [ug/l]
Model Predicted In-Lake [TP]			**60.1 [ug/l]**
Observed In-Lake [TP]			**256.8 [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]			**16.8 [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) =	3,233 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	52.0 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	58.5 [ug/l]
		G (Kinematic factor) =	0.19 [--]
		F_s (Flushing Rate) =	9.92 [$year^{-1}$]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	1.09 [m]
	$F_s = \frac{Q}{V}$; $a = \frac{1}{SD} - 0.025 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	0.10 [m^{-1}]
		S (Secchi Depth) =	0.89 [m]
		Maximum lake depth =	1.09 [m]
Model Predicted In-Lake [Chl-a]			**40.7 [ug/l]**
Observed In-Lake [Chl-a]			**90.7 [ug/l]**
SECCHI DEPTH			
	$SD = \frac{CS}{(\mathrm{a} + 0.025 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.10 [m^{-1}]
Model Predicted In-Lake SD			**0.89 [m]**
Observed In-Lake SD			**0.44 [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} =		**13 [kg/yr]**

TMDL Loading Summary for: Meadow Lake at Goal

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [km²]	Runoff Depth [m/yr]	Discharge [10⁶ m³/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [kg/yr]
1	Watershed	0.42	0.46	0.194	46.5	0.19	9.0
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	*0.42*	*0.46*	*0.19*	*46.5*		*9.0*

Inflow from Upstream Lakes

	Name	Discharge [10⁶ m³/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
1			-	1.0	
2			-	1.0	
3			-	1.0	
	Summation	*0.00*	-		*0.0*

Atmosphere

Lake Area [km²]	Precipitation [m/yr]	Evaporation [m/yr]	Net Inflow [10⁶ m³/yr]	Aerial Loading Rate [kg/km²-yr]	Calibration Factor [--]	Load [kg/yr]
0.04	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 [km²]	Groundwater Flux [m/yr]	Net Inflow [10⁶ m³/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [kg/yr]
0.04	0.0	0.00	0	1.0	0.0

Internal

Lake Area [km²]	Anoxic Factor [days]	Release Rate [mg/m²-day]	Calibration Factor [--]	Load [kg/yr]
0.04	70.0	2.0	1.0	5.7

Net Discharge [10⁶ m³/yr] = 0.19 | **Net Load [kg/yr] = 15.8**

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: Meadow Lake at Goal

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	16 [kg/yr]
		Q (lake outflow) =	0.2 [10^6 m^3/yr]
		V (modeled lake volume) =	0.0211 [10^6 m^3]
		T = V/Q =	0.11 [yr]
		P_i = W/Q =	81 [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]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	60 [ug/l]
		N (Total Nitrogen) =	3,361 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	51.6 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	58.2 [ug/l]
		G (Kinematic factor) =	0.19 [--]
		F_s (Flushing Rate) =	9.18 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	1.09 [m]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.50 [m^{-1}]
		S (Secchi Depth) =	0.69 [m]
		Maximum lake depth =	1.09 [m]
Model Predicted In-Lake [Chl-a]			**37.7 [ug/l]**
Observed In-Lake [Chl-a]			**- [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.50 [m^{-1}]
Model Predicted In-Lake SD			**0.69 [m]**
Observed In-Lake SD			**- [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) =	**4 [kg/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**12 [kg/yr]**

Appendix B

Water Quality Monitoring

1.0 Water Quality Monitoring

Water quality monitoring has been conducted in the Shingle Creek watershed since 1990 as a part of the Citizen Assisted Monitoring Program (CAMP) program. This appendix is focused on characterizing current conditions and diagnosing key problems degrading current water quality.

1.1 PREVIOUS STUDIES AND MONITORING ON MEADOW LAKE

1.1.1 Citizen Assisted Monitoring Program (CAMP)

Since 1990, the Shingle Creek Watershed Management Commission (SCWMC) has participated in the Citizens Assisted Monitoring Program (CAMP) operated by the Metropolitan Council Environmental Services (MCES). The CAMP program is a volunteer monitoring program where volunteers collect data and samples biweekly including samples for total phosphorus, total Kjeldahl nitrogen, and Secchi depth. Meadow Lake has been monitored through this program every three years since 1995. The SCWMC has no professional lakes monitoring program at this time.

1.2 MONITORING PARAMETERS

1.2.1 Temperature and Dissolved Oxygen

Understanding lake stratification is important to the development of both the nutrient budget for a lake as well as ecosystem management strategies. Lakes that are dimictic (mix from top to bottom in the spring and fall) can have very different nutrient budgets than lakes that are completely mixed 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. Shallow lakes such as Meadow Lake often mix periodically throughout the year as a result of wind and wave action. No data is available to determine how often Meadow Lake mixes.

1.2.2 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.

1.2.3 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.

1.3 LAKE MONITORING RESULTS

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

1.3.1 Historical Data

Spring and summer average water quality for Meadow Lake 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 Meadow Lake.

	Chlorophyll-a (µg/L)		Total Phosphorus (mg/L)		Secchi Depth (m)		Total Kjeldahl Nitrogen (mg/L)	
Year	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**
1994								
1996	2	11.4	2	0.085	2	0.7	2	1.2
1999	4	49.5	4	0.122	4	0.5	4	2.2
2002	2	53.0	2	0.164	2	0.5	2	2.2
2005	2	3.2	2	0.225	2	0.6	2	5.1

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

	Chlorophyll-a (µg/L)		Total Phosphorus (mg/L)		Secchi Depth (m)		Total Kjeldahl Nitrogen (mg/L)	
Year	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**
1994					15	0.3		
1996	8	93.2	8	0.266	8	0.3	8	3.3
1999	8	125.6	8	0.191	8	0.3	8	3.0
2002	5	192.0	6	0.242	6	0.3	6	4.1
2005	6	90.7	6	0.257	6	0.4	6	3.2

1.3.2 Temperature and Dissolved Oxygen

There are no temperature or dissolved oxygen data available for Meadow Lake.

1.3.3 Phosphorus

As can be seen in Figures 1.1 and 1.2, total phosphorus concentration generally increases throughout the summer, with maximum concentration generally occurring in August or early September.

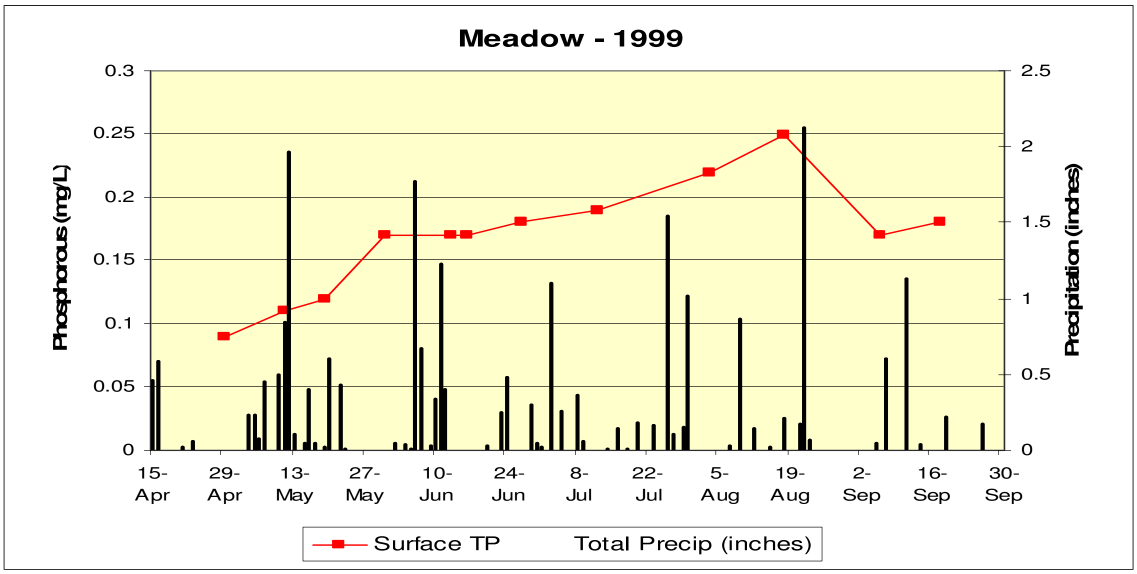


Figure 1.1. Surface total phosphorus concentrations and total precipitation for Meadow Lake in 1999.

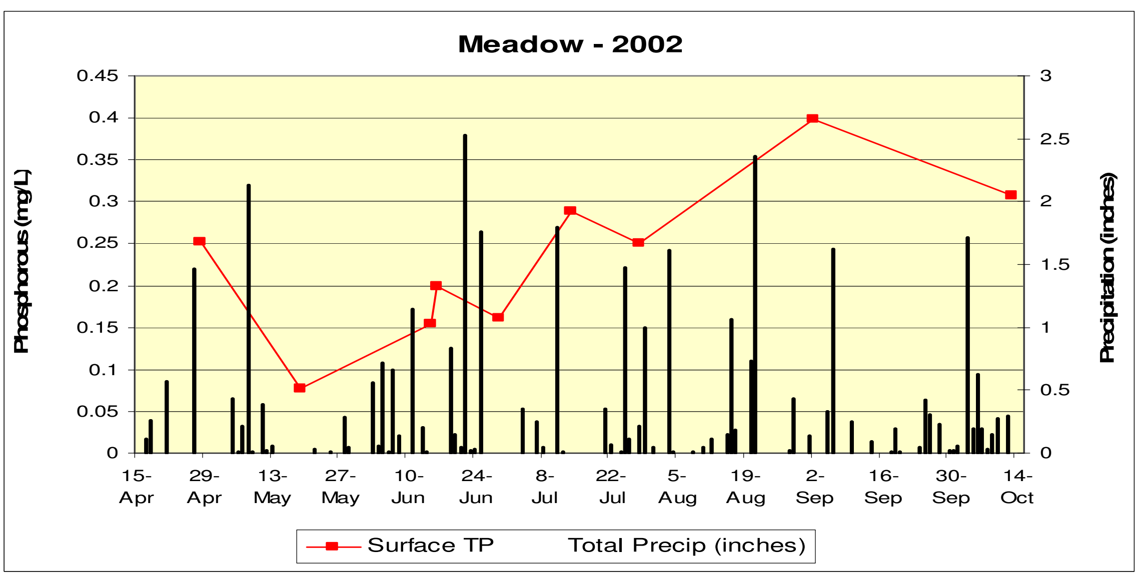


Figure 1.2. Surface total phosphorus concentrations and total precipitation for Meadow Lake in 2002.

1.3.4 Chlorophyll-a

Chlorophyll-a concentrations generally track with TP concentrations increasing through the spring and early summer. Figure 1.3 and 1.4 show data from 1999 and 2002.

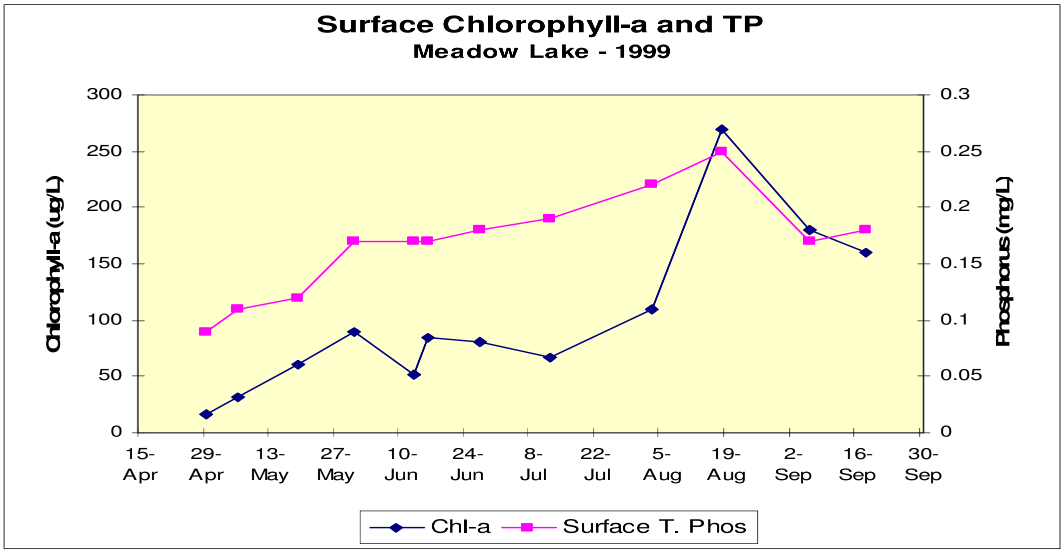


Figure 1.3. Chlorophyll-a and phosphorus concentrations in the epilimnion of the Meadow Lake for 1999.

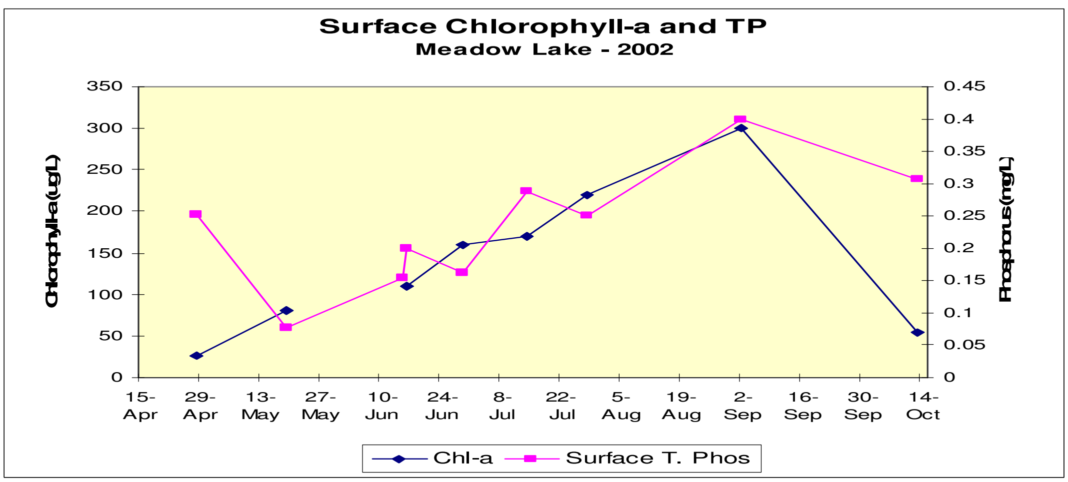


Figure 1.4. Chlorophyll-a and phosphorus concentrations in the epilimnion of the Meadow Lake for 2002.

1.4 CONCLUSIONS

Monitoring data suggest that Meadow Lake is a productive system in which water quality significantly exceeds the shallow lake standards for total phosphorus (≤60µg/L), chlorophyll-a (≤20µg/L), and Secchi depth (≥1.0 meters) in all monitored years. The lake exhibits severe late season algae blooms.