# Ann Lake and Lake Emma Excess Nutrient TMDL

Prepared for

Wright County Soil and
Water Conservation District

Wenck

October 2011

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# Ann Lake and Lake Emma Excess Nutrient TMDL Report

**Wenck File #2268-01**

Prepared for:

**WRIGHT COUNTY SOIL AND WATER CONSERVATION DISTRICT**

**MINNESOTA POLLUTION CONTRO L AGENCY**

October 2011

Prepared by:

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# TMDL Summary

| TMDL Summary Table | | | |
|---|---|---|---|
| **EPA/MPCA Required Elements** | **Summary** | | **TMDL Section** |
| | Ann- Atmospheric Load | 0.2 | |
| | Ann- Internal Load | 0.6 | |
| | | | |
| | Emma- Watershed | 0.8 | |
| | Emma- Upstream Lake | 2.7 | |
| | Emma- Atmospheric | 0.1 | |
| | Emma- Internal | 0.5 | |
| **Margin of Safety** | The margin of safety is implicit in each TMDL due to the conservative assumptions of the model and the proposed iterative nutrient reduction strategy with monitoring. An additional 5% of the total load was allocated for an explicit margin of safety. | | 4.1.4 |
| **Seasonal Variation** | Seasonal variation is accounted for by developing targets for the summer critical period where 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. | | 4.3 |
| **Reasonable Assurance** | Reasonable assurance is provided by implementing the TMDL through the County Water Plan and CROW Watershed Management Plan. | | 7 |
| **Monitoring** | The Wright County SWCD plans to continue monitoring Ann Lake on a monthly basis in the summer for total phosphorus, chlorophyll-a, and Secchi depth. The SWCD also plans to continue monitoring County Ditch 10, the primary tributary to Ann Lake for total phosphorus and discharge. | | 6 |
| **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. Implementation costs will range between $500,000 and $5 Million. | | 6 |
| **Public Participation** | Stakeholder and Public participation was accomplished through a series of technical and public meetings. Feedback garnered from these meetings was incorporated into the TMDL Report. | | 5 |

# Executive Summary

This Total Maximum Daily Load (TMDL) study addresses nutrient impairments for Ann (DNR #86-0190) and Emma (DNR #86-0188) Lake located in the NFCR (07040201), Upper Mississippi River Basin in Wright County, Minnesota. The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients. The numeric water quality standards for both lakes are a summer average total phosphorus concentration of 60 µg/L, 20 µg/L chlorophyll-a, and greater than one meter in Secchi depth. Water quality does not meet state standards for nutrient concentration for shallow lakes in the North Central Hardwood Forest ecoregion in either lake.

Land use in the Ann Lake and Lake Emma watersheds is predominantly agriculture (>77%) including row crops (corn/soybean rotation) and animal agriculture. Both lakes are quite shallow with an average depth less than 10 feet. Lake Emma receives water from Ann Lake via a short channel and then discharges downstream to the Crow River. Both lakes have a long history of carp and curly-leaf pondweed infestation while carp removal has occurred periodically at Ann Lake.

Nutrient budgets were developed for both lakes as well as a lake response model to set the Load and Wasteload Allocations. Phosphorus sources to Ann Lake include watershed runoff (68%) and internal sediment release of phosphorus (30%) with the remaining phosphorus coming from atmospheric deposition. Lake Emma receives most of its phosphorus from Ann Lake (74%) with the remaining phosphorus coming from internal loading (17%) and the direct watershed (9%). TMDL allocations for the lakes to meet state water quality standards were 1,591 pounds per year ( 81% reduction) for Ann Lake and 1,586 pounds per year (60% reduction) for Lake Emma.

The primary sources of phosphorus for Ann Lake include runoff from an agricultural watershed with both row crops and animal agriculture. Based on a Generalized Watershed Loading Function Model (GWLF), the primary source of nutrients is from animal manure. There are over 6,000 animal units in the Ann Lake watershed which produce over 1.4 million pounds of phosphorus per year. A large proportion of this manure is land applied in the Ann Lake watershed, some of which eventually makes its way into surface waters. Nutrient management in the watershed will need to focus on manure management. Internal nutrient loading is also a significant source of phosphorus (30%) and will need to be addressed through internal load controls.

The primary source of phosphorus to Lake Emma is from Ann Lake (74%) so restoration of Ann Lake will benefit Lake Emma tremendously. Some animal agriculture occurs in the direct watershed to Lake Emma and manure management will need to occur there as well. Internal loading will also need to be addressed to meet the established TMDL.

# 1.0 Introduction

## 1.1 PURPOSE

This Total Maximum Daily Load (TMDL) study addresses nutrient impairments in Ann and Emma Lakes. The goal of this TMDL is to quantify the pollutant reductions needed to meet state water quality standards for nutrients in Ann and Emma Lakes. The Ann-Emma 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 Ann Lake and Lake Emma exceed the state-established standards for nutrients.

This TMDL provides wasteload allocations (WLAs) and load allocations (LAs) for Ann and Emma 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

Ann Lake (DNR Lake # 86-0190) and Lake Emma (DNR Lake #86-0188) are located in the Upper Mississippi River Basin in Wright County, Minnesota. Ann Lake was placed on the 2002 State of Minnesota's 303(d) list of impaired waters. Lake Emma was not placed on the 2002 list because of a lack of data. Data collected in 2008 and 2009 demonstrate that Lake Emma is impaired and it is scheduled to be placed on the 2012 303(d) list. Therefore, it was included in this TMDL because it is hydrologically connected to Ann Lake. Ann Lake and Lake Emma were identified for impairment of aquatic recreation. Water quality does not meet state standards for nutrient concentration for shallow lakes in the North Central Hardwood Forest ecoregion.

The primary recreation activities supported by the lakes include boating and fishing. These lakes are recreational water bodies within Wright County with a public access on Ann Lake. They have a very active Lake Association comprised of lake shore property owners who are active in the management of the lake. The TMDL was prioritized to begin because of strong local support from the Lake Association and Wright County Soil and Water Conservation District. The TMDL is scheduled to be completed in 2011.

Water quality in Ann Lake has been periodically monitored over the past 20 years with the most intensive monitoring occurring in 2008 and 2009 as a part of various lake management planning efforts. Average summer mean values (June 1 through September 30) for total phosphorus have ranged from 145 to 395 µg/L and averaged 229 µg/L. Chlorophyll-a concentrations ranged from 25.4 to 76.6 µg/L and averaged 55.4 µg/L. Finally, Secchi depth transparencies averaged about 1.3 m with a range over the monitoring years of 0.5 to 2.1 m. Values for all three parameters exceeded the state standards for lakes in the North Central Hardwood Forest ecoregion in some or all of the years. Although Ann Lake often meets the Secchi disk transparency standard, the lake need only exceed one of the three criteria to be considered impaired.

Lake Emma has considerably less water quality data with samples collected in 2008 and 2009 as a part of this TMDL. Lake Emma exceeded both the total phosphorus and chlorophyll-a standards in both years but met the Secchi depth standard in 2009. Based on these data, Lake Emma is considered impaired for excess nutrients.

## 1.3 IMPAIRED WATERS AND MINNESOTA WATER QUALITY STANDARDS

### 1.3.1 State of Minnesota Water Quality Standards and Designated Uses

Ann Lake and Lake Emma are located in the North Central Hardwood Forests ecoregion and are designated as class 2B waters. The Class 2B designation specifies aquatic life and recreation as the protected beneficial use of the water body.

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

The numeric target used to list these lakes was the phosphorus standard for Class 2B waters in the North Central Hardwood Forest ecoregion (60 µg/L); this TMDL presents load and wasteload allocations and estimated load reductions for the 60 µg/L target. Although the TMDL is set for the total phosphorus standard, the two other lake eutrophication standards (chlorophyll-a and Secchi depth) must also be met (Table 1.1). All three of these parameters were assessed in this TMDL to ensure that the TMDL will result in compliance with state standards. Numeric standards applicable to Ann Lake and Lake Emma for chlorophyll-a and Secchi depth are 20 µg/L and 1.0 meter, respectively, as a growing season mean. All values are growing season means.

**Table 1.1. Numeric targets for shallow lakes in the North Central Hardwood Forest ecoregion.**

| Parameters | North Central Hardwood Forest (Shallow Lakes)[1] |
|---|---|
| Phosphorus Concentration (µg/L) | 60 |
| Chlorophyll-a Concentration (µg/L) | 20 |
| Secchi disk transparency (meters) | >1.0 |

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

# 2.0 Watershed and Lake Characterization

## 2.1 LAKE AND WATERSHED DESCRIPTIONS

Ann Lake is a 375 acre lake located in the northwest portion of the Twin Cities Metropolitan Area in Wright County (Figure 2.1). The lake's maximum depth is approximately 19 feet and most of the lake is less than 15 feet deep or littoral (Table 2.1). Lake Emma is a 188 acre lake connected to Ann Lake via a small channel in the southeast corner of Ann Lake. Lake Emma is also very shallow with a maximum depth of 16 feet and 96% less than 15 feet. Typically, the greater the percentage of the lake that is littoral, the greater the influences of biological processes (fish, zooplankton, and plants) on water quality. Ann Lake and Lake Emma likely will respond to both watershed inputs as well as changes in the lake's biological system.

Ann Lake and Lake Emma have short residence times, averaging between 2 to four months. The watershed-to-lake area ratio is 55:1 and 122:1 respectively, which indicates that the lakes will be somewhat sensitive to watershed nutrient inputs. The Ann Lake and Lake Emma watersheds and the general flow patterns of the contributing tributaries ditches are presented in Figure 2.2.

**Table 2.1. Ann Lake and Lake Emma morphometric and watershed characteristics.**

| Parameter | Ann Lake | Lake Emma |
|---|---|---|
| Surface Area (acres) | 375 | 188 |
| Average Depth (ft) | 10 | 8 |
| Maximum Depth (ft) | 18.5 | 16 |
| Volume (ac-ft) | 3,750 | 1,421 |
| Residence Time (years) | 0.36<br>(~4 months) | 0.2<br>(~2.5 months) |
| Littoral Area (acres) | 375 | 180 |
| Littoral Area (%) | 98% | 96% |
| Watershed (acres) | 20,657 | 23,017 |
| Watershed:Lake Area ratio | 55 | 122 |

## 2.2 DRAINAGE PATTERNS

The Ann Lake and Lake Emma drainage areas consist of several small tributaries that drain to County Ditch #10 which is the primary inflow to Ann Lake (Figure 2.2). County Ditch #10 is the primary drainage channel that flows east from the outlet of Grass Lake to Ann Lake. The watershed also includes five small lakes in the upper subwatersheds and one large wetland (Grass Lake) that County Ditch #10 flows through before discharging to Ann Lake. Lake Emma is connected to Ann Lake via a small channel. Water discharging from Ann Lake goes through Lake Emma and then discharges to the North Fork Crow River. Lake Emma also receives water from Black Dog Lake and Round Lake from the south as well as a small direct contributing area.

## 2.3 LAND USE

Land use data for the Ann Lake and Lake Emma watersheds are presented in Table 2.2 and Figure 2.3. Land use is primarily corn and soybean rotations and other row crops (54%) and pasture and grassland (23%). The remaining land area is comprised of wetlands including the Grass Lake complex, woodland areas, and roadways (developed).

**Table 2.2. Land use in the Ann Lake and Lake Emma watersheds.**

| Land Use* | Acres | Percent |
|---|---|---|
| Cultivated Land | 12,440 | 54% |
| Grassland/Pasture | 5,250 | 23% |
| Wetlands | 1,368 | 6% |
| Developed | 1,694 | 7% |
| Woodland | 1,220 | 5% |
| Lakes/Open Water | 1,044 | 5% |
| TOTAL | 23,017 | 100% |

*Source: 2008 NASS landuse coverage

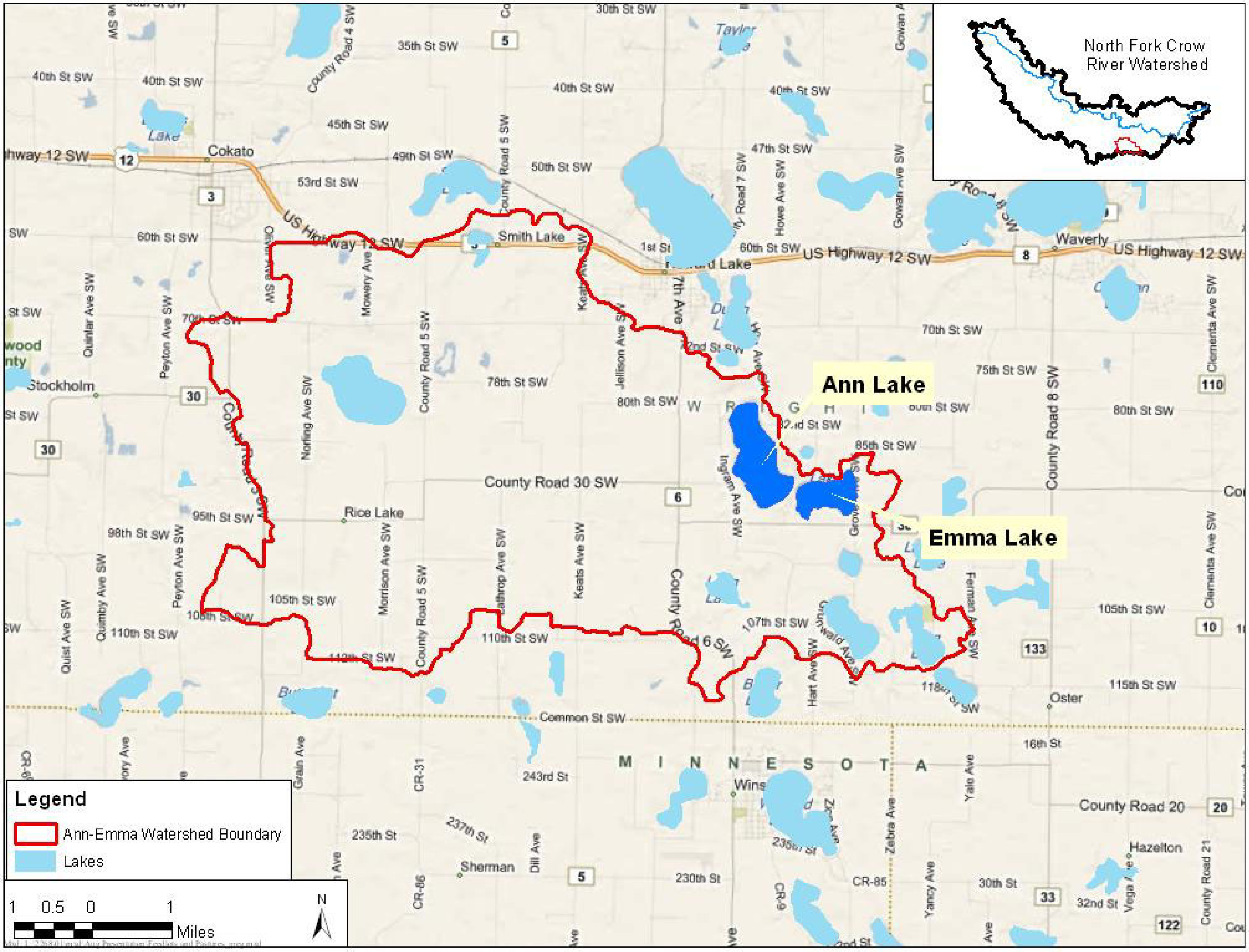


**Figure 2.1. Location Map**

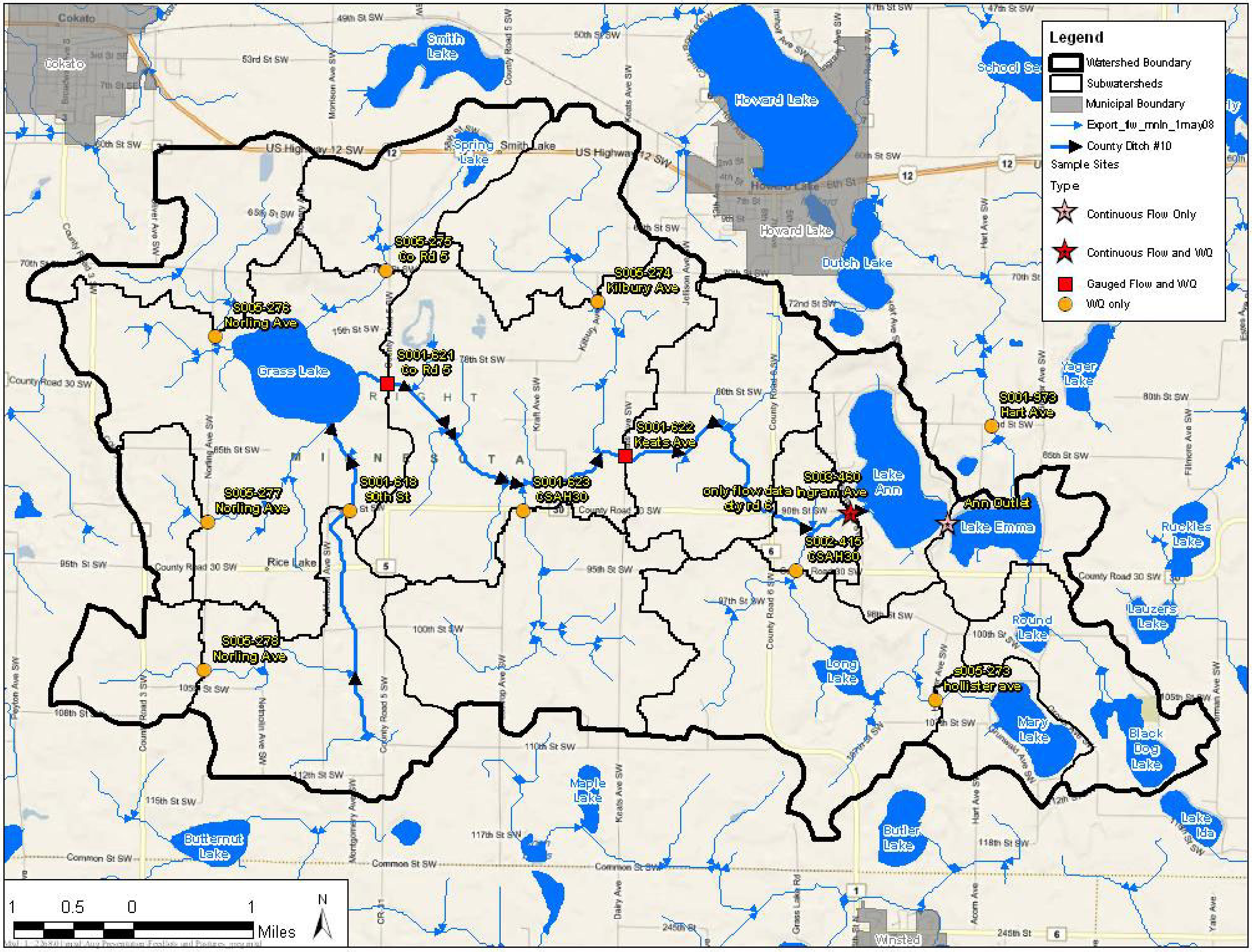

Figure 2.2. Drainage patterns and subwatershed monitoring locations

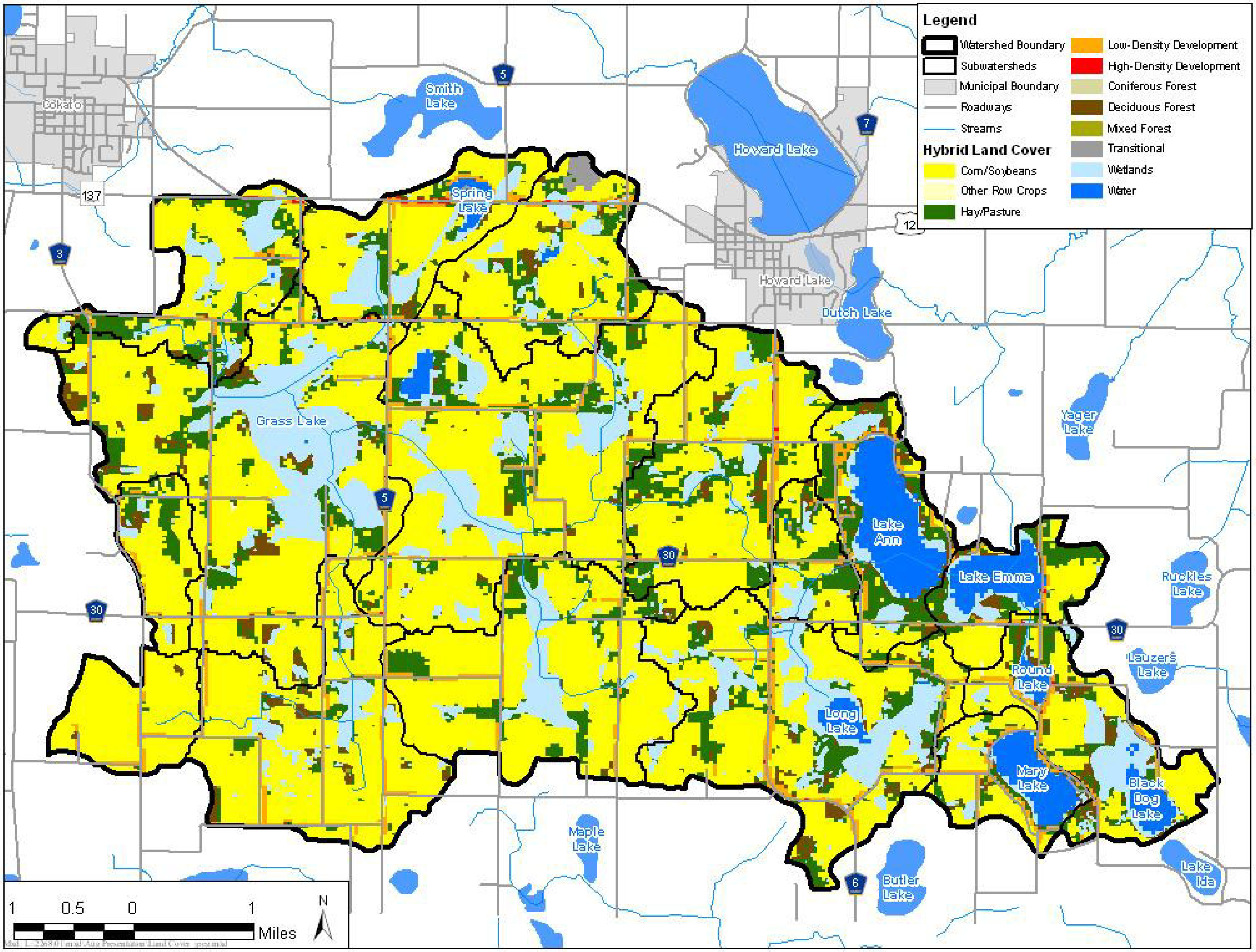


Figure 2.3. 2005 Metropolitan Council Land Use

### 2.3.1 Lake Water Quality

#### 2.3.1.1 Introduction

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 or light 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, measured by lowering a black and white disk until it can no longer be seen from the surface. Higher Secchi depths indicate less light refracting particulates in the water column and better water quality. Conversely, high total phosphorus and chlorophyll-a concentrations point to poorer water quality and thus lower water clarity. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

#### 2.3.1.2 Lake Monitoring

Water quality monitoring has been conducted on Ann Lake and Lake Emma under a variety of efforts. Secchi depth measurements for Ann Lake have been taken almost yearly since 1992, while phosphorus and chlorophyll a samples were collected less frequently in 1995 and 1996 and from 2002 through 2009 (Table 2.3). Collection efforts have recently been conducted by the Wright County SWCD. A majority of these samples have been collected from one site (201); however, four4 other sites (101, 102, 202 and 203) were sampled periodically. For this study, data from all five stations were combined into one dataset and organized by date. Any day with more than one sample was averaged to represent a single value. Only sample results collected during the growing season (June 1 through September 30) are presented in this report. Emma Lake has one monitoring station with only 2 years (2008-2009) of Secchi, chlorophyll a and total phosphorus data. This data was sorted, consolidated and averaged by sampling date (Table 2.4).

**Table 2.3. Ann Lake water quality sampling efforts since 1992.**

| Sampling Season | Secchi (N) | Secchi (m) | Chl-a (N) | Chl-a (µg/L) | TP (N) | TP (µg/L) |
|---|---|---|---|---|---|---|
| 1992 | 9 | 1.10 | -- | -- | -- | -- |
| 1993 | 10 | 1.20 | -- | -- | -- | -- |
| 1994 | -- | -- | -- | -- | -- | -- |
| 1995 | 3 | 1.53 | 3 | -- | 3 | 250 |
| 1996 | 20 | 1.46 | 4 | 25.4 | 4 | 280 |
| 1997 | 23 | 2.09 | -- | -- | -- | -- |
| 1998 | 17 | 1.46 | -- | -- | -- | -- |
| 1999 | 18 | 1.22 | -- | -- | -- | -- |
| 2000 | 15 | 1.12 | -- | -- | -- | -- |
| 2001 | 14 | 0.90 | -- | -- | -- | -- |
| 2002 | 6 | 0.54 | 7 | 60.3 | 7 | 395 |
| 2003 | 4 | 1.07 | 4 | 41.0 | 4 | 291 |
| 2004 | 3 | 1.22 | 3 | | 3 | 278 |
| 2005 | 4 | 1.37 | 4 | 56.3 | 4 | 219 |
| 2006 | 3 | 1.27 | 3 | -- | 3 | 134 |
| 2007 | 1 | -- | 1 | -- | 1 | |
| 2008 | 15 | 0.97 | 10 | 76.6 | 10 | 145 |
| 2009 | 14 | 1.09 | 12 | 59.8 | 12 | 169 |

**Table 2.4. Emma Lake water quality sampling.**

| Sampling Season | Secchi (N) | Secchi (m) | Chl-a (N) | Chl-a (µg/L) | TP (N) | TP (µg/L) |
|---|---|---|---|---|---|---|
| 2008 | 6 | 0.81 | 6 | 58 | 6 | 117 |
| 2009 | 5 | 1.22 | 6 | 49 | 5 | 132 |

### 2.3.2 Lake Monitoring Results

#### 2.3.2.1 Temperature and Dissolved Oxygen

All dissolved oxygen profiles for Ann and Emma Lakes are presented in Appendix A. These profiles show slight stratification and temperature gradients between the surface and bottom waters during the mid-summer months (Appendix A). Dissolved oxygen (DO) profiles demonstrate anoxia (DO ≤ 2 mg/L) often occurs in the bottom 1-2 meters of the water column during the warm summer months (July to early September). 2002 profiles displayed extremely low dissolved oxygen concentrations throughout the entire water column for much of the summer. These temperature and dissolved oxygen conditions in Ann Lake demonstrate the potential for internal loading of phosphorus. However, it should be noted that Ann Lake is a shallow system with relatively high surface area to depth ratios causing the lake to be more susceptible to wind-driven mixing events. Thus the lake does not sustain a strong thermocline and large anoxic area for the entire summer period.

### 2.3.2.2 Total Phosphorus

Summer average total phosphorus concentrations for Ann and Emma Lake exceeded the state standard of 60 µg/L in all monitoring years (Figures 2.4 and 2.5). The highest summer average concentration for Ann Lake was measured in 2000 and reached over 500 µg/L. Summer average total phosphorus concentrations for Ann (145 – 395 µg/L ) and Emma (132 – 225 µg/L) suggest both lakes consistently exceed the shallow lake eutrophication standard of 60 µg/L and indicate extremely high inputs from the watershed or in-lake sources.

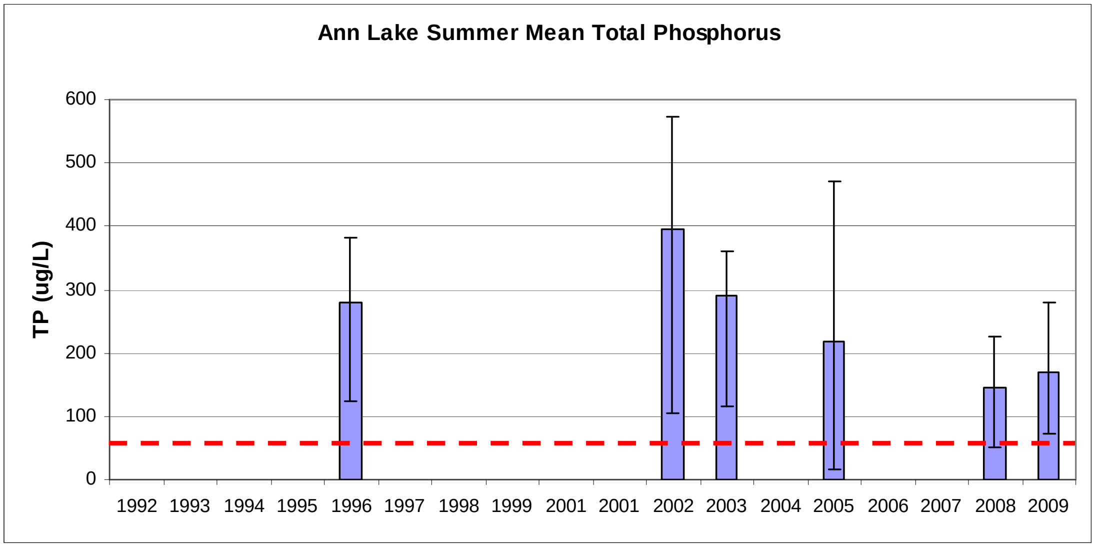


**Figure 2.4. Summer (June 1 –September 30) mean total phosphorus concentrations for Ann Lake. The red dotted line indicates the current State standard for the North Central Hardwood Forest ecoregion. Error bars represent the maximum and minimum total phosphorus measurements for each season. Only sampling seasons with four or more measurements are displayed.**

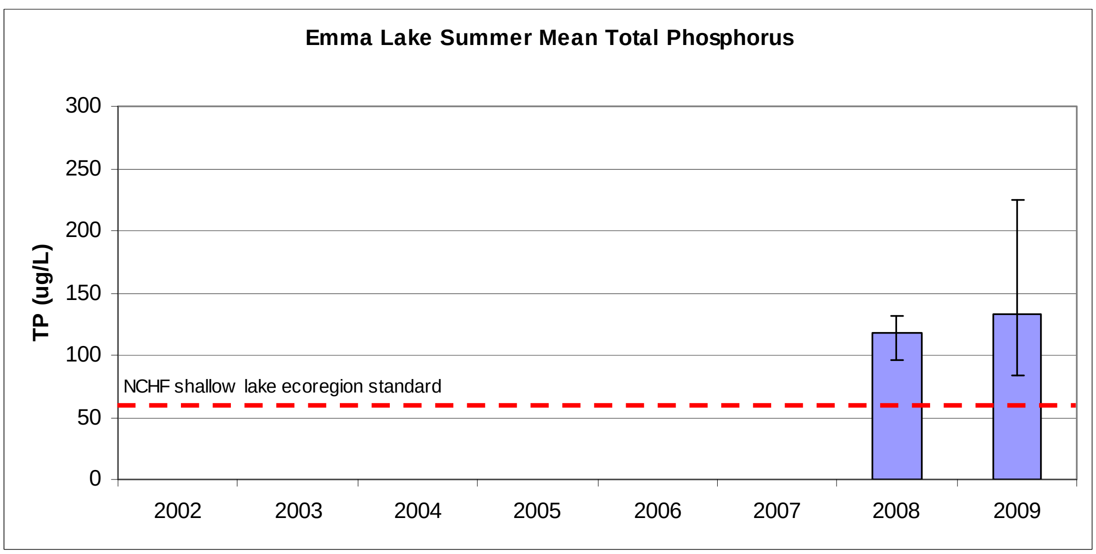


**Figure 2.5. Summer (June 1 –September 30) mean total phosphorus concentrations for Emma Lake. The red dotted line indicates the current State standard for the North Central Hardwood Forest ecoregion. Error bars represent the maximum and minimum total phosphorus measurements for each season. Only sampling seasons with four or more measurements are displayed.**

### 2.3.2.3 Chlorophyll-a

Average chlorophyll-a concentration in Ann Lake and Lake Emma has ranged from 25 to as high as 77 µg/L for years with four samples or more during the summer season (Figures 2.6 and 2.7). These values are approximately 1-3 times higher than the State standard. Chlorophyll-a concentrations in this range indicate a high incidence of nuisance algae blooms.

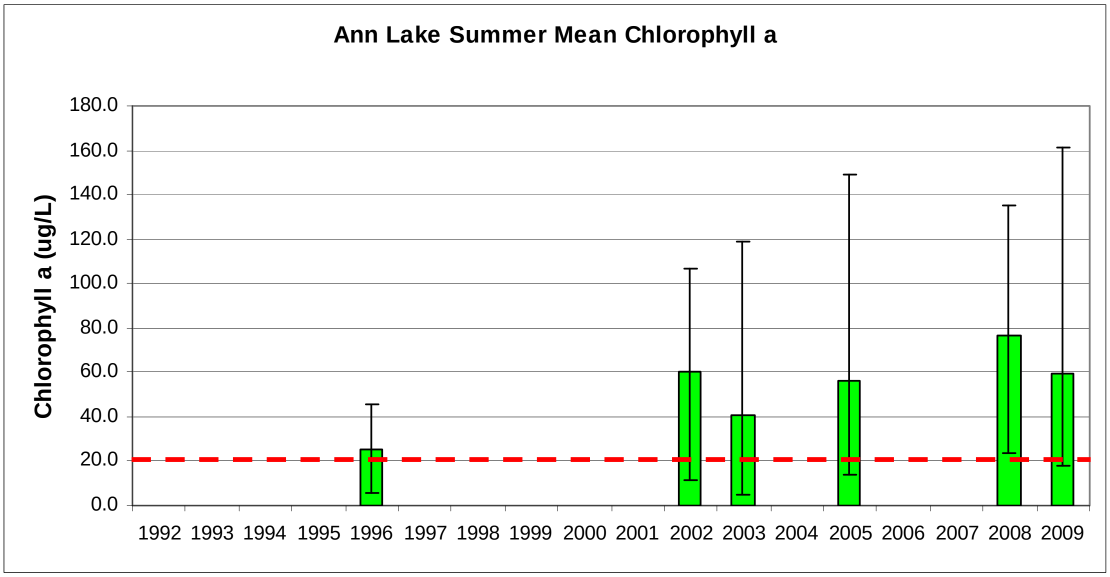


**Figure 2.6. Summer (June 1 –September 30) mean chlorophyll-a concentrations for Ann Lake. The red dotted line indicates the current State standard for the North Central Hardwood Forest ecoregion. Error bars represent the maximum and minimum chlorophyll a measurements for each season. Only sampling seasons with four or more measurements are displayed.**

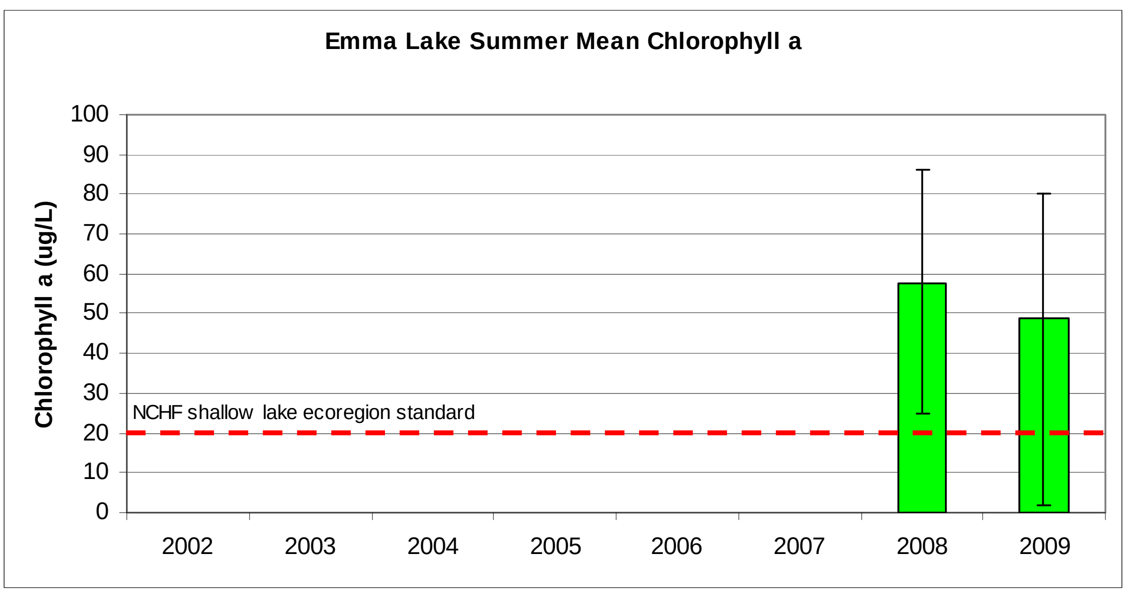


**Figure 2.7. Summer (June 1 –September 30) mean chlorophyll-a concentrations for Emma Lake. The red dotted line indicates the current State standard for the North Central Hardwood Forest ecoregion. Error bars represent the maximum and minimum chlorophyll-a measurements for each season. Only sampling seasons with four or more measurements are displayed.**

### 2.3.2.4 Secchi Depth

Water clarity (Secchi depth) data for Ann Lake and Lake Emma show very high inter-annual variability (Figures 2.8 and 2.9). Minimum values are consistently below the 1.0 meter Secchi standard for shallow lakes in the North Central Hardwood Forest ecoregion even though summer maximums and averages are typically at or above the standard.

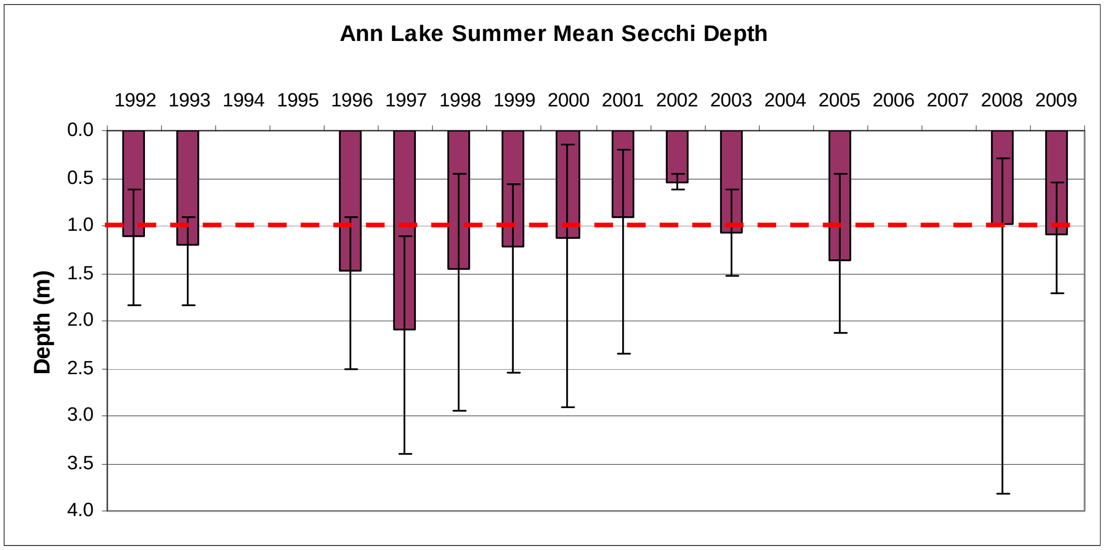


**Figure 2.8. Summer (June 1 –September 30) mean Secchi depth (meters) for Ann Lake. The red dotted line indicates the current State standard for the North Central Hardwood Forest ecoregion. Error bars represent the maximum and minimum Secchi measurements for each season. Only sampling seasons with four or more measurements are displayed.**

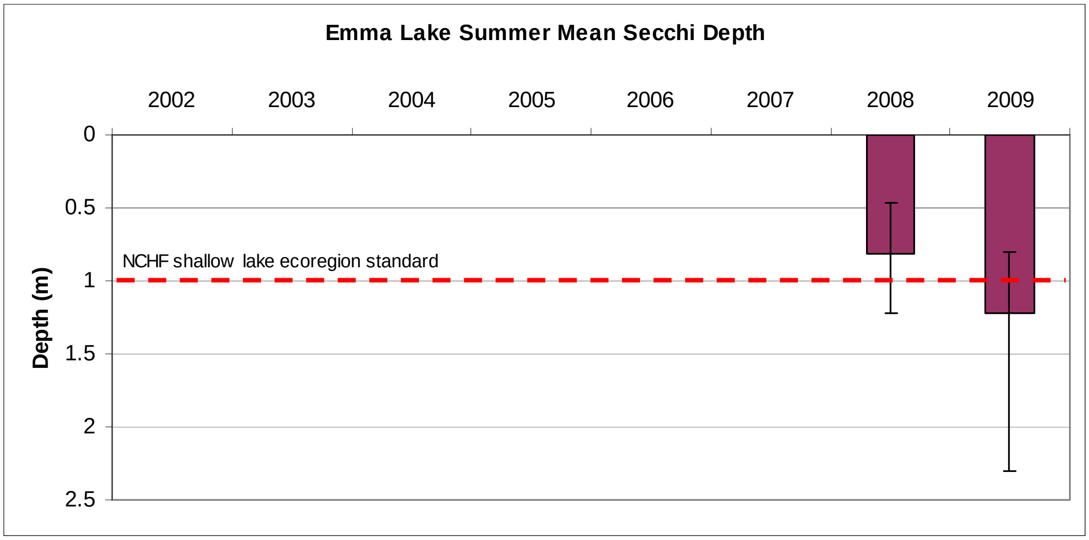


**Figure 2.9. Summer (June 1 –September 30) mean Secchi depth (meters) for Emma Lake. The red dotted line indicates the current State standard for the North Central Hardwood Forest ecoregion. Error bars represent the maximum and minimum Secchi measurements for each season. Only sampling seasons with four or more measurements are displayed.**

### 2.3.3 Conclusions

Overall, both Ann Lake and Lake Emma have not met current state standards since consistent monitoring programs have been established. While there is some variability in the monitoring data from year to year, trends over that time show that the water quality is relatively stable in its current state. There does not appear to be a significant decline or improvement in the water quality of either lake over this time period.

## 2.4 WATERSHED MONITORING

### 2.4.1 County Ditch #10 Monitoring Data

Wright County and Crow River Organization of Waters (CROW) staff collected total phosphorus, ortho-phosphorus, TKN and chlorophyll a data from 12 sampling locations throughout County Ditch #10 and its tributaries approximately once every two weeks in 2008 and 2009 (Figure 2.2 and Table 2.5). Continuous flow was recorded near the Ann Lake inlet (S003-460) and Emma Lake outlet stations (S001-973). In addition, gauged flow measurements were taken at two CD #10 main-stem stations (S001-621 and S001-622) below Grass Lake in 2009.

**Table 2.5. Summary of water quality and flow data collected for County Ditch #10. Flow data collected by MPCA is continuous while those collected by SWCD staff are discrete gauged flow measurements.**

| Site ID | Description | Years | Flow data | TP (N) | SRP (N) | TKN (N) | Chl-a (N) |
|---|---|---|---|---|---|---|---|
| S001-973 | 12 mile Creek at Hart Ave Emma Outlet | 08-09 | 0 (STORET); 583 (MPCA) | 20 | 13 | 11 | 13 |
| S001-618 | 90th St above Grass Lake | 02, 08-09 | 1 (STORET); 0 (CROW) | 22 | 15 | 11 | 15 |
| S001-621 | Co Rd 5, Grass Lake Outlet | 02, 08-09 | 2 (STORET); 6 (CROW) | 28 | 18 | 15 | 17 |
| S001-622 | Keats Ave | 08-09 | 0 (STORET); 13 (CROW) | 24 | 13 | 11 | 19 |
| S003-460 | Ingram Ave (Ann Inlet) | 02, 08-09 | 2 (STORET); 611 (MPCA) | 31 | 22 | 19 | 19 |
| S001-623 | Trib at CSAH 30 b/w CR5 and Keats | 08-09 | None | 17 | 11 | 9 | 11 |
| S005-274 | Trib at Kilbury Ave b/w CR5 and Keats | 08-09 | None | 15 | 9 | 7 | 9 |
| S002-415 | Trib at CSAH 30 b/w Keats and Ingram Ave | 08-09 | none | 15 | 9 | 7 | 9 |
| S005-276 | Trib to Grass Lake at Norling Ave (north) | 08-09 | none | 12 | 8 | 6 | 8 |
| S005-278 | Trib to CD 10 at Norling Ave (south) | 08-09 | none | 24 | 17 | 14 | 17 |
| S005-275 | Trib to Grass Lake at CR 5 | 08-09 | none | 15 | 9 | 7 | 9 |
| S005-277 | Trib to Grass Lake at Norling Ave (southwest) | 08-09 | none | 16 | 11 | 8 | 11 |

### 2.4.2 County Ditch #10 Flow Data

Flow relationships were explored between the gauged flow data recorded by CROW staff and the continuous flow data recorded by the MPCA at Ingram Avenue (Figure 2.10). Paired flow data between the Ingram and Keats Avenue stations suggest different regression relationships during high (>15 cfs) and low (<15 cfs) flow conditions. These relationships showed good correlation ($R^2$ of 0.90 and 0.99) and were used to construct continuous flow time series for the gauged flow stations for the entire period of record in which the monitoring equipment was deployed from 2007-2009 (Figure 2.11). The continuous data shows the watershed contributes high flows during spring runoff and early summer rain events. Flows quickly decrease to very low baseflow conditions (typically <1.0 cfs) in mid-late July.

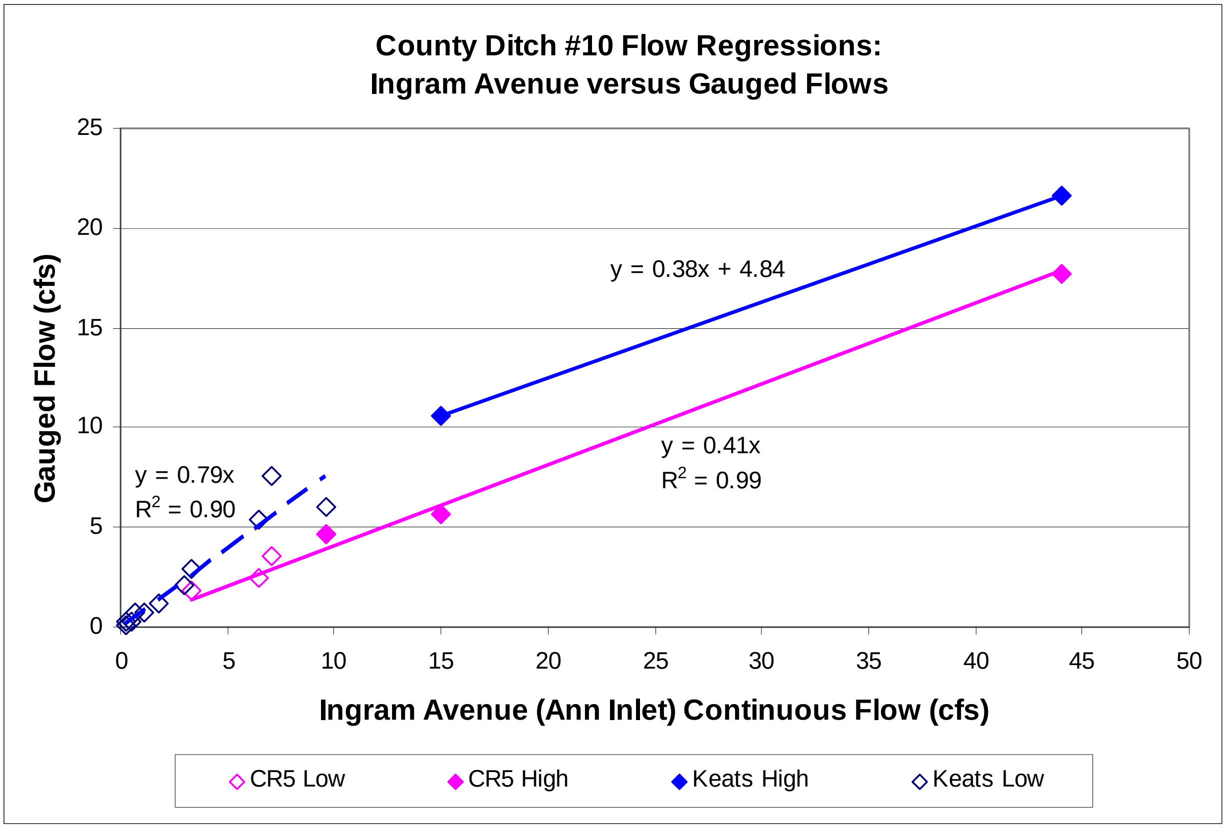


**Figure 2.10. County Ditch #10 flow regressions between the MPCA's continuous data recorded at the Ingram Avenue station (S003-460) and gauged flows from the Keats Avenue and County Road 5 stations. Keats Avenue gauged flows were grouped by flow regime as two high separate regressions were used to estimate continuous flow during high (>15 cfs) and low (<15 cfs) flow.**

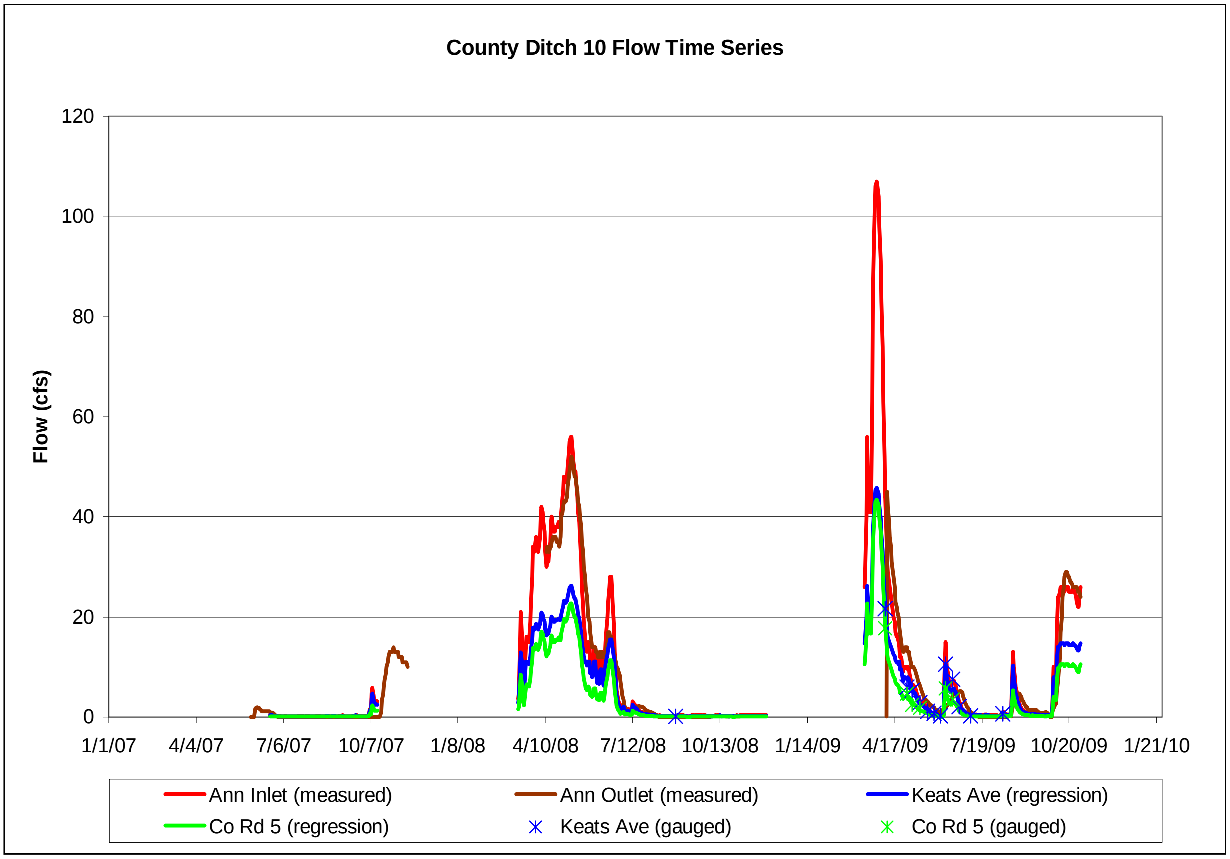


**Figure 2.11. County Ditch 10 gauged and continuous flow time series. Co Rd 5 and Keats Avenue flow time series were developed based on the regressions presented in Figure 3.1.**

### 2.4.3 County Ditch #10 Phosphorus Data

Ann and Emma watershed stream total phosphorus monitoring data is presented here as a series of box plots (Figures 2.12 and 2.13). All sampling stations throughout the watershed have exhibited total phosphorus concentrations that exceed reference concentrations for North Central Hardwood Forest ecoregion streams. Main stem County Ditch #10 data show a general increase in total phosphorus concentrations downstream of Grass Lake. This trend indicates the wetland system may be a source of phosphorus to CD #10 (Figure 2.12). Tributary data suggests concentrations are high and consistently above typical ecoregion concentrations (Figure 2.13). However, concentrations are slightly lower in the two tributaries upstream of Grass Lake in the southwest portion of the watershed (S005-278 and S005-277).

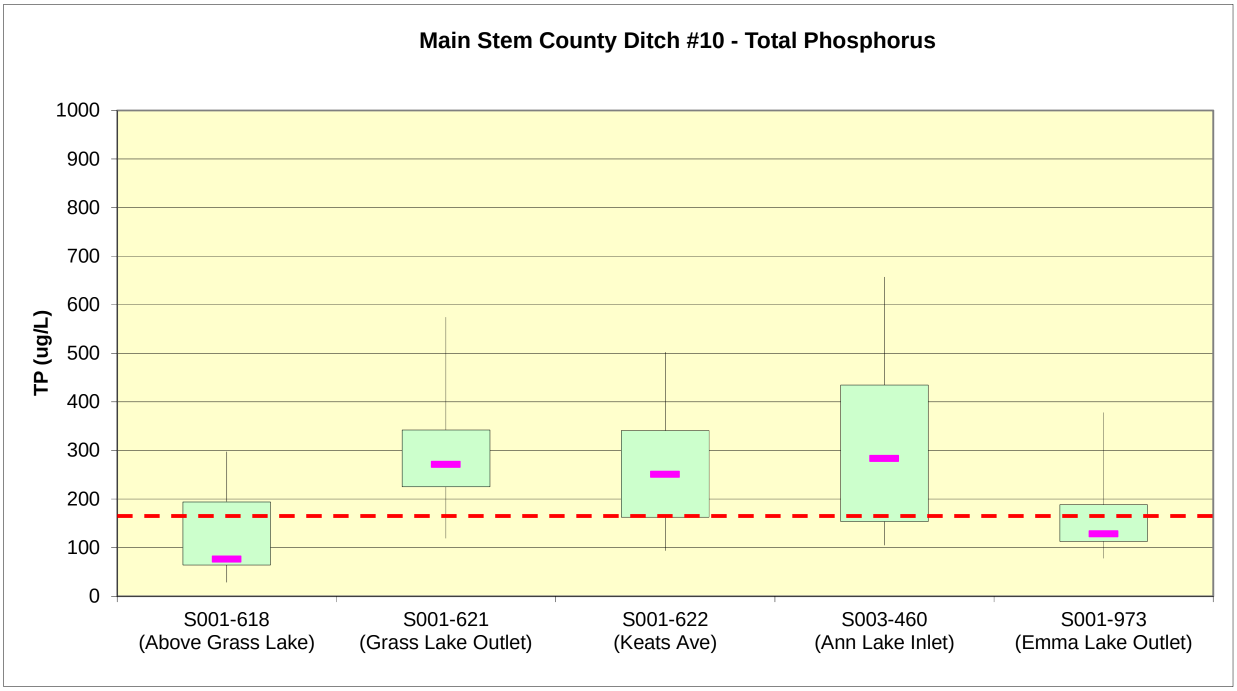


**Figure 2.12. County Ditch #10 main-stem monitoring station total phosphorus concentrations. The upper and lower edge of each box represent the 75th and 25th percentile of the data range for each site. Error bars above and below each box represent the 95th and 5th percentile of the dataset. The pink dash is the median TP concentration of all data collected. The dotted red line represents the upper end of the typical annual TP concentration for North Central Hardwood Forest ecoregion streams (170 µg/L).**

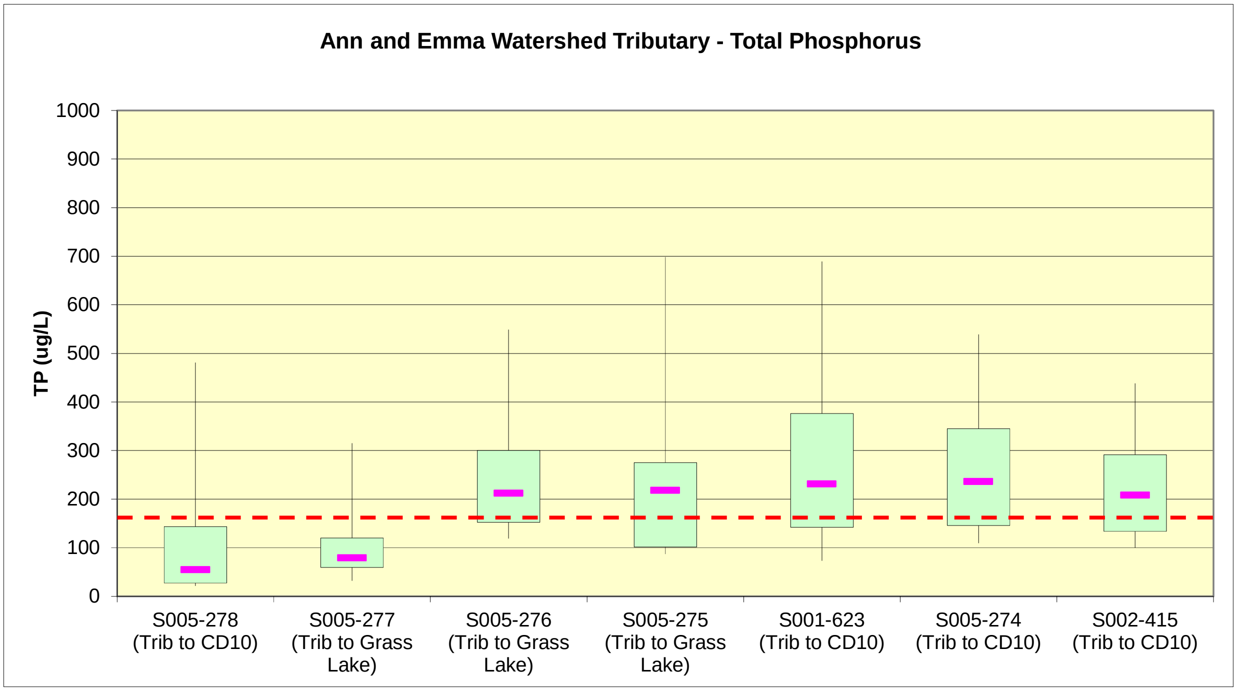


**Figure 2.13. Ann and Emma watershed tributary monitoring station total phosphorus concentrations. The upper and lower edges of each box represent the 75th and 25th percentile of the data range for each site. Error bars above and below each box represent the 95th and 5th percentile of the dataset. The pink dash is the median TP concentration of all data collected. The dotted red line represents the upper end of the typical annual TP concentration for North Central Hardwood Forest ecoregion streams (170 µg/L).**

## 2.5 FISH POPULATIONS AND FISH HEALTH

### 2.5.1 Fish Populations

The fisheries lake management plan and fish survey reports for Ann and Emma Lakes were provided by the DNR Area Fisheries Office in Montrose, MN. The first DNR fish survey for Ann and Emma were conducted in 1990 and 1974, respectively. Standard survey methods used by the DNR include gill net and trap nets. These sampling methods do have some sampling bias, including focusing on game management species (i.e., northern pike and walleye), under representing small minnow and darter species presence/abundance, and under representing certain management species such as largemouth bass. The current methods also likely under represent carp populations in the lakes. However, in our experience, when carp are present in the lakes, the sampling methods do capture some of the population. So, although carp density is likely under represented, the methods do provide a reasonable year to year comparison.

There have been 14 species collected during DNR surveys:

- Black Bullhead
- Black Crappie
- Bluegill
- Bowfin
- Common Carp
- Golden shiner
- Hybrid Sunfish
- Largemouth Bass
- Northern Pike
- Pumpkinseed
- Walleye
- White Sucker
- Yellow Bullhead
- Yellow Perch

Fish community data for each lake was summarized by trophic groups (Figures 2.14 through 2.17). Species within a trophic group serve the same ecological process in the lake (i.e., panfish species feed on zooplankton and invertebrates; may serve as prey for predators). Analyzing all the species as a group is often a more accurate summary of the fish community then analyzing individual species trends. The following conclusions can be drawn from the fish data:

- Rough fish species, primarily Black Bullhead, were the most abundant group in Ann Lake during the 1990 and 1996 surveys. Pan fish species were most abundant during the 2002 and 2006 surveys.
- Rough fish species comprised the largest percentage of the total biomass catch during the 1990 Ann Lake survey before shifting to top predators in the 1996 and 2006 survey.
- The most recent Ann Lake survey (2006) displayed a more balanced trophic biomass distribution between top predators, forage species and pan fish. Two significant events occurred in recent years that may explain this shift in trophic balance. In 2002, extensive flooding caused low levels of dissolved oxygen and a partial fish kill as a wide range of fish species were impacted. Then, in late winter 2006, a commercial fisherman removed 120,000 pounds of carp, 310 pounds per acre.
- The recent shift to a large panfish population in Ann Lake may produce significant grazing pressure on the zooplankton community in the lake. However, since no

zooplankton data have been collected on the lake, it is difficult to determine the impact on the zooplankton community.

- Emma Lake data suggests carp and other rough fish make up a large portion of the fish community in terms of both biomass and total numbers. Similar to Ann Lake, 2006 data shows slightly better balance even though rough fish were still prevalent.

### 2.5.2 Carp

Common carp have both direct and indirect effects on aquatic environments. Carp uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments and nutrients. These activities can lead to increased nutrients in the water column ultimately resulting in increased nuisance algal blooms. Carp and other rough fish are present in Ann and Emma Lakes, but their size and composition is currently unclear. Standard DNR methods are not particularly effective at capturing carp. However, when carp populations are quite large, the DNR methods often do catch some. Common carp have been captured in all Emma Lake surveys and three out of the four Ann Lake DNR surveys. Further analysis may be needed to better characterize the carp population for both lakes. However, based on year to year comparisons from DNR surveys, current carp populations appear to be relatively small and likely are having little impact on lake water quality. This may be a reflection of the recent rough fish removal efforts by a commercial fisherman in 2006. Due to sampling bias in current DNR survey methods, only a targeted assessment of the carp density would verify this assumption.

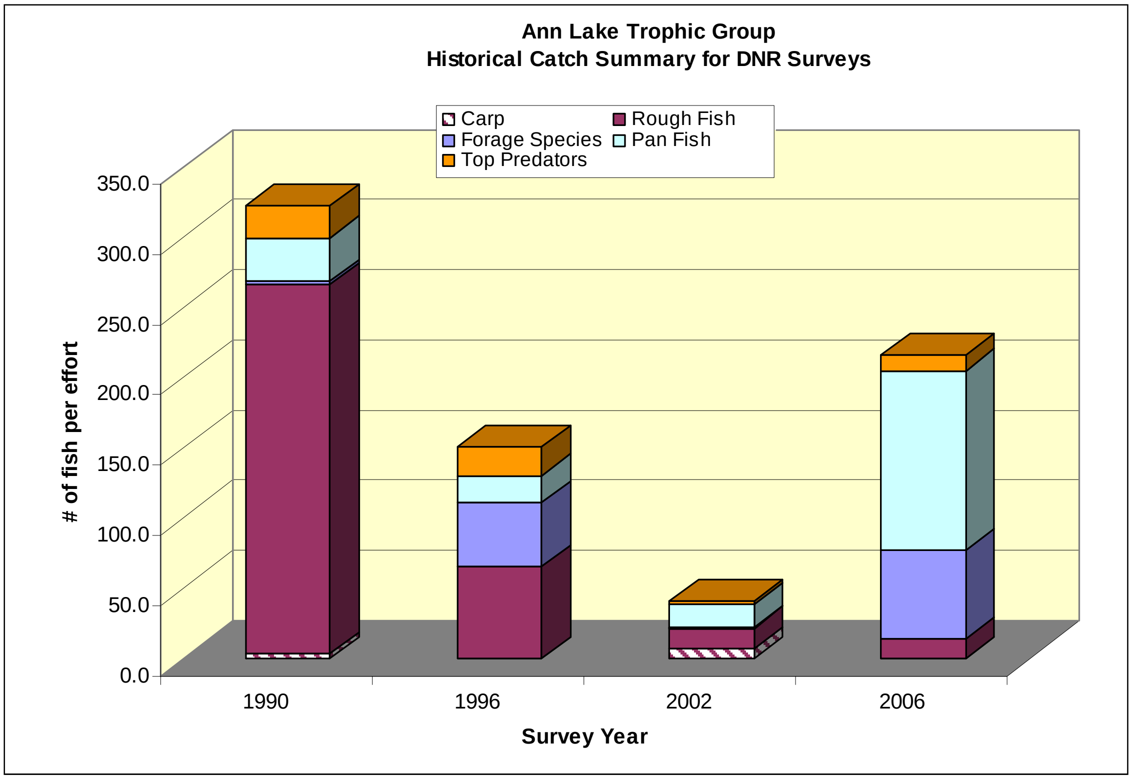


**Figure 2.14. Historical fish survey results for trophic group abundance in Ann Lake.**

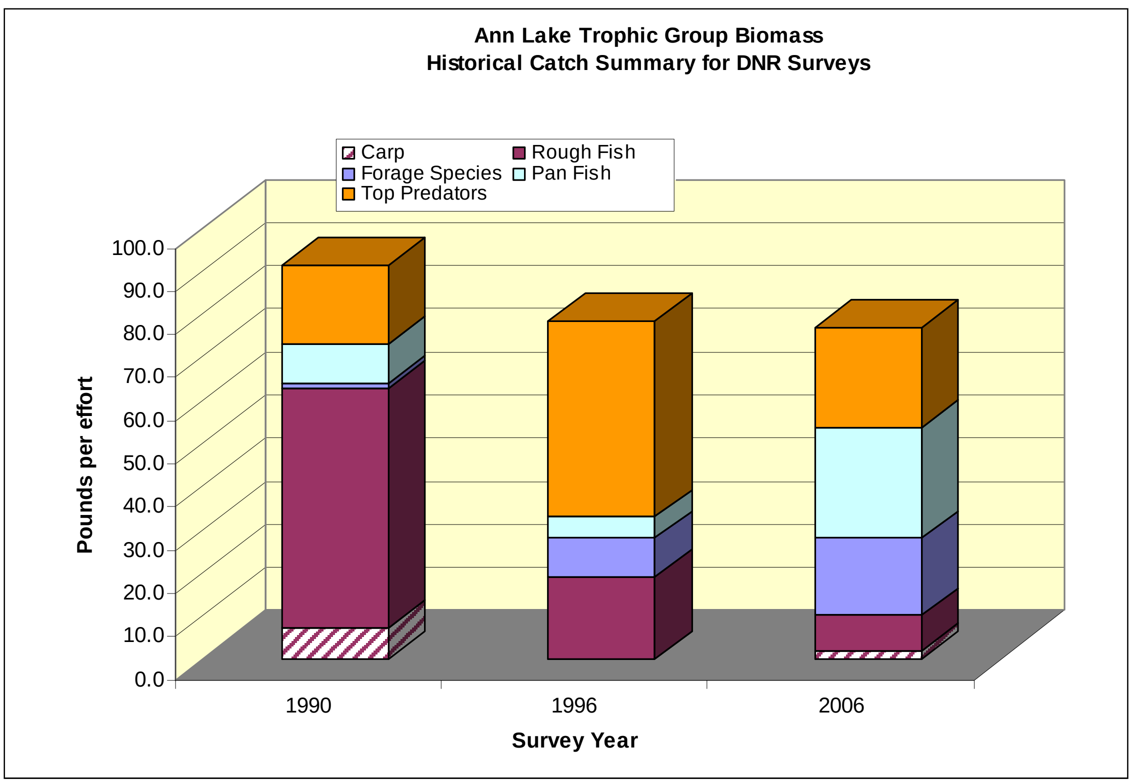


**Figure 2.15. Historical fish survey results for trophic group biomass in Ann Lake.**

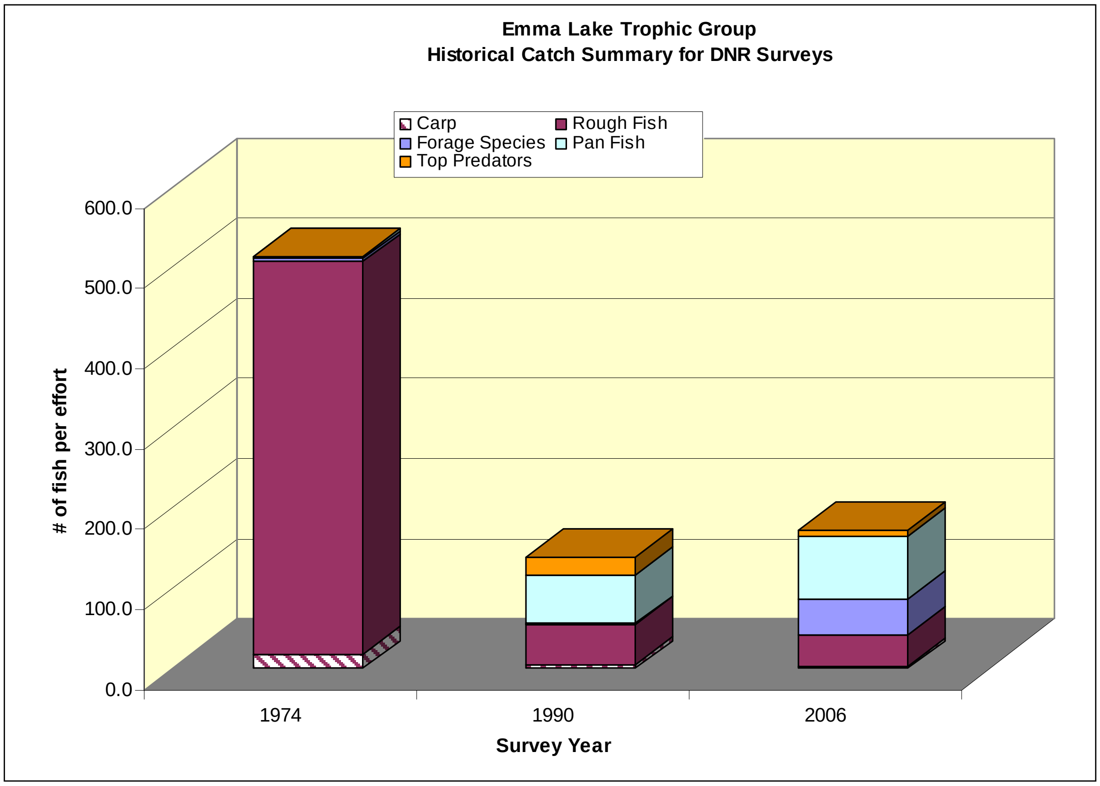


**Figure 2.16. Historical fish survey results for trophic group abundance in Emma Lake.**

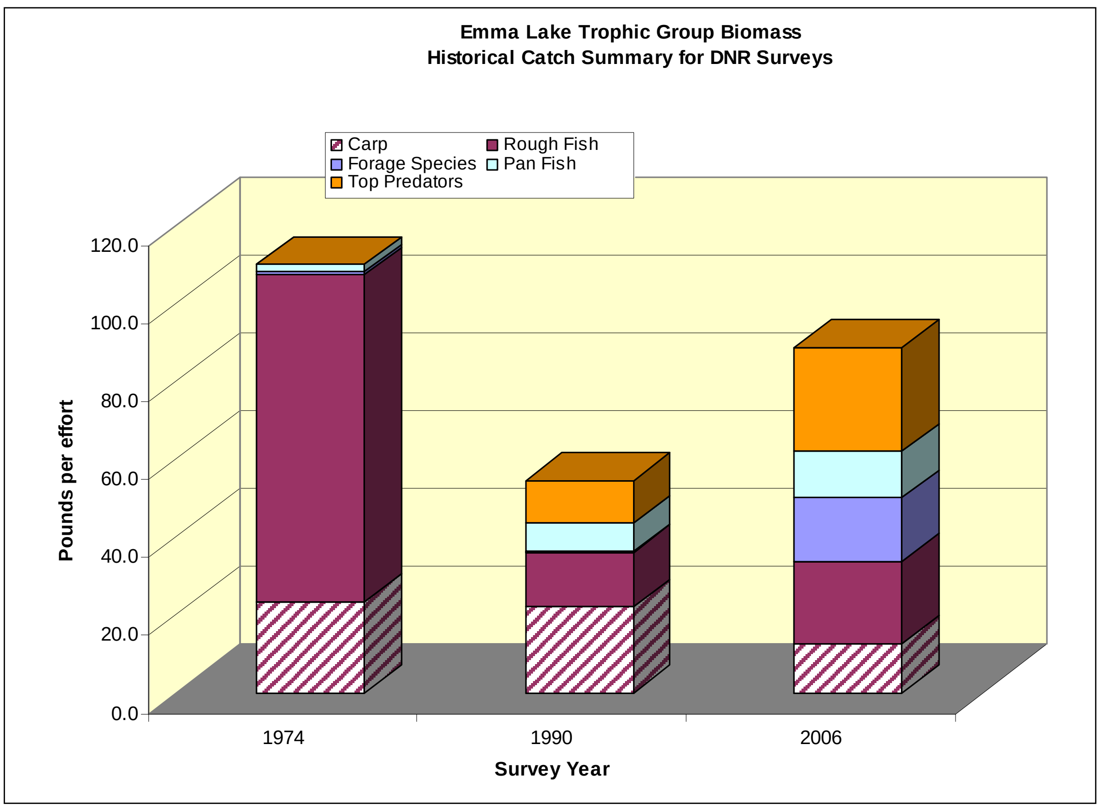


**Figure 2.17. Historical fish survey results for trophic group biomass in Emma Lake.**

## 2.6 AQUATIC PLANTS

### 2.6.1 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 high abundance and density they limit recreation activities, such as boating and swimming, and may reduce aesthetic value. Excess nutrients in lakes can lead to non-native, invasive aquatic plants taking over a lake. Some exotics can lead to special problems in lakes. For example, under the right conditions, Eurasian watermilfoil 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 within the aquatic plant community in any lake ecosystem.

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 warm water fishes (e.g. bass, walleye, and panfish). Ann Lake and Lake Emma are predominantly littoral and should support a healthy rooted aquatic plant community. The key is fostering a diverse population of rooted aquatic plants that is dominated by native (non-invasive) species.

### 2.6.2 Aquatic Plants in Ann Lake

Vegetation surveys for Ann and Emma Lake were performed by the DNR in conjunction with the fish surveys. Survey results indicate both lakes have a moderately diverse aquatic plant community with 5 and 12 different submerged species observed for Ann and Emma Lake, respectively across the three surveys (Figures 2.18 and 2.19).

The two most common native submerged plant species observed were Canada waterweed and sago pondweed for Ann Lake. Sago pondweed and horned pondweed were two of the most common species observed in Emma Lake. Coontail and narrowleaf pondweed are the other native submerged plant species observed in both lakes at varying densities over the years.

One of the submerged species noted in both Ann and Emma, curly leaf pond weed, is invasive and has been one of the more dominant species in these surveys since 1990. Curly-leaf pondweed is an invasive, like Eurasian watermilfoil, that can easily take over a lake’s aquatic macrophyte community. Curly-leaf pondweed presents a unique problem in that it is believed to significantly affect the in-lake availability of phosphorus, contributing to the eutrophication problem. Curly-leaf pondweed begins growing in late-fall, continues growing under the ice, and dies back relatively early in summer, releasing nutrients into the water column as it decomposes, possibly contributing to algal blooms. Curly-leaf pondweed can also out-compete more desirable native plant species. Curly-leaf has been noted in each Ann and Emma Lake DNR survey since 1990.

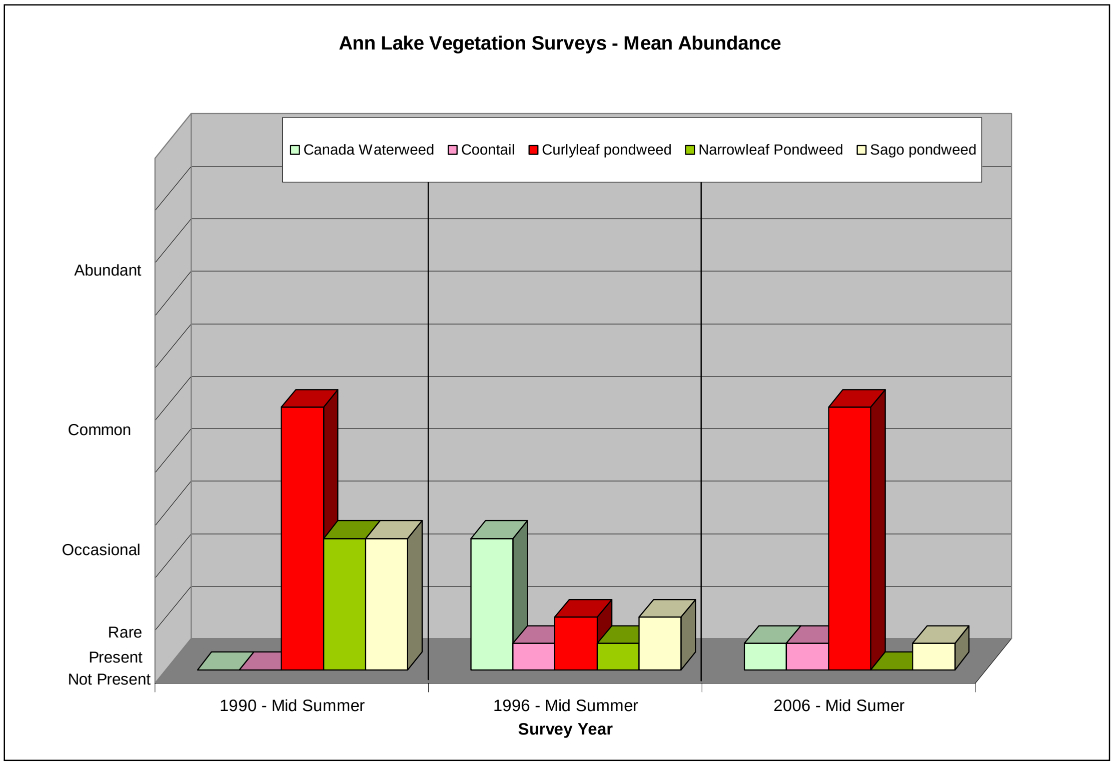


**Figure 2.18. Submerged vegetation survey data for Ann Lake.**

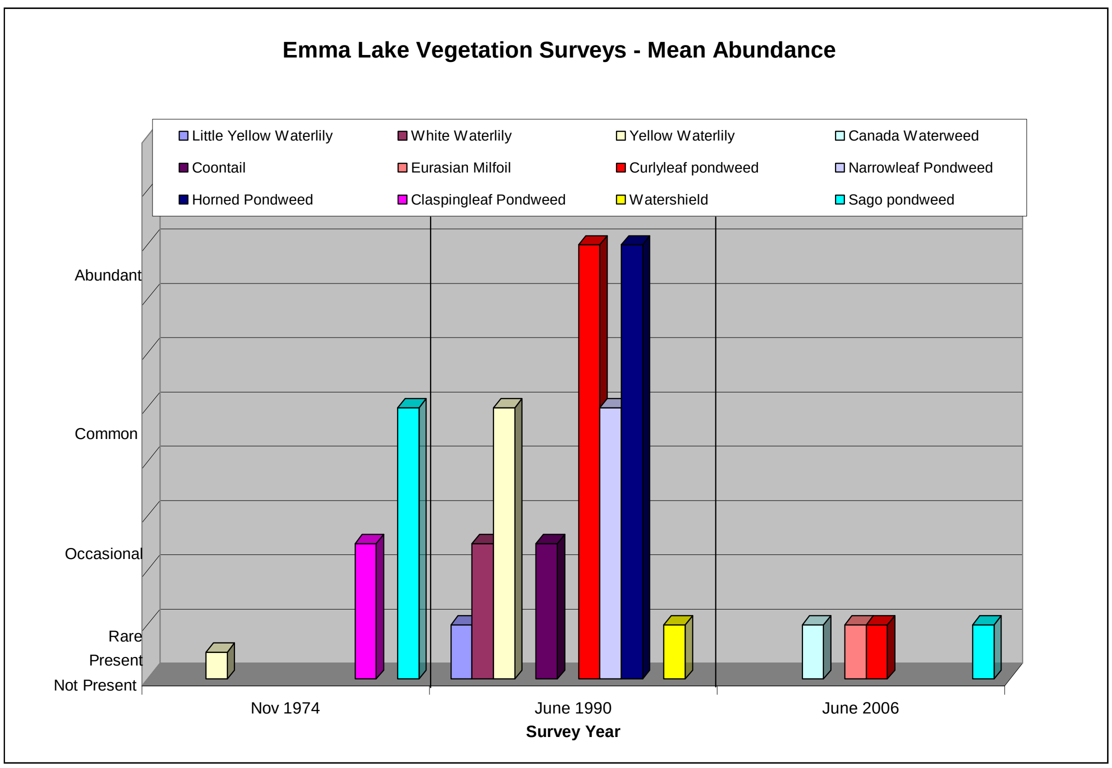


**Figure 2.19. Submerged vegetation survey data for Lake Emma.**

## 2.7 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. In addition to the ecological benefits, natural shorelines can stabilize sediments, and protect lake edges from wave-induced erosion. Natural shoreland exists around Ann Lake and Lake Emma; however, no quantitative data have been collected to date.

# 3.0 Nutrient Sources and Lake Response

## 3.1 INTRODUCTION

Understanding the sources of nutrients to a lake is a key component in developing an excess nutrient TMDL for lakes. To that end, a phosphorus budget that sets forth the current phosphorus load contributions from each potential source was developed using the modeling and collected data described below. Additionally, lake response models can be developed to understand how different lake variables respond to changes in nutrient loads.

## 3.2 MODELING APPROACH

Several models were used to develop the nutrient budget necessary to establish load and wasteload allocations.

### 3.2.1 Watershed Model

The first step in understanding nutrient loading to Ann Lake and Lake Emma is to develop an estimate of watershed water and nutrient loads. To that end, a Generalized Watershed Loading Function (GWLF) model was developed for the Ann Lake and Lake Emma watersheds. GWLF is a GIS-based continuous simulation model which uses daily weather data to calculate water balance and simulate runoff, sediment and nutrient loading (Evans et al. 2002). The GWLF model was calibrated to two years of intensive monitoring (2008 and 2009). For the purposes of this TMDL, monitoring data was used where available including 2008 and 2009. The GWLF model was used to predict runoff and nutrient loads for unmonitored areas and for years where no monitoring data was available. The model was also used to identify major source areas including animal agriculture, row crops, and developed areas.

#### 3.2.1.1 GWLF Calibration

The Ann-Emma watershed GWLF model was initially established using the following GIS layers: daily temperatures and rainfall, watershed boundary, ditch/stream network, 30 meter digital elevation model (DEM), Soil Survey Geographic (SSURGO) database and National Agricutural Statistics Service (NASS) land-use. These are the minimum GIS data layers needed to run GWLF. Watershed animal feedlot population and subsurface draintile GIS layers were incorporated into GWLF during the calibration process to further refine the model. All GIS layers were supplied or made available by the National Weather Service, Wright County, MPCA, Minnesota DNR, NRCS or the USDA.

The GWLF model was calibrated to observed monthly water yields first prior to analyzing water quality output. Initial model runs over-predicted storm peaks and under-predicted observed summer baseflow. To correct for this, model runoff curve numbers were lowered approximately

20% from their original value. This effectively lowered summer runoff peaks and increased baseflow to produce a well-calibrated hydrologic model (Figure 3.1).

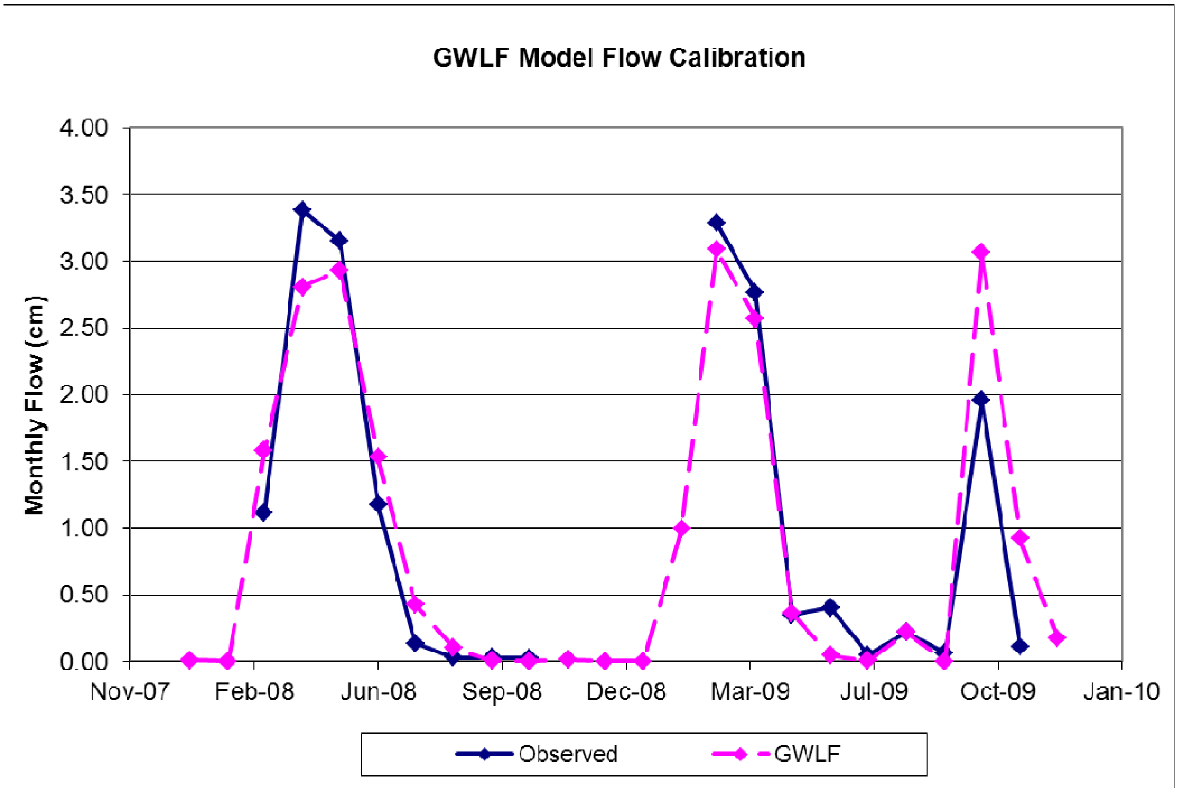


**Figure 3.1. GWLF predicted monthly runoff versus observed monthly runoff**

Once the model was calibrated for flow, monthly GWLF predicted total phosphorus loads were analyzed and compared to observed values. Initial model runs were significantly higher than the observed loads to Ann Lake. It was noted that in these early model runs predicted a significant proportion (well over 50%) of the TP load was particulate phosphorus (sediment) rather than dissolved. 2009 monitoring data suggests soluble phosphorus typically accounts for 75% or more of the total phosphorus fraction (see Figure 3.4). While total suspended solids were not measured in 2008 or 2009, transparency observations suggest watershed sediment loading to Ann Lake was likely low during the monitored period (see Figure 3.5). Thus, the model was likely over-predicting Ann-Emma watershed TSS loads which, in turn led to higher than observed phosphorus loads. To correct for this, model predicted sediment loss and delivery parameters were turned down to lower TSS loading to Ann Lake. Finally, the model's manure application routine was adjusted to better match observed monthly loading trends (Figure 3.2.). The following manure application assumptions were necessary to produce a well calibrated phosphorus model:

- 35% of manure (based on watershed animal populations) was applied February through March. Assumed application rates were 5% in February, 20% in March and 10% in April; remaining manure was assumed to be applied in the fall
- Manure loss/runoff rates is higher in March due to frozen ground and lower canopy cover
- There is little to no summer manure application

- Approximately 10% of manure is incorporated (model not sensitive to this parameter)

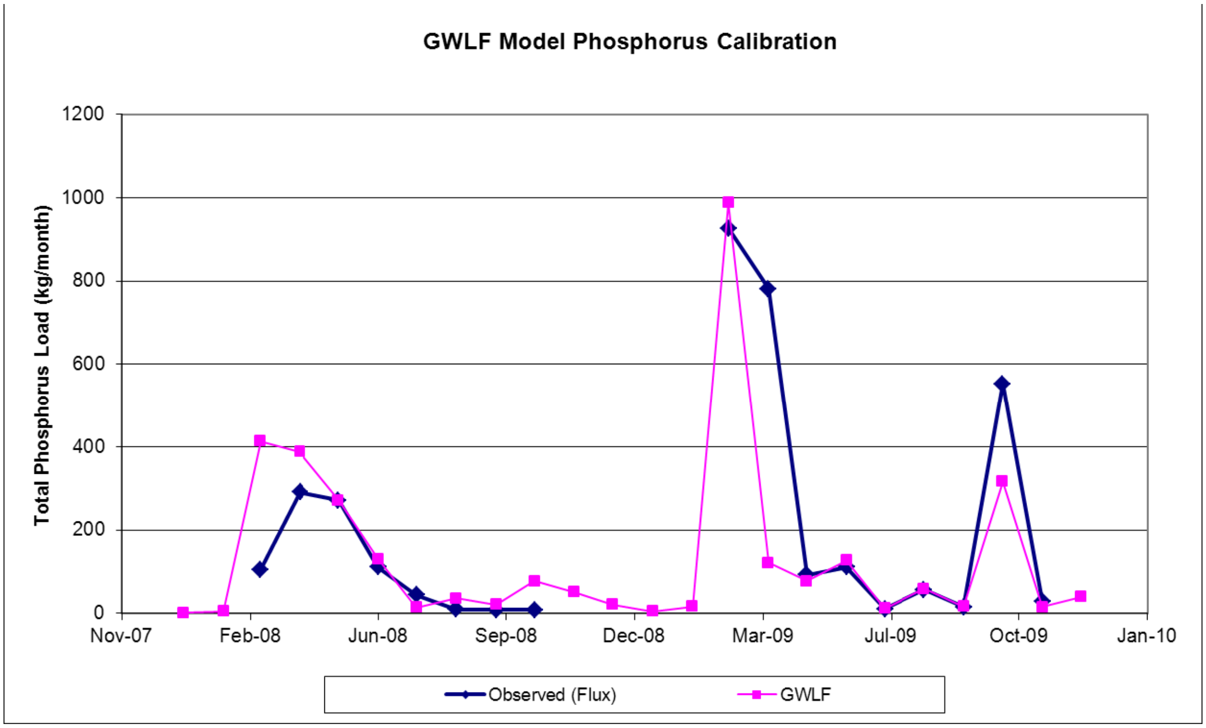


**Figure 3.2. GWLF predicted versus observed total phosphorus loading in the Ann Lake watershed.**

### 3.2.2 Internal Loading

The next step in developing an understanding of nutrient loading to Ann Lake and Lake Emma is to estimate internal nutrient loads. Internal phosphorus loading from lake sediments 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.

To estimate internal loading, an anoxic factor (Nürnberg 2004), which estimates the period where anoxic conditions exist over the sediments, is estimated from the dissolved oxygen profile data. The anoxic factor is expressed in days but is normalized over the area of the lake. The anoxic factor is then used along with a sediment release rate to estimate the total phosphorus load from the sediments. Phosphorus release rates were estimated by collecting sediment cores from each lake and incubating them in the lab under anoxic conditions (ACOE-ERD 2008; Appendix B).

### 3.2.3 Atmospheric Load

The atmospheric load refers to the load applied directly to the surface of the lake through atmospheric deposition. 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. These values are equivalent to 0.22, 0.24, and 0.26 pounds/acre-year for dry, average, and wet years in English units, respectively.

### 3.2.4 BATHTUB Model (Lake Response)

Once the nutrient budget for a lake has been developed, the response of the lake to those nutrient loads must be established. The focus of the lake response modeling is on total phosphorus, chlorophyll-a and Secchi depth. For this TMDL, the BATHTUB model was selected to link phosphorus loads with in-lake water quality. A publicly available model, BATHTUB was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). BATHTUB has been used successfully in many lake studies in Minnesota and throughout the United States. BATHTUB is a steady-state annual or seasonal model that predicts a lake's summer (June – September) mean surface water quality. BATHTUB's time-scales are appropriate because watershed P loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. BATHTUB has built-in statistical calculations that account for data variability and provide a means for estimating confidence in model predictions. The heart of BATHTUB is a mass-balance P model that accounts for water and P inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and (if appropriate) groundwater; and outputs through the lake outlet, groundwater (if appropriate), water loss via evaporation, and P sedimentation and retention in the lake sediments. BATHTUB allows choice among several different mass-balance P models. For deep lakes in Minnesota, the option of the Canfield-Bachmann lake formulation has proven to be appropriate in most cases. For shallow Minnesota lakes, other options such as a second order decay model have often been more useful. BATHTUB's in-lake water quality predictions include two response variables, chlorophyll-*a* concentration and Secchi depth, in addition to total phosphorus concentration. Empirical relationships between in-lake total phosphorus, chlorophyll-*a*, and Secchi depth form the basis for predicting the two response variables. Among the key empirical model parameters is the ratio of the inverse of Secchi depth (the inverse being proportional to the light extinction coefficient) to the chlorophyll-*a* concentration. The ratio's default value in the model is 0.025 meters squared per milligram ($m^2$/mg); however, the experience of Minnesota Pollution Control Agency staff supports a lower value, as low as 0.015 $m^2$/mg, as typical of Minnesota lakes in general.

A BATHTUB lake response model was constructed using the nutrient budget developed using the methods previously described in this section. Ten 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 "VS. CHLA & 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. No calibration factors were applied to the response models.

## 3.3 ESTIMATION OF SOURCE LOADS

### 3.3.1 Atmospheric Load

The atmospheric loads (pounds/year) for Ann Lake and Lake Emma were calculated by multiplying the lake area (acres) by the atmospheric deposition rate (pounds/acre-year). For example, in an average precipitation year the atmospheric load to Lake Ann would be 0.239 pounds/acre-year times the lake surface area (375 acres), which is 83.3 pounds/year. The watershed is small enough that it is unlikely that there are significant geographic differences in rainfall intensity and amounts across the watershed.

### 3.3.2 County Ditch #10 Phosphorus Loading

Total phosphorus loads for each County Ditch #10 sampling station (Figure 2.2) were estimated using the Flux32 Load Estimation Software supplied by the U.S. Army Corps of Engineers (Walker, 1999). Average daily flow data (see Section 2.4.2) for each station was used and winter data gaps were filled assuming a 0.38 cfs winter baseflow at the Ingram Avenue station. All 2008 and 2009 monitoring data was combined in to one data set and high/low flow total phosphorus measurements were separated to calculate weighted concentrations by flow regime (Table 3.1).

**Table 3.1. Stratification and statistical calculation methods used to calculate 2008-2009 phosphorus loads at each County Ditch 10 flow monitoring station.**

| Site | Flow Stratification | Calculation Method | Coefficient of Variation | 2008-2009 Mean TP Concentration (ug/L) |
|---|---|---|---|---|
| County Road 5 | 3 cfs | C/Q Reg1 | 0.2475 | 249 |
| Keats Ave | 3 cfs | C/Q Reg2 | 0.2084 | 248 |
| Ingram Ave | 5 cfs | Flow Weighted IJC | 0.2978 | 228 |

Annual load estimates suggest a significant portion (approximately 44%) of the CD #10 total phosphorus load to Ann/Emma Lake originates either in or above the Grass Lake wetland system (Table 3.2).

**Table 3.2. 2008 and 2009 total phosphorus loads (lbs/year) for each main-stem CD #10 sampling station. Loads were calculated using Flux 32 Load Estimation Software.**

| Year | County Rd 5: Grass Lake Outlet (S001-621) | Keats Avenue (S001-622) | Ingram Avenue: Ann Lake inlet (S003-460) |
|---|---|---|---|
| 2008 | 1,656 | 2,296 | 3,758 |
| 2009 | 1,701 | 2,296 | 3,831 |

#### 3.3.2.1 Grass Lake

Grass Lake is a large type 5 wetland complex located in the western portion of the watershed. Grass Lake receives drainage from approximately 8,455 acres of land representing 37% of the watershed. Grass Lake is infested with common carp and has been hydrologically altered to increase drainage from surrounding land. Grass Lake is a potential source of phosphorous to Ann Lake and Lake Emma.

Monitoring was conducted in 2008 and 2009 to evaluate the potential role of Grass Lake as a phosphorus source to Ann Lake and Lake Emma. Several monitoring sites were established upstream of the wetland complex as well as the outlet. Total phosphorus concentrations are higher at the outlet of Grass Lake than most of the upstream sampling sites suggesting that the wetland complex itself may be contributing some phosphorus to surface waters (Figure 3.3). It is also important to note that 44% of the load to Ann Lake comes through the Grass Lake wetland complex even though it only represents 37% of the drainage area.

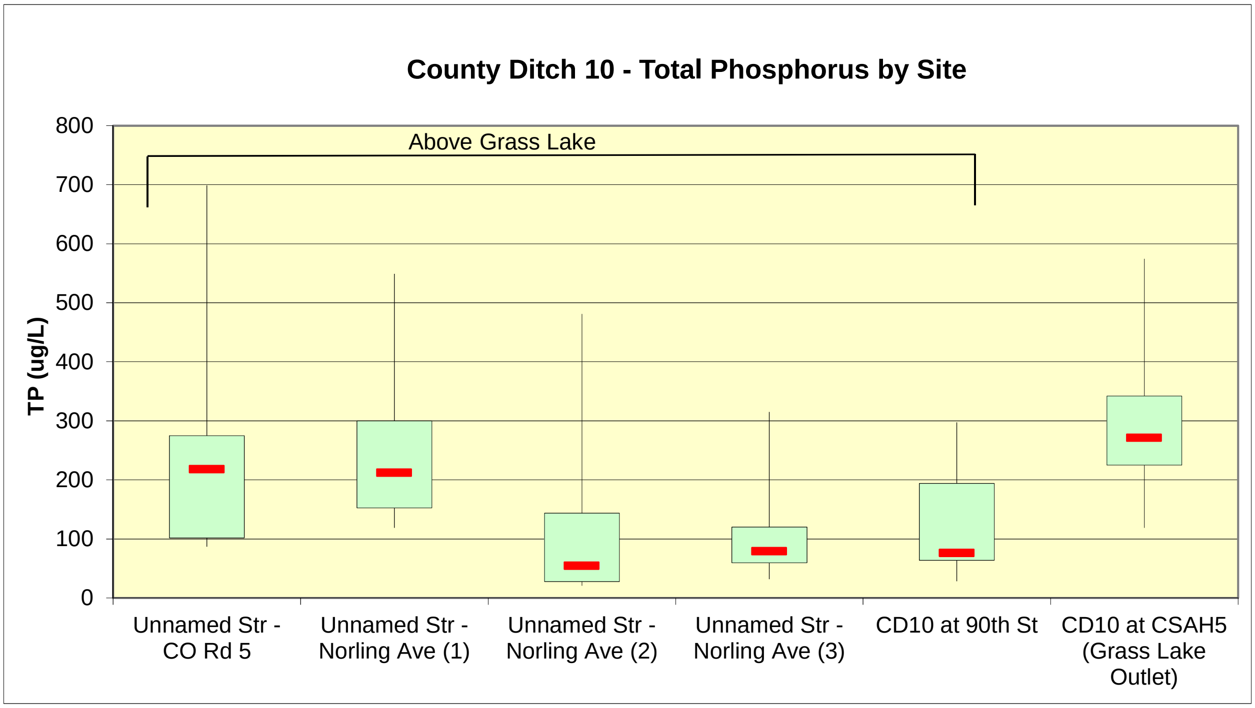


**Figure 3.3. Grass Lake watershed tributary monitoring station total phosphorus concentrations. The upper and lower edge of each box represent the 75$^{th}$ and 25$^{th}$ percentile of the data range for each site. Error bars above and below each box represent the 95$^{th}$ and 5$^{th}$ percentile of the dataset. The pink dash is the median TP concentration of all data collected.**

A basic mass balance was conducted for the Grass Lake wetland complex to further evaluate the role of the wetland in phosphorus loading to Ann Lake (Table 3.3). The mass balance demonstrates a significant increase in TP occurred at the wetland outlet in 2008 but was approximately the same as inflow in 2009. This analysis suggests that the Grass Lake wetland complex has the potential to add phosphorus to surface waters; however this does not occur in all years. Further evaluation of the wetland may be warranted. Inflow loading and concentrations to the wetland complex are high and need to be addressed prior to significant wetland restoration or enhancement efforts.

**Table 3.3. A simple mass balance for Grass Lake in 2008 and 2009.**

| | Monitored Grass Lake Inflow | | | Unmonitored Grass Lake Inflow | | | Grass lake Outflow | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Water Load | TP Conc. | TP Load | Water Load | TP Conc. | TP Load | Water Load | TP Conc. | TP Load | Difference |
| 2008 | 1,432 | 178 | 314 | 977 | 178 | 214 | 2,420 | 344 | 1,026 | 497 |
| 2009 | 1,441 | 252 | 449 | 983 | 252 | 306 | 2,435 | 249 | 748 | -7 |

More importantly, it appears that Grass Lake is acting as a transformer of phosphorus, transforming phosphorus from a particulate form to a soluble reactive form (Figure 3.4). Soluble reactive phosphorus is more problematic for algae growth because it is readily available for uptake whereas most particulate phosphorus is unavailable.

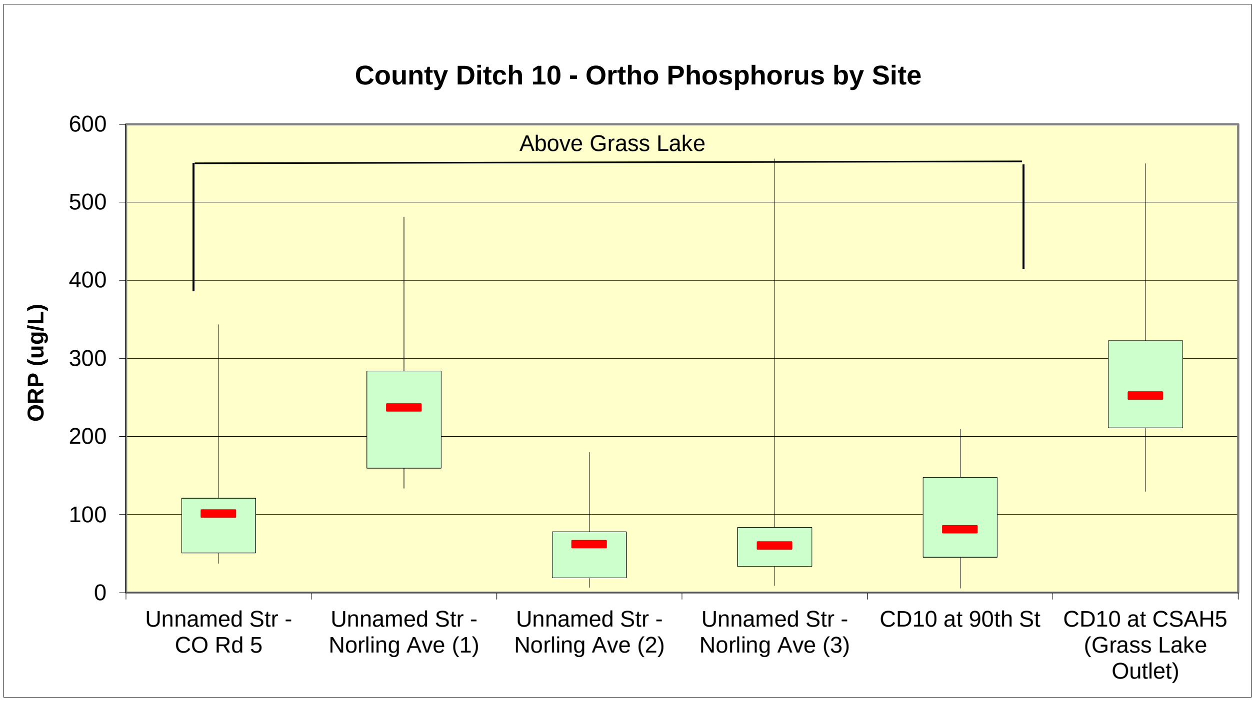


**Figure 3.4. Ann and Emma watershed tributary monitoring station ortho-reactive phosphorus concentrations. The upper and lower edge of each box represent the 75th and 25th percentile of the data range for each site. Error bars above and below each box represent the 95th and 5th percentile of the dataset. The pink dash is the median TP concentration of all data collected.**

### 3.3.2.2 Upstream Lakes

Besides Grass Lake, there are five other lakes located in the Ann-Emma watershed. Three of these lakes (Mary, Long and Spring) are located upstream of Ann and flow to County Ditch #10 while two (Round and Dog Lakes) are located upstream of Lake Emma and do not flow to Ann Lake. Mary Lake is the only lake with observed water quality data. Total phosphorus, chlorophyll a and Secchi readings for Mary are all well below state standards likely due to its higher volume to surface area and small watershed. Dog, Round, Spring and Long Lakes have not been monitored but, like Mary, have significantly smaller watersheds and are generally deeper than Ann and Emma. Lake water clarity estimates by the University of Minnesota based on satellite imagery suggest water clarity of these lakes is similar or slightly better than Ann and Emma (Table 3.4). Thus it was assumed upstream lakes in the Ann Lake and Lake Emma watershed are not a significant source of nutrients to either lake.

**Table 3.4. Satellite predicted water clarity for lakes in the Ann Lake and Lake Emma watersheds.**

| Lake Name | ID | Max Depth (ft) | Lake Clarity by Satellite Imagery (ft) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1985 | 1990 | 1995 | 2000 | 2005 |
| Ann | 86-0190 | 19 | 1.5-3.0 | 3.0-6.0 | 3.0-6.0 | 3.0-6.0 | 1.5-3.0 |
| Emma | 86-0188 | 16 | <1.5 | 3.0-6.0 | 1.5-3.0 | 1.5-3.0 | 3.0-6.0 |
| Mary | 86-0193 | 47 | 3.0-6.0 | 3.0-6.0 | 3.0-6.0 | 3.0-6.0 | 3.0-6.0 |
| Dog | 86-0178 | 25 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 |
| Round | 86-0192 | 28 | 1.5-3.0 | 1.5-3.0 | <1.5 | 1.5-3.0 | 1.5-3.0 |
| Spring | 86-0200 | No data | 1.5-3.0 | 6-12 | 3.0-6.0 | <1.5 | <1.5 |
| Long | 86-0194 | No data | 3.0-6.0 | 3.0-6.0 | 1.5-3.0 | 3.0-6.0 | 1.5-3.0 |
| Grass | 86-0257 | No data | No data | No data | No data | No data | No data |

### 3.3.2.3 Agriculture

The predominant land use in the Ann Lake and Lake Emma watersheds is row crops (corn/soybean rotation) followed by pasture land. Phosphorus applied as fertilizer to row crops can be lost to surface waters causing eutrophication. Loss from row crops is often associated with soil loss because phosphorus tends to adhere to soil particles. Consequently, if significant soil loss from row crops is a total phosphorus source to surface waters, total suspended solids (TSS) are expected to demonstrate high concentrations as well.

TSS data are not available for the Ann Lake and Lake Emma watersheds, although some water clarity data is available. Water clarity data can be used as an indicator of TSS because water clarity decreases with increases in TSS. In stream water clarity in the Ann Lake and Lake Emma watersheds is relatively good (<20 cm) even under high flow conditions where soil loss would be expected to occur (Figure 3.5). A few samples are high suggesting some soil loss may be occurring; however it does not appear to be a dominant source of TP in surface waters. Furthermore, the soil loss potential as assessed by combining slope and soil characteristics is only moderate in the watershed (Figure 3.6). As such, soil loss from row crops are not considered a primary phosphorus source to Ann Lake and Lake Emma. The high proportion of dissolved phosphorus (75%) in stream monitoring data is further evidence that soil loss is not a primary TP source.

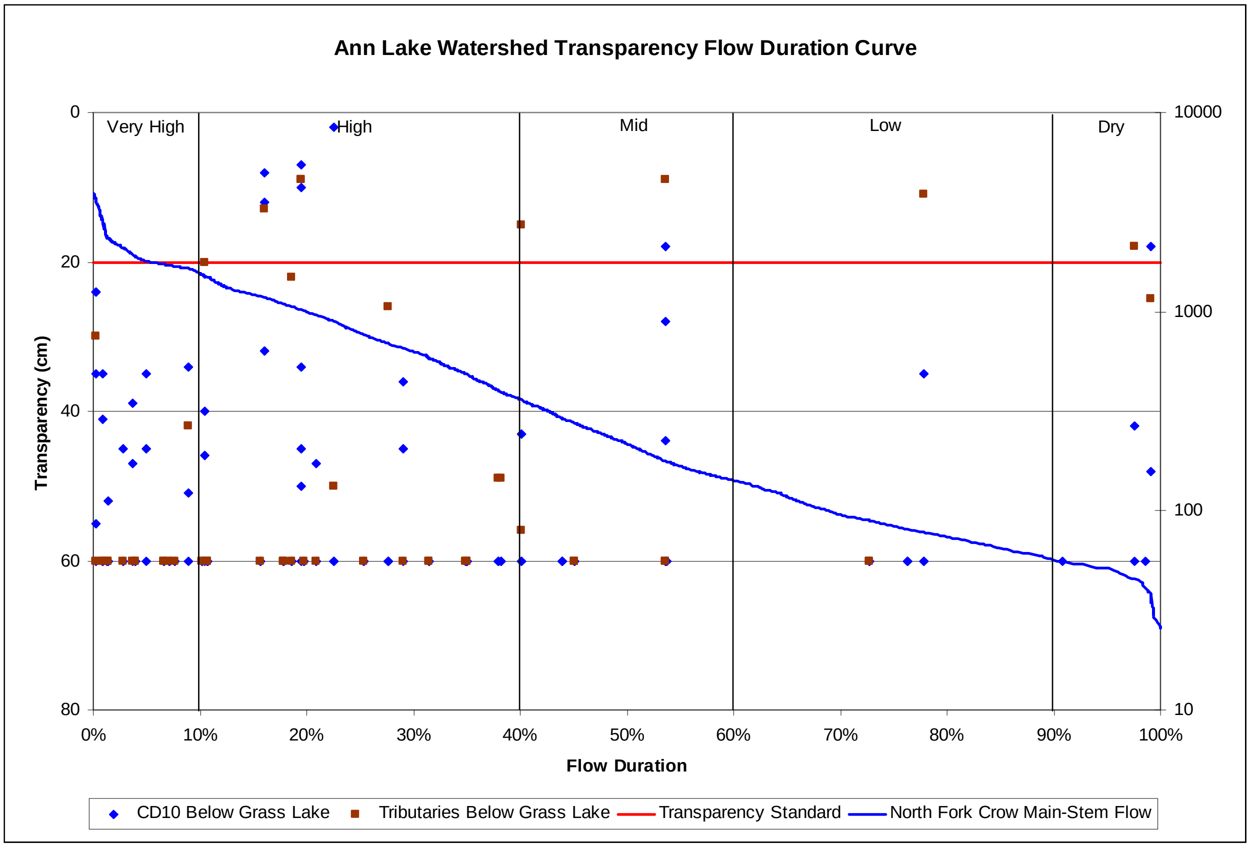

**Figure 3.5. Water clarity as measured by turbidity tube (cm) in the Ann Lake watershed.**

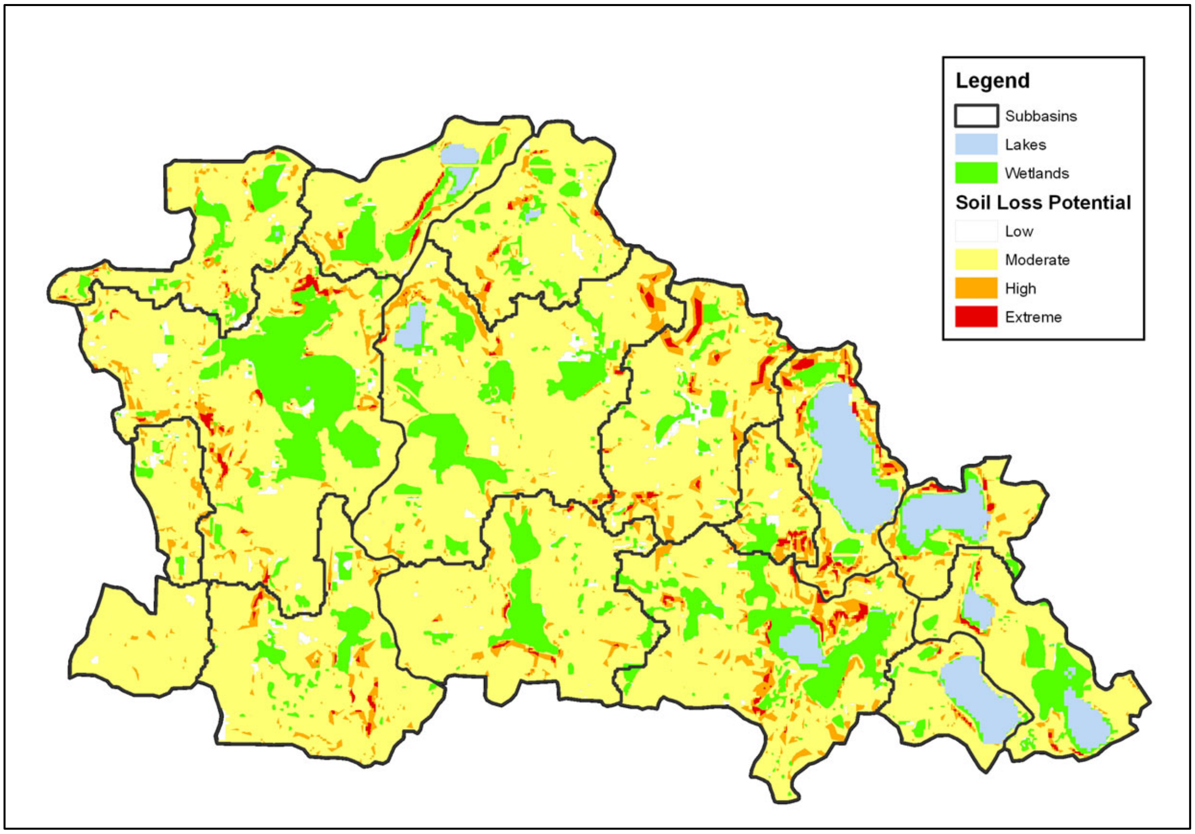


**Figure 3.6. Soil loss potential in the Ann Lake and Lake Emma watersheds.**

Although soil loss does not appear to be a primary TP source, row crops may still play a role in nutrient delivery to surface waters. Many of the crops and pastures receive manure for fertilizer which may be lost to surface waters in both a particulate and dissolved form. Animal agriculture is further explored in the following section.

### 3.3.2.4 Animal Agriculture

Animal agriculture is a prominent use in the Ann Lake and Lake Emma watersheds. Manure produced by the animals in the watershed is applied to fields and pastures for fertilizer as well as general manure management. Manure that is applied beyond the nutrient uptake ability of the fields moves easily into surface waters adding to eutrophication and nutrient loads.

To assess the role of manure management on surface water nutrient concentrations and loads, an inventory of all the animals in the watershed was conducted. The MPCA maintains a statewide database of Confined Animal Feeding Operations (CAFO; greater than 1,000 animals) and registered feedlots (greater than 300 animals). These data are then linked in GIS to evaluate the spatial distribution of animals in the watershed (Figure 3.7).

Owners of an animal feedlot or manure storage area with 50 or more animal units are required to register with the MPCA. Owners with fewer than 300 animal units are not required to have a permit for the construction of a new facility or expansion of an existing facility as long as construction is in accordance with the technical standards. For owners with 300 animal units or more, and less than 1,000 animal units, a streamlined short-form permit is required for construction/expansion activities.  Feedlots greater than 1,000 animal units are considered large confined animal feedlot operations (CAFOs) and, by state law, are required to apply for a National Pollutant Discharge Elimination System (NPDES) or State Disposal System (SDS) permit.  These operations, by law, are not allowed to discharge to waters of the state (Minn R. 7020.2003).

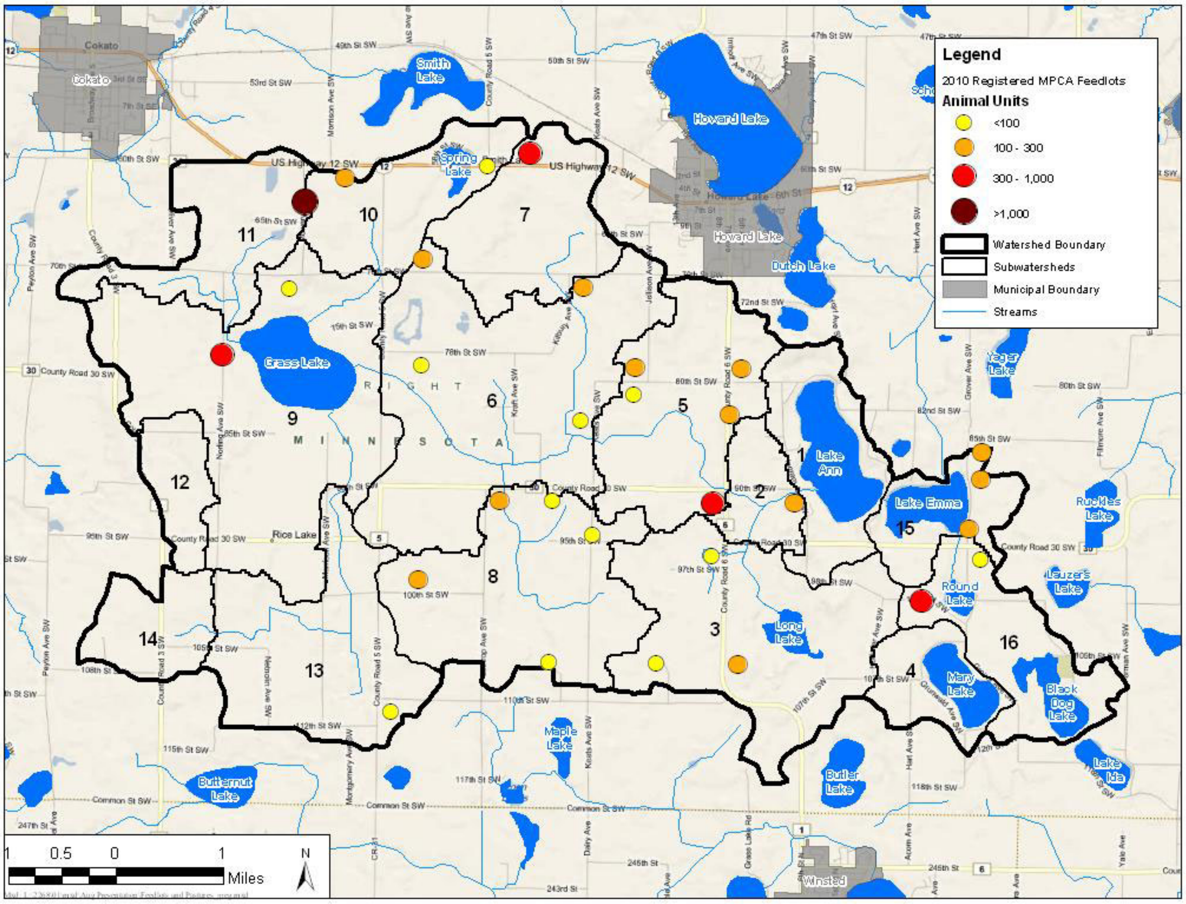

**Figure 3.7. Animal units in the Ann Lake and Lake Emma watersheds based on the 2010 MPCA database.**

There are over 6,000 animal units currently in the Ann Lake and Lake Emma watershed including predominantly dairy and beef cows, chickens, and turkeys (Table 3.5).  Much of the manure is land applied and may become available for delivery to surface waters.  The total mass of phosphorus produced by each animal unit category can be estimated using literature values (GWLF Users' Manual 1992).  Based on these estimates, over 681,000 pounds of phosphorus are produced in the watershed while almost 340,000 pounds of phosphorus are applied to land in the watershed in the form of manure.  It was determined that the one large feedlot that houses chickens applies the majority of their manure outside of the watershed (Wright County Feedlot Officer, pers. comm.) and that of the 347,625 pounds of phosphorus produced, only 6,120 pounds are actually applied in the watershed.  To put this in perspective, loading to Ann Lake is typically around 3,800 pounds or less than 1% of the phosphorus applied to the land.  Only a small proportion of this phosphorus need make its way into Ann Lake to cause serious eutrophication issues. Furthermore, much of the phosphorus loading in the watershed is in a dissolved form, further indicating that manure is a primary contributing source of phosphorus to surface waters in the Ann Lake and Lake Emma watersheds.

**Table 3.5. Animal units and phosphorus in manure in the Ann Lake and Lake Emma watershed.**

| Animal Type | Animal Units | TP Produced per Animal Unit (lbs/day) | Daily TP Production (lbs/day) | Annual TP Production (lbs/year) | Annual TP Applied (lbs/year) |
|---|---|---|---|---|---|
| Dairy Cows | 2,583 | 0.15 | 399 | 145,490 | 145,490 |
| Beef Cows | 1,540 | 0.20 | 306 | 111,544 | 111,544 |
| Swine | 17 | 0.33 | 6 | 2,064 | 2,064 |
| Horses | 14 | 0.13 | 2 | 676 | 676 |
| Sheep | 2 | 0.22 | <1 | 121 | 121 |
| Chickens | 1,440 | 0.66 | 952 | 347,625 | 6,120 |
| Turkeys | 457 | 0.44 | 201 | 73,532 | 73,532 |
| Totals | 6,053 | | 1,866 | 681,052 | 339,547 |

[1]Total animal units are calculated based on dividing total animal weight by 1,000 lbs

The timing and location of animal manure spreading can also play a role in the delivery of nutrients to surface waters. If manure is spread too early in the spring without incorporation, manure can easily wash into surface waters with snow melt events or spring storms. If manure is applied too close to the streams or over tile intakes, nutrients from manure can get directly into surface waters. The following assumptions were used in assessing manure application in the watershed:

- 35% applied in February through March
    - 5% in February
    - 20% in March
    - 10% in April
- Little to no summer application
- Remaining manure is applied in the fall

Figure 3.8 shows nutrient concentrations in County Ditch 10, the main tributary to Ann Lake, by month. Concentrations in March, when soils are likely still frozen, are very high suggesting that early application of manure may be contributing phosphorus to surface waters. The relatively high summer concentrations suggest that pastures and animal access to streams may be contributing phosphorus to streams because manure is not applied to corn/soybean rotations in the summer. Overall, manure appears to be the primary phosphorus source to Ann Lake.

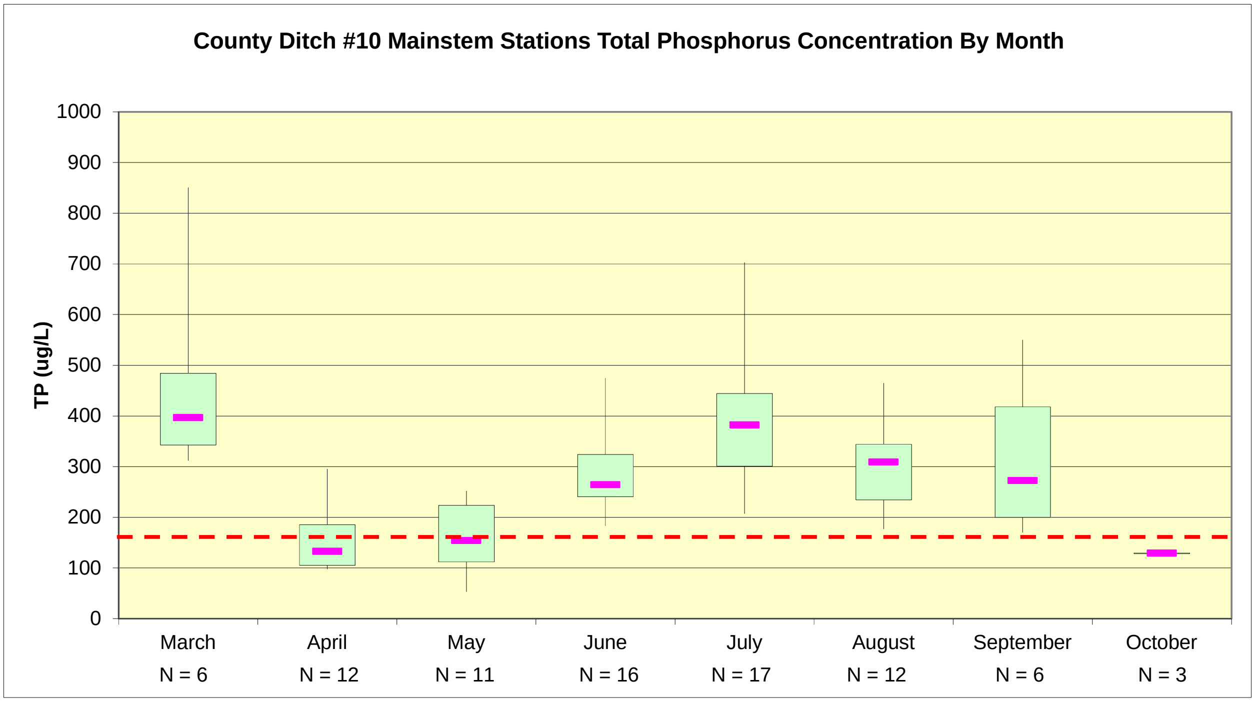


**Figure 3.8. County Ditch #10 main-stem monitoring station total phosphorus concentrations by month. The upper and lower edge of each box represent the 75$^{th}$ and 25$^{th}$ percentile of the data range for each month. Error bars above and below each box represent the 95$^{th}$ and 5$^{th}$ percentile of the monthly dataset. The pink dash is the median TP concentration of all data collected in each month. The dotted red line represents the upper end of the typical annual TP concentration for North Central Hardwood Forest ecoregion streams (170 µg/L).**

### 3.3.3 Septic Systems

There are currently no data available as to the exact number of septic systems in the Ann-Emma watershed. It is assumed the entire watershed uses subsurface septic systems (SSTS) for human waste storage as there are no municipal wastewater treatment facilities located within the watershed. 2000 Census data suggest there are approximately 363 residents in the Ann-Emma watershed. This would equate to approximately 130 SSTS for the watershed assuming there are, on average, 2.8 people per household. If all the systems were failing, phosphorus loading from septic systems would represent less that 10% of the lake phosphorus budgets. However, it is unlikely that all of the systems are failing. The most likely scenario where less than 20% of the systems are failing resulted in a phosphorus load (71 pounds) of approximately 1% of the overall load to Ann Lake and Lake Emma.

### 3.3.4 Internal Phosphorus Loading

Both Ann and Emma demonstrate some anoxia over the bottom sediments throughout the summer with peak anoxic areas occurring in mid to late summer. As discussed previously, anoxic conditions in lakes are often expressed as the number of days anoxia occurs over the entire lake or basin; this term is referred to as the anoxic factor. The anoxic factor was 12/18 days for Ann Lake and 14/23 days for Emma Lake in 2008 and 2009, respectively.

Once anoxia is quantified, the next step is to identify the rate at which sediments release phosphorus under anoxic conditions. The measured rate of phosphorus release from anoxic sediments are 5.2 and 9.1 mg/m$^2$/day for Ann and Emma, respectively. This rate can then be used to estimate the gross internal loading based on the anoxic factor for the lake (Nürnburg 2004). The estimated gross loads for Ann and Emma are presented in Table 3.6 and were used in the lake response model to estimate the role of internal loading on current lake water quality.

**Table 3.6. Anoxic factors and release rates for Ann Lake and Lake Emma.**

| Lake | Year | Release Rate (mg/m$^2$/day) | Anoxic Factor (days) | Gross Load (kg) | Gross Load (lbs) |
|---|---|---|---|---|---|
| Ann | 2008[1] | 5.2 | 12 | 94 | 207 |
| | 2009[1] | 5.2 | 18 | 140 | 309 |
| | Average | 5.2 | 31 | 247 | 543 |
| | Oxic | 4.7 | 122 | 878 | 1,935 |
| Emma | 2008 | 9.1 | 14 | 97 | 214 |
| | 2009 | 9.1 | 23 | 157 | 346 |
| | Average | 9.1 | 18.5 | 159 | 351 |
| | Oxic | 1.3 | 122 | 121 | 266 |

[1]Based on incomplete data for the summer season.

The anoxic factors for Ann Lake ranged from 18 in 2009 to 36 in 2002 even though 2002 was an incomplete data set. Calculation of an anoxic factor for shallow lakes (Nürnburg 2004) estimates an anoxic factor of 62. For this model, an anoxic factor of 36 was selected as an average for Ann Lake based on model fit. It was also assumed that both Ann Lake and Lake Emma release phosphorus at a rate of 4.7 and 1.3 mg/m$^2$/day respectively under oxic conditions for the entire summer (122 days). These numbers were selected based on model performance and professional experience.

## 3.4 LINKING WATER QUALITY TARGETS AND SOURCES

The final step in understanding lake response to nutrient loads is to link the previously described nutrient budgets to lake water quality. This step is accomplished through the use of lake response models previously described in Section 3.2.5. The lake response model was applied using default model values and the water and nutrient budgets previously described in this section. Physical lake attributes such as volume, average depth, and surface area were derived from GIS and Minnesota DNR contour maps. All model inputs are detailed in Appendix C.

## 3.5 FIT OF THE LAKE RESPONSE MODEL

Figures 3.9 and 3.10 present the results of the total phosphorus lake response model for Ann Lake and Lake Emma respectively. Four years were modeled for Ann Lake and all years were predicted within 15% of the monitored values. Two years were modeled for Lake Emma and both years were within 15% of monitored values. No calibration factors were applied for the lake response models. Lake response models were considered reasonably calibrated for total phosphorus.

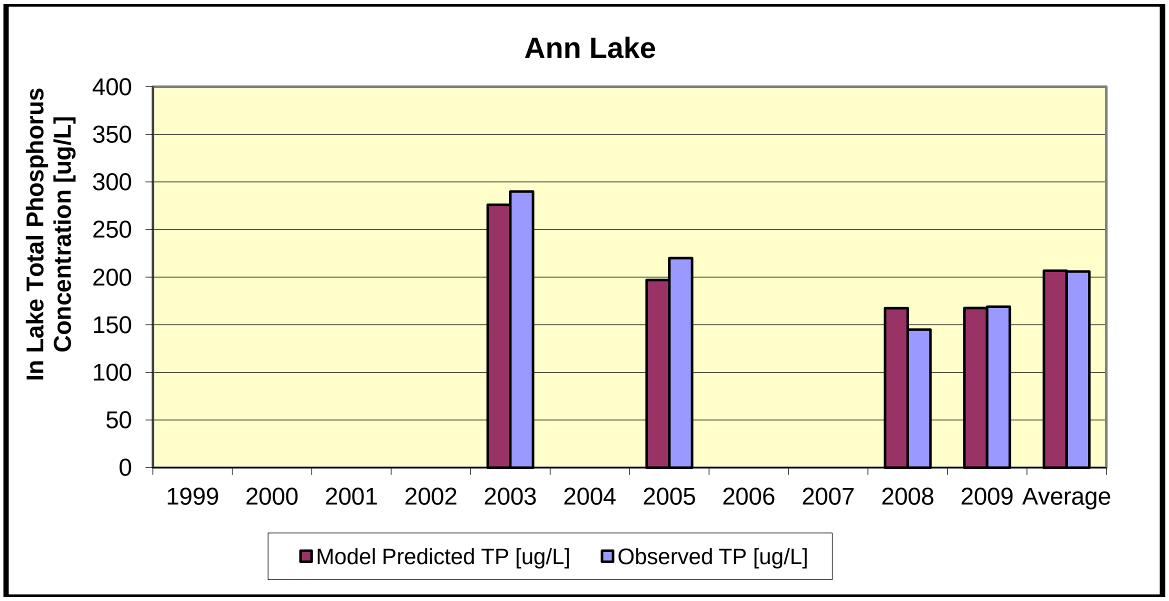


**Figure 3.9. Model predicted and observed total phosphorus concentrations in Ann Lake. To set the TMDL, the average of 2003, 2005 , 2008 and 2009 was used.**

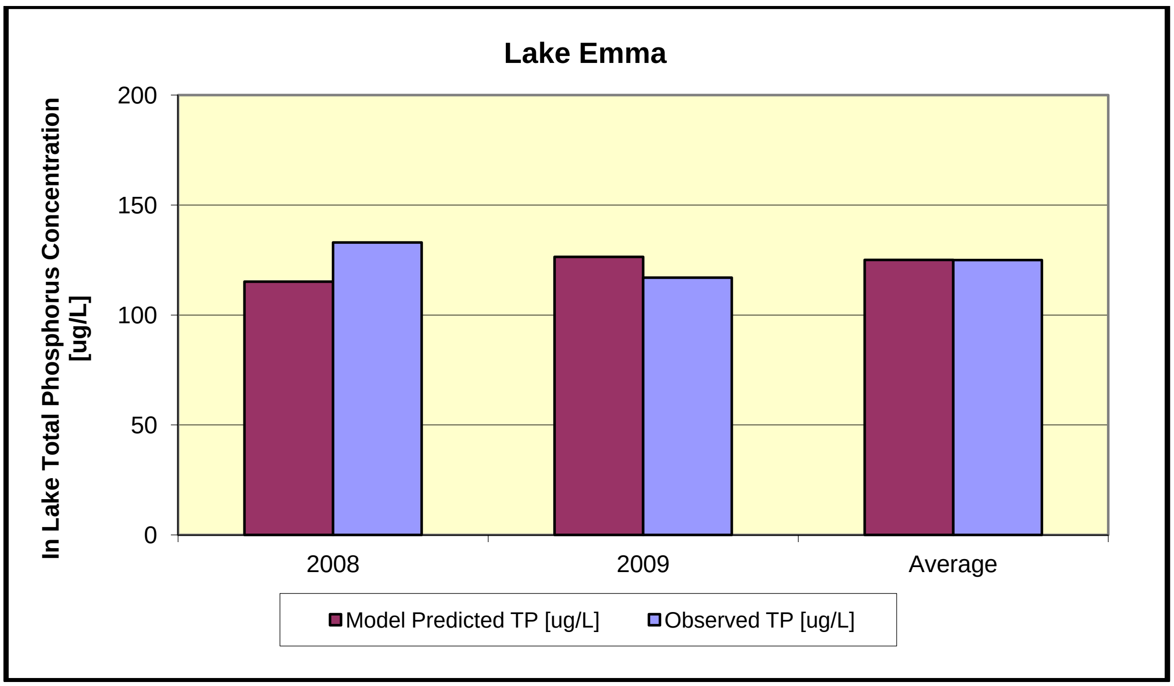


**Figure 3.10. Model predicted and observed total phosphorus concentrations in Lake Emma. To set the TMDL, the average of 2008 and 2009 was used.**

The chlorophyll-a response model performed reasonably well, predicting chlorophyll-a concentrations typically within 15% of the measured values in both Ann Lake and Lake Emma (Figures 3.11 and 3.12). No calibration factors were applied for the chlorophyll-a lake response models. Lake response models were considered reasonably calibrated for chlorophyll-a.

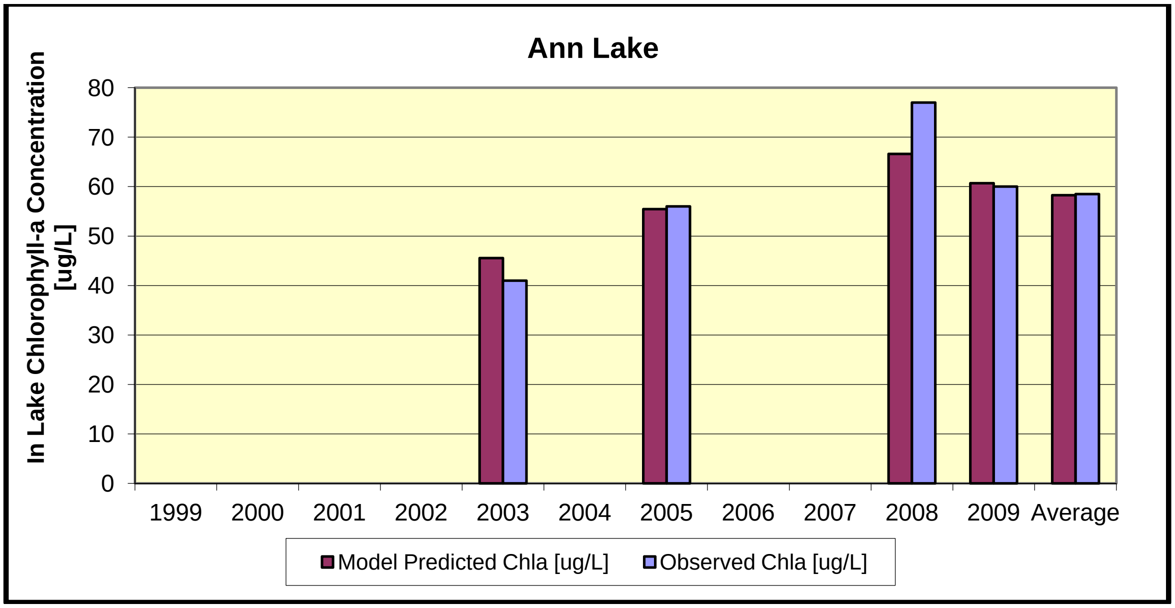


**Figure 3.11. Model predicted and observed chlorophyll-a concentrations in Ann Lake. To set the TMDL, the average of 2003, 2005 , 2008 and 2009 was used.**

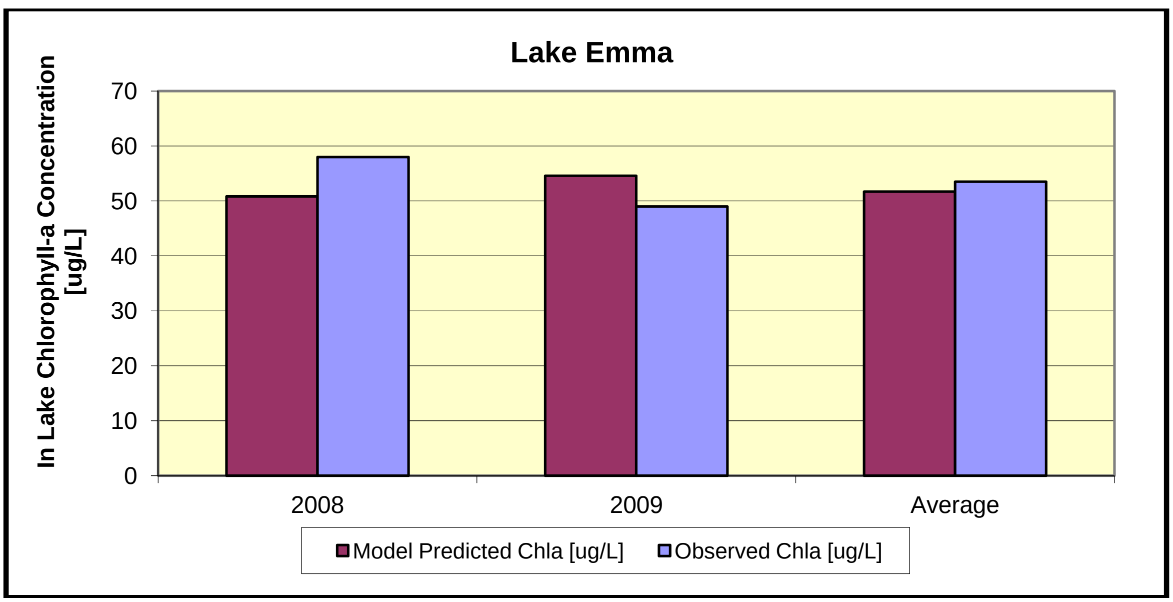


**Figure 3.12. Model predicted and observed chlorophyll-a concentrations in Lake Emma. To set the TMDL, the average of 2008 and 2009 was used.**

The Secchi disk transparency response model also performed reasonably well, predicting values typically within 5% of the measured values in both Ann Lake and Lake Emma (Figures 3.13 and 3.14). No calibration factors were applied for the Secchi depth lake response models. Lake response models were considered reasonably calibrated for Secchi depth.

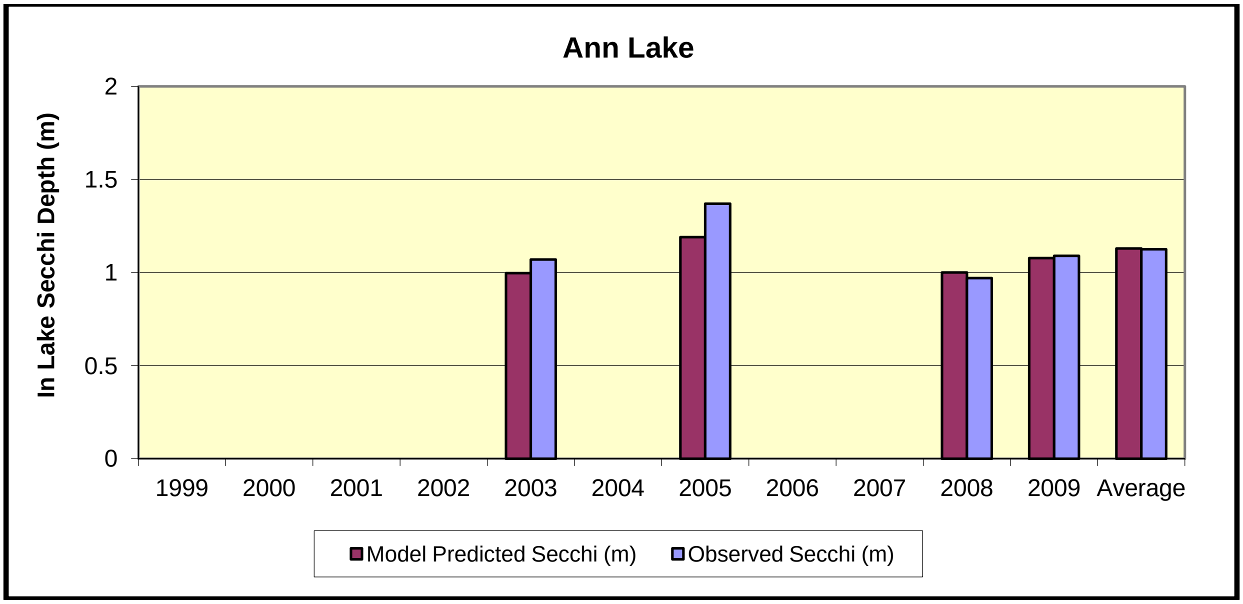


**Figure 3.13. Model predicted and observed Secchi disk transparency in Ann Lake. To set the TMDL, the average of 2003, 2005 , 2008 and 2009 was used.**

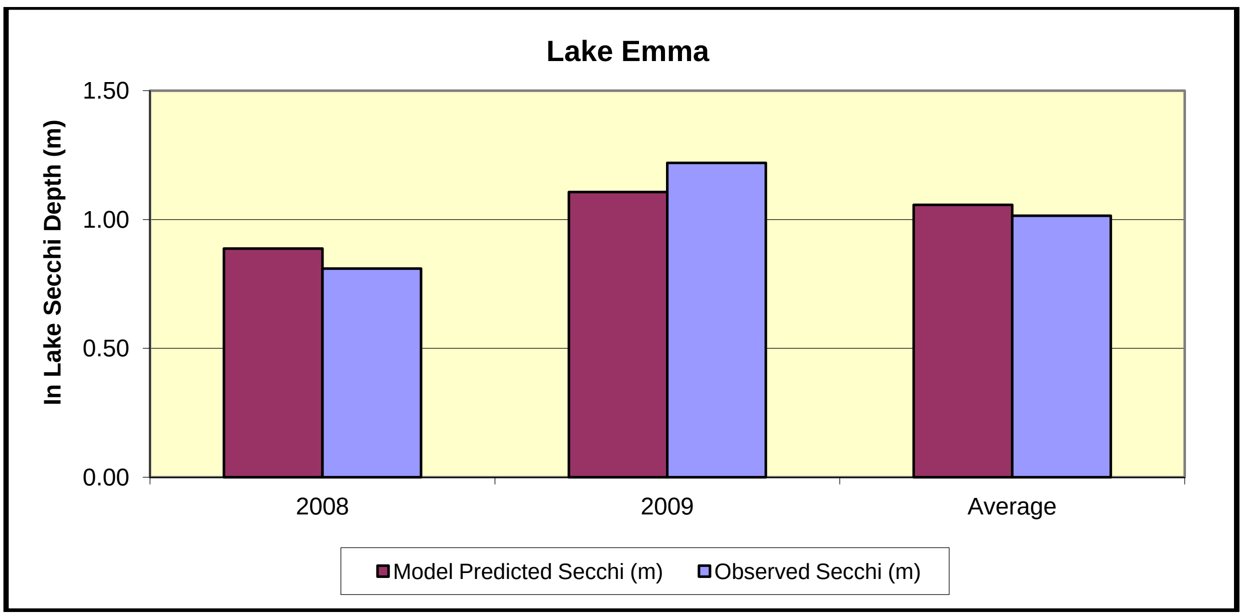


**Figure 3.14. Model predicted and observed Secchi disk transparency in Lake Emma. To set the TMDL, the average of 2008 and 2009 was used.**

Each of the previous three figures also includes an average response for Ann Lake and Lake Emma. The average for Ann Lake is for 2003, 2005, 2008, and 2009 and the average for Lake Emma is for 2008 and 2009. The average year models are simply the average of the nutrient and water budgets over that period of time. The average periods and associated lake response was used to develop the TMDL allocations described in the next section.

# 4.0 TMDL Allocation

## 4.1 TOTAL MAXIMUM DAILY LOAD CALCULATIONS

The numerical TMDL for Ann Lake and Lake Emma 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. However, both the chlorophyll-a and Secchi response were predicted to determine if nutrient reductions would result in meeting all three state standards. This TMDL is written to solve the TMDL equation for a numeric target of 60 µg/L of total phosphorus as a summer growing season average.

### 4.1.1 Total Loading Capacity

The first step in developing an excess nutrient TMDL for lakes is to determine the total nutrient loading capacity for the lake. To determine the total loading capacity, the current nutrient budget and the lake response modeling (average of 2003,2005, 2008, 2009 for Ann Lake and 2008 and 2009 for Lake Emma) presented in Section 3 were used as the starting point. The nutrient inputs were then systematically reduced until the model predicted that the lakes met the current total phosphorus standard of 60 µg/L as a growing season mean. The reductions were applied first to the internal load and then the watershed sources. Once the total phosphorus goal is met, both the chlorophyll-a and Secchi response models are reviewed to ensure that the two response variables are predicted to meet the state standards as well. Further details of how this was applied are included in the following sections.

### 4.1.2 Load Allocations

The Load Allocation includes all non-permitted sources including stormwater runoff not covered by a state or federal permit, atmospheric deposition and internal loading. These sources include agricultural runoff, degraded wetlands, internal nutrient loads and atmospheric loading. No changes were expected for atmospheric deposition because this source is impossible to control.

One of the first steps in determining the allowable phosphorus loads to the lakes is setting the appropriate internal load release rate. Measured release rates in Ann Lake and Lake Emma (anoxic release of 5.2 and 9.1 mg/m$^2$/day respectively) were compared to expected release rates for mesotrophic lakes (Figure 4.1; Nurnberg 1997). Mesotrophic lakes demonstrate internal phosphorus release rates ranging from 0 to 12 mg/m$^2$/day with a median release rate around 4 mg/m$^2$/day. Although the median is 4 mg/m$^2$/day, there is a broad range of internal loads in mesotrophic lakes which makes selecting an appropriate number difficult. Furthermore, the majority of lakes in this database are deep lakes whereas Ann Lake and Lake Emma are shallow lakes. Anoxic release rates in Oneka Lake, a shallow, submerged aquatic vegetation dominated lake, were below detection (Oneka is the only healthy shallow lake with release measurements in the area). Therefore, as a conservative approach, an allowed anoxic internal release rate of 0.5 mg/m$^2$/day was selected for Ann Lake. Because water quality in Lake Emma is mostly controlled by Ann Lake inputs, a more conservative allowed release rate of 1.4 mg/m$^2$/day was selected.

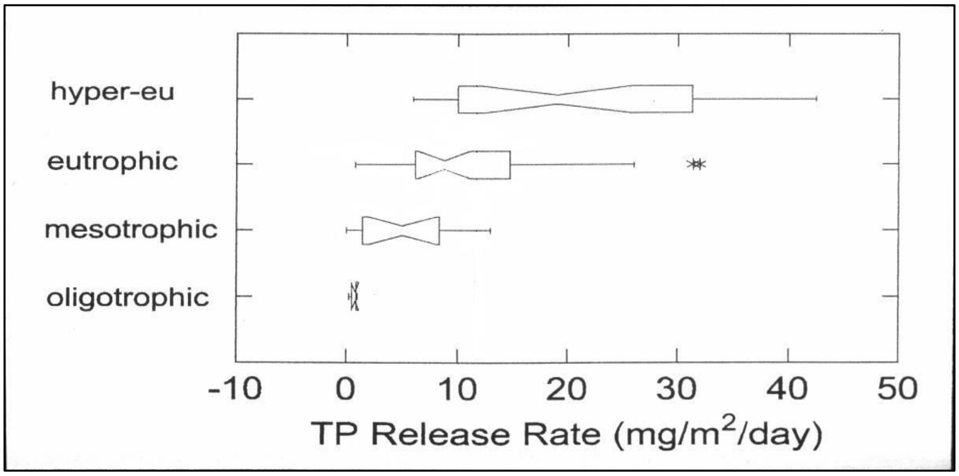


**Figure 4.1. Sediment phosphorus release rates by eutrophic condition. (Nürnberg 1997**).

Oxic release of phosphorus was also measured in both lakes although no release was detected. However, because the lab incubation time was likely too short for these measurements, an allowed rate of 0.5 mg/m$^2$/day was applied for both of the lakes. The remaining load reductions come from watershed source reductions.

It is also important to note that the selected Canfield-Bachmann lake response model implicitly accounts for some internal loading because the response is predicted from external loads from a database that includes lakes with internal loading. Therefore, the assigned internal load in these models is included above and beyond the implicitly included internal load. Therefore, the lake can likely demonstrate an internal load greater than what is explicitly identified in the TMDL and still meet state water quality standards.

To determine the allowable watershed phosphorus load, the lake response model was updated with the selected allowable internal load as determined in the previous section. Next, current estimated watershed loading in the lake response models was reduced until the models predicted an in-lake phosphorus concentration of 60 µg/L. This method resulted in a required 79% reduction of watershed nutrient loads to Ann Lake and a 12% reduction in watershed nutrient loads to Lake Emma. It is important to note that the majority of the nutrient loads for Lake Emma come from Ann Lake.

### 4.1.3 Wasteload Allocations

The Wasteload Allocation includes permitted discharges such as industrial point source and regulated stormwater discharges. Stormwater discharges are regulated under NPDES, and allocations of nutrient reductions are considered Wasteloads that must be divided among permit holders. There are no MS4 permit holders in the Ann Lake and Lake Emma watersheds so no allocations are given for MS4 stormwater.

#### 4.1.3.1 Construction and Industrial Stormwater

Review of National Pollutant Discharge Elimination System (NPDES) construction permits in the watershed showed minimal construction activities (<1% of the watershed area). The wasteload allocation was determined based on estimated percentage of land in the impaired reach watersheds. To account for future growth (reserve capacity), allocations in the TMDL were rounded to one percent.

There is currently one industrial stormwater permit (A00000530) in the Ann Lake and Lake Emma watersheds. To account for this permit and future growth (reserve capacity), allocations for industrial stormwater in the TMDL are set at a half percent.

#### 4.1.3.2 Confined Animal Feeding Operations (CAFOs)

There are numerous CAFOs in the Ann Lake and Lake Emma watersheds. CAFOs are not permitted to discharge from the lots by rule and therefore are considered to not be currently discharging any phosphorus. Furthermore, CAFOs are assigned an allocation of zero based on the state rules. Manure from these lots is spread on nearby fields and is an important source of watershed runoff. Manure on fields is included in the watershed runoff portion of the load allocation. CAFO permits in the Ann Lake and Lake Emma watersheds are listed below.

| | | | | | |
|---|---|---|---|---|---|
| 171-67717 | 171-67410 | 171-67670 | 171-67522 | 171-67668 | 171-102361 |
| 171-67509 | 171-67499 | 171-102369 | 171-113596 | 171-82303 | 171-67380 |
| 171-67743 | 171-67544 | 171-67426 | 171-67505 | 171-67705 | 171-67470 |
| 171-97320 | 171-67493 | 171-102368 | 171-67673 | 171-67703 | 171-50001 |
| 171-67466 | 171-67755 | 171-67704 | 171-67712 | 171-50002 | 171-67531 |
| 171-110798 | 171-67365 | 171-67534 | | | |

### 4.1.4 Margin of Safety

Both an implicit and explicit margin of safety has been included in this TMDL. Following is the rationale for an implicit margin of safety.

1. Achieving runoff total P load reductions would require greater percentage reductions in soluble reactive P (likely from animal waste, fertilizer, or septic and wetland discharge), which has a greater impact on lake algal productivity, as compared with other forms of phosphorus that are less biologically available (Walker, 1985).

2. Best Management Practices for reducing phosphorus loads from agriculture (Sharpley et al., 2006) and other sources could be conservatively designed in the process of implementation.

3. The 60 ppb lake standard is at the lower end of the 60-80 ppb range derived by Heiskary & Lindon (2005) as a TP criterion for shallow lakes. While this does not provide a margin of safety for achieving the lake P standard, it could be interpreted to provide a margin of safety for achieving the beneficial uses, upon which the lake P standard is conservatively based.

4. The selected Canfield-Bachmann lake response model implicitly accounts for some internal loading because the response is predicted from external loads from a database that includes lakes with internal loading. Therefore, the assigned internal load in these models is included above and beyond the implicitly included internal load. Therefore, the lake can likely demonstrate an internal load greater than what is explicitly identified in the TMDL and still meet state water quality standards.

As a further margin of safety, 5% of the load has been set aside to account for any uncertainty in the modeling.

### 4.1.5 Summary of TMDL Allocations

Table 4.1 summarizes the TMDL allocations for Ann Lake. A 5% margin of safety is explicit in the TMDL equation. An overall 82% nutrient reduction is required for Ann Lake to meet the state standard of 60 µg/L as a summer average. To achieve this TMDL, a 91% reduction in internal loading and a 79% reduction in watershed loading will need to be achieved.

Table 4.2 summarizes the TMDL allocations for Lake Emma. To achieve this TMDL, a 69% reduction in internal loading and a 12% reduction in direct watershed loading will need to be achieved. Furthermore, Ann Lake will need to meet state standards because it discharges to Lake Emma, which assumes a 64% reduction in loading from Ann Lake.

**Table 4.1. TMDL total phosphorus daily loads partitioned among the major sources for Ann Lake assuming the lake standard of 60 µg/L.**

| Allocation | Source | Existing TP Load[1] | | TP Allocations (WLA & LA) | | Load Reduction | Load Reduction |
|---|---|---|---|---|---|---|---|
| | | (lbs/year) | (lbs/day)[2] | (lbs/year) | (lbs/day)[2] | (lbs/year) | Percent |
| Wasteload | Industrial and Construction Stormwater | 86 | 0 | 18 | 0.05 | 68 | 79% |
| | CAFO | NA[3] | NA[3] | 0 | 0 | 0 | 0% |
| Load | County Ditch 10/Direct | 5,676 | 15.5 | 1,181 | 3.2 | 4,495 | 79% |
| | Atmospheric | 83 | 0.2 | 83 | 0.2 | 0 | 0% |
| | Internal Load | 2,481 | 6.8 | 229 | 0.6 | 2,252 | 91% |
| | MOS | -- | -- | 80 | 0.2 | -- | -- |
| | TOTAL LOAD | 8,326 | 22.5 | 1,591 | 4.25 | 6,815 | 82% |

[1] Existing load is the average for the years 2003,2005, 2008, 2009.
[2] Annual loads converted to daily by dividing by 365.25 days per year accounting for leap years
[3]Loads from feedlots are not permitted by rule, so zero loading was assumed in this TMDL

**Table 4.2. TMDL total phosphorus daily loads partitioned among the major sources for Lake Emma assuming the lake standard of 60 µg/L.**

| Allocation | Source | Existing TP Load [1] | | TP Allocations (WLA & LA) | | Load Reduction | Load Reduction |
|---|---|---|---|---|---|---|---|
| | | (lbs/year) | (lbs/day)[2] | (lbs/year) | (lbs/day)[2] | (lbs/year) | Percent |
| Wasteload | Industrial and Construction Stormwater | 5 | 0.01 | 4 | 0.01 | 1 | 20% |
| | CAFO | NA[3] | NA[3] | 0 | 0 | 0 | 0% |
| Load | Direct Watershed | 322 | 0.9 | 284 | 0.8 | 38 | 12% |
| | Atmospheric | 42 | 0.1 | 42 | 0.1 | 0 | 0% |
| | Upstream Lake (Ann) | 2,746 | 7.5 | 985 | 2.7 | 1,761 | 64% |
| | Internal Load | 617 | 1.7 | 193 | 0.5 | 424 | 69% |
| | MOS | -- | -- | 78 | 0.2 | -- | -- |
| | TOTAL LOAD | 3,732 | 10.2 | 1,586 | 4.31 | 2,224 | 60% |

[1] Existing load is the average for the years 2008 and 2009.
[2] Annual loads converted to daily by dividing by 365.25 days per year accounting for leap years
[3]Loads from feedlots are not permitted by rule, so zero loading was assumed in this TMDL

## 4.2 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 algae. Consequently, to understand the impacts of the phosphorus loads to the lake, a water quality response model was used to predict the water quality after load reductions are implemented. Utilization of this approach allows for a better understanding of potential lake conditions under numerous load scenarios. The following sections describe the results from the water quality response modeling.

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

### 4.2.1 Chlorophyll-a

Modeled chlorophyll-a concentrations expected at various phosphorus loads for Ann Lake and Lake Emma are presented in Figures 4.2 and 4.3. The lake response model predicts that the chlorophyll-a target of 20 µg/L as a summer growing season mean would be met at the TMDL designated load for Ann Lake and Lake Emma (1,591 and 1,586 pounds/year respectively).

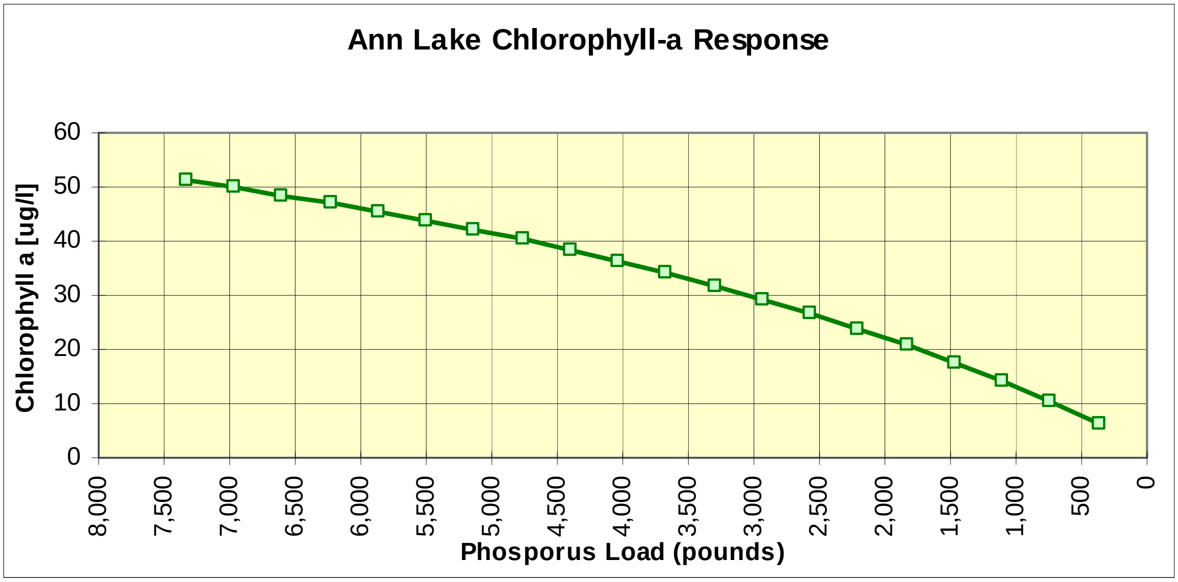


**Figure 4.2. In-lake chlorophyll-a concentrations predicted for total phosphorus load reductions applied to all sources in Ann Lake.**

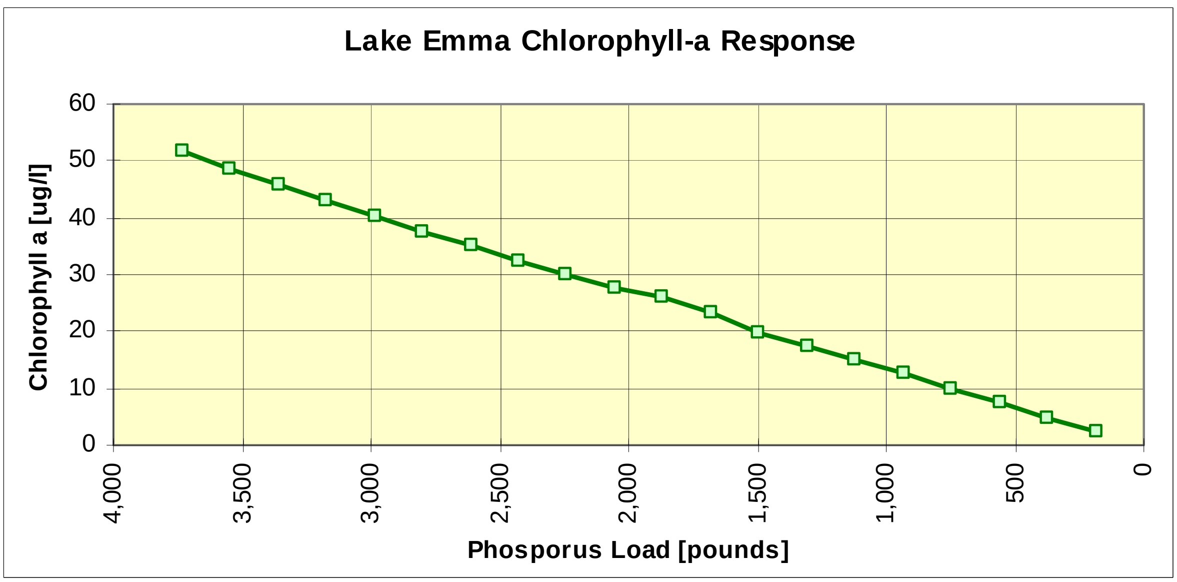


**Figure 4.3. In-lake chlorophyll-a concentrations predicted for total phosphorus load reductions applied to all sources to Lake Emma.**

### 4.2.2 Secchi Depth

Model predicted water clarity with incremental load reductions in Ann Lake and Lake Emma is presented in Figures 4.4 and 4.5. The lake response model predicts that the Secchi depth target of greater than 1 meter as a summer growing season mean would be met at the TMDL designated load for Ann Lake and Lake Emma (1,591 and 1,586 pounds/year respectively). In fact, both lakes currently meet this water quality standard and modeling predicts that Secchi depth would far exceed standards at the TMDL allocations.

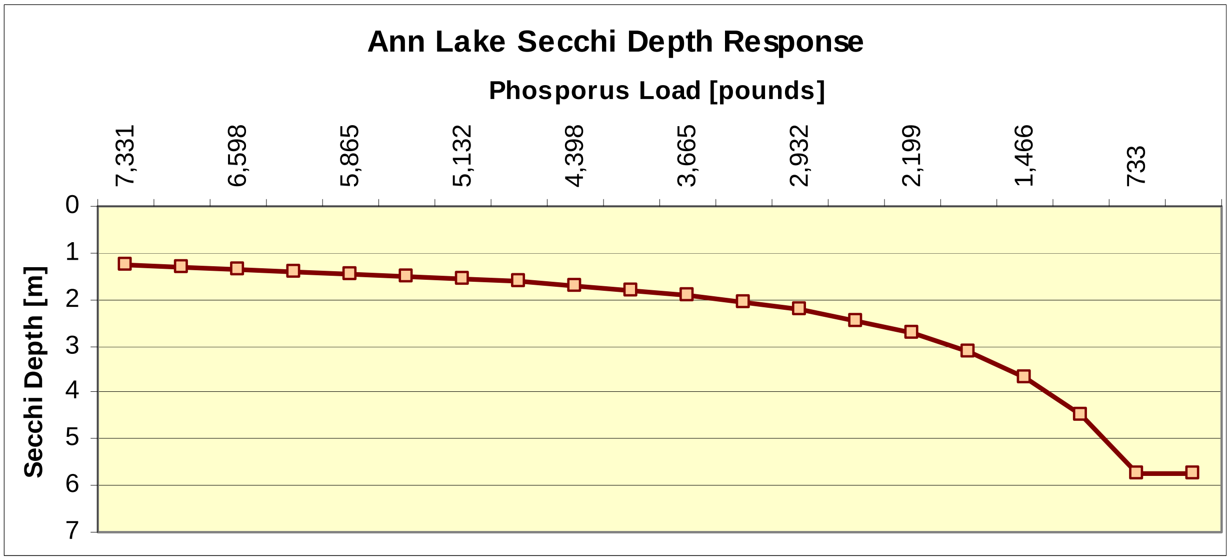


**Figure 4.4. Secchi depth predicted for total phosphorus load reductions applied to all sources to Ann Lake.**

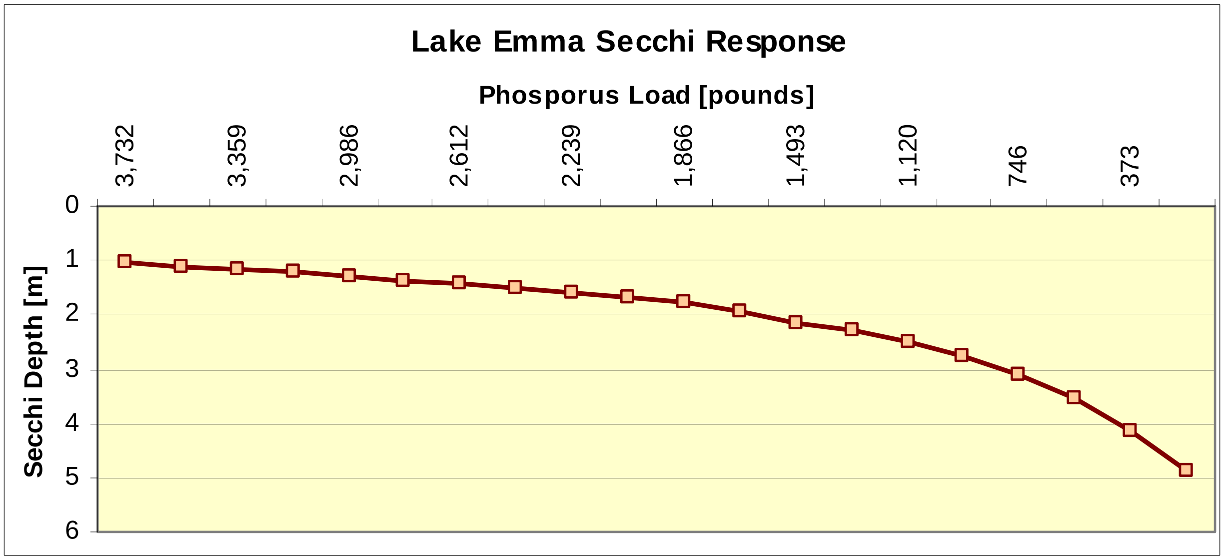


**Figure 4.5. Secchi depth predicted for total phosphorus load reductions applied to all sources to Lake Emma.**

## 4.3 SEASONAL AND ANNUAL VARIATION

The daily load reduction targets in this TMDL are calculated from the current phosphorus budgets for Ann Lake and Lake Emma. 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 where 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.

## 4.4 RESERVE CAPACITY

The amount of land in agricultural use in the Ann Lake and Lake Emma watersheds is likely to remain fairly constant over the next several decades. The watershed is comprised mainly of row crops (corn and soybeans) with some land used for pasture and hay. While the majority of the landscape is likely to remain in an agricultural land use, it is possible a modest shift between pasture/hay and row crops may occur. Any such shift would likely not affect the loading capacity of the lakes, since that capacity is based on long-term flow records over which time land use changes have likely occurred. Thus, slight shifts in land use should not appreciably change the magnitude of the land use runoff variability that the period of record already reflects.

# 5.0 Public Participation

## 5.1 INTRODUCTION

TMDL development should be a stakeholder-driven process that develops an understanding of the issues and the processes driving the impairments. To that end, a detailed stakeholder process was employed that included working with a Technical Advisory Committee comprised of local stakeholders. These groups represent the stakeholders ultimately responsible for implementation of the TMDLs who need to be fully engaged in the applied science. It is our goal for this TMDL to result in a science based, implementable TMDL with a full understanding of the scientific tools developed to make informed, science based decisions.

## 5.2 STAKEHOLDER MEETINGS

Public participation for the Ann/Emma TMDL study was focused on the residents of the entire watershed. Every parcel owner was sent project information as well as invitations to attend multiple informational meets. For each meeting, over 500 invitations were mailed to residents in the watershed. The goal of the process was to incorporate as many participants as possible from a broad range of stakeholders including lake users, farmers, local officials, and local governing agencies. The meetings were attending by representatives of each group including the Minnesota Pollution Control Agency, Minnesota DNR, Natural Resources Conservation District and the Wright County Soil and Water Conservation District. The goals of the meetings was to help the stakeholders understand what at TMDL is and how it may affect them. Once the stakeholders were comfortable with the TMDL, the discussions focused on implementation.

The kick-off meeting was held on March 11$^{th}$ 2009. Two update meetings were conducted on August 18$^{th}$ 2010, one at 3:00 pm and the other at 6:00 pm. These meetings were held back to back to better accommodate the lakeshore and farm residents. Another update meeting to review the TMDL results was held November 18$^{th}$ 2010.

# 6.0 Implementation

## 6.1 INTRODUCTION

The purpose of the implementation section of the TMDL is to develop an implementation strategy for meeting the load and wasteload allocations set forth in this TMDL. This section is not meant to be a comprehensive implementation plan; rather it is the identification of a strategy that will be further developed in an implementation plan separate from this document.

## 6.2 REDUCTION STRATEGIES

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. Following is a description of potential actions for controlling nutrients in Ann Lake and Lake Emma and their respective watersheds that will be further developed in the Ann Lake and Lake Emma Implementation Plan. The estimated cost of implementing these and other potential BMPs ranges from $1,000,000 to $2,500,000 (Table 6.1).

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**Table 6.1. Estimated costs associated with each implementation activity.**

| **Program Element** | **Activity** | **Cost** | **Responsible Parties** |
|---|---|---|---|
| Education | Coordination | 5 hours/month | Wright County SWCD, Ann Lake Association |
| | Lakeshore and Land Management Impacts | $2,000 annually | Wright County SWCD, Ann Lake Association |
| | Lake Recreation Impacts | $2,000 annually | Wright County SWCD, Ann Lake Association |
| | Public Education and Outreach | $2,000 annually | Wright County SWCD, Wright County, CROW, Minnesota DNR, MPCA, Ann Lake Association |
| | Public Official and Staff Education | $2,000 annually | Wright County SWCD, Wright County, CROW, Minnesota DNR, MPCA, Ann Lake Association |
| | Demonstration Projects | $5,000 annually | Wright County SWCD, Wright County, CROW, Ann Lake Association |

**Table 6.1, cont. Estimated costs associated with each implementation activity.**

| | | | |
|---|---|---|---|
| Monitoring | Ann Lake and Lake Emma Water Quality | $5,000 per event | Wright County SWCD |
| | County Ditch #10 Water Quality | $5,000 | Wright County SWCD |
| | Vegetation Monitoring | $5,000 | Ann Lake Association |
| | Fish Monitoring | $5,000 | Minnesota DNR |
| Watershed Activities | Feedlot Management | $500,000 | Wright County SWCD |
| | Buffers and Fencing Along Pastures | $250,000 | Wright County SWCD |
| | Manure Management Plans | $50,000 | Wright County SWCD |
| | Manure Management Demonstration Projects | $250,000 | Wright County SWCD |
| | Increase Infiltration in Watershed | $5,000 annually | Wright County SWCD, Wright County |
| | Shoreline Management and Restoration | $150,000 | Wright County SWCD, Wright County, Ann Lake Association |
| | Evaluate and Prioritize Wetlands | $30,000 | Wright County SWCD, Wright County, CROW |
| | Inspect Septic Systems in Ann Lake and Lake Emma Watershed | $5,000 annually | Wright County SWCD, Wright County, CROW, MPCA |
| | Upgrade Nonconforming Septic Systems | $50,000 to $500,000 | Wright County SWCD, Wright County, CROW |
| | Construction Stormwater | Current Program | MPCA |
| In-Lake Activities | Internal Load Reduction Feasibility Study | $30,000 | Wright County, Wright County SWCD |
| | Implement Internal Load Reduction and Biomanipulation Alternative | $250,000 to $1 Million | Wright County, Wright County SWCD, CROW, Minnesota DNR, Ann Lake Association |
| | Implement Vegetation Management Plan | $10,000 | Minnesota DNR, Ann Lake Association |
| | Manage Fish Populations | $10,000 | Minnesota DNR |
| | Rough Fish Assessment and Management | $15,000 | Minnesota DNR, Ann Lake Association |
| Total Range | | $1M to $2.5M | |

## 6.3 IMPLEMENTATION FRAMEWORK

### 6.3.1 Watershed and Local Plans

Numerous governing units have water quality responsibilities in the watershed, including the Crow River Organization of Water, Wright County and the Wright County SWCD. Each of these organizations maintain water plans aimed at improving water quality in their respective jurisdictions. These plans set the framework for implementing the TMDLs.

### 6.3.2 Adaptive Management

The Load and Wasteload allocations in the TMDL represent aggressive goals for nutrient reductions. Consequently, implementation will be conducted using adaptive management principles (Figure 6.1). 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 strategies for attaining the water quality goals established in this TMDL.

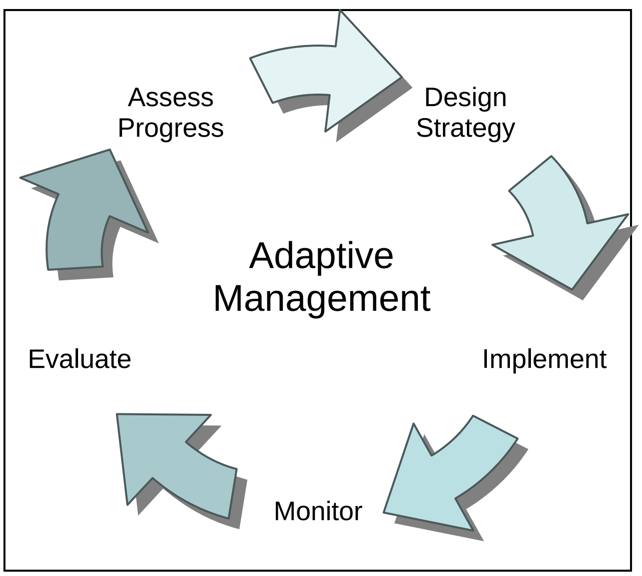


**Figure 6.1. Adaptive management.**

## 6.4 NUTRIENT REDUCTION STRATEGIES

Following is a description of potential actions for controlling nutrients in the Ann Lake and Lake Emma watersheds that will be further developed in the Implementation Plan.

### 6.4.1 External Nutrient Load Reductions

This TMDL for Ann Lake and Lake Emma requires a 79% and 12% reduction from watershed sources respectively. Because much of the nutrient budget to Lake Emma is from Ann Lake, implementation should focus on restoring Ann Lake. To meet the required load reduction, various watershed management activities will be implemented on an opportunistic basis, including the following:

*Protect and restore high-value wetlands to prevent phosphorus export.* Numerous high-value wetlands are present in the watershed. As development or redevelopment occurs, there is the potential to discharge to them stormwater and additional nutrients and sediment, altering the hydroperiod and natural assimilative characteristics and converting the wetlands from nutrient sinks to nutrient sources. Protecting the wetlands from these impacts will ensure they don't increase nutrient loading to the lake. Furthermore, fixing wetlands that are discharging phosphorus will decrease nutrient loads.

*Increase infiltration and filtration in the watershed.* One method for reducing phosphorus loading to Ann Lake and Lake Emma is to increase infiltration and filtration in the watersheds. This can be accomplished through large scale infiltration areas, removing tile lines, adding buffers, or adding vegetated swales.

*Manure Management.* Minnesota feedlot rules (Minn. R. ch. 7020) now require manure management plans for feedlots greater than 300 animal units that do not employ a certified manure applicator. These plans require manure accounting and record-keeping as well as manure application risk assessment based on method, time and place of application. The following BMPs will be considered in all manure management plans to reduce potential nutrient delivery to surface waters:

- Immediate incorporation of manure into topsoil
- Reduction of winter spreading, especially on slopes
- Eliminate spreading near open inlets and sensitive areas
- Apply at agronomic rates
- Follow setbacks in feedlot rules for spreading manure
- Erosion control through conservation tillage and vegetated buffers

Additional technologies will be evaluated including chemical addition to manure prior to field application to reduce phosphorus availability and mobility.

*Pasture Management.* Overgrazed pastures, reduction of pastureland and direct access of livestock to streams may contribute a significant amount of nutrients to surface waters throughout all flow conditions. The following livestock grazing practices are for the most part economically feasible and are extremely effective measures in reducing nutrient runoff from feedlots:

- Livestock exclusion from public waters through setback enforcement and fencing
- Creating alternate livestock watering systems

- Rotational grazing
- Vegetated buffer strips between grazing land and surface water bodies

*Manure Stockpile Runoff Controls.* There are a variety of options for controlling manure stockpile runoff that reduce nonpoint source nutrient loading, including:

- Move fences or altering layout of feedlot
- Eliminate open tile intakes and/or feedlot runoff to direct intakes
- Install clean water diversions and rain gutters
- Install grass buffers
- Maintain buffer areas
- Construct solid settling area(s)
- Prevent manure accumulations
- Manage feed storage
- Manage watering devices
- Total runoff control and storage
- Install roofs
- Runoff containment with irrigation onto cropland/grassland
- Vegetated infiltration areas or tile-drained vegetated infiltration area with secondary filter strips

These practices should be applied where appropriate.

*Subsurface Septic Treatment Systems.* While septic systems are not believed to be a major source of nutrients to either Ann Lake or Lake Emma, failing or nonconforming septic systems should be addressed. Wright County shall continue to identify and address systems that are not meeting adopted septic ordinances. Special attention shall be given to systems with high nutrient loading potential based on proximity to the lake, streams and systems that may discharge directly to surface water.

*Soil Phosphorus Testing.* Because the amount of manure applied in the Ann Lake and Lake Emma watersheds is so high, soil testing would help manage where manure can be applied with little or no loss to surface waters. A soil phosphorus testing program will allow managers to make better decisions about where P from manure is needed and where it may be applied in excess.

*Encourage shoreline restoration.* Many property owners maintain a turfed edge to the shoreline. Property owners should be encouraged to restore their shoreline with native plants to reduce erosion and capture direct runoff. Shoreline restoration can cost $30-50 per linear foot, depending on the width of the buffer installed. The Wright County SWCD and Crow River Organization of Water will develop some demonstration projects as well as work with all willing landowners to naturalize their shorelines.

*Implement construction and industrial stormwater regulation.* 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

Industrial stormwater activities are also considered in compliance with provisions of the TMDL if they obtain an Industrial Stormwater General Permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install, and maintain all BMPs required under the permit, or meet local industrial stormwater requirements if they are more restrictive than requirements of the State General Permit.

### 6.4.2 Internal Nutrient Load Reductions

Internal nutrient loads will need to be reduced to meet the TMDL allocations presented in this document. There are numerous options for reducing internal nutrient loads ranging from simple chemical inactivation of sediment phosphorus to complex infrastructure techniques including hypolimnetic aeration.

*Internal load reduction technical review*. Prior to implementation of any strategy to reduce internal loading in Ann Lake and Lake Emma, a technical review needs to be completed to evaluate the cost and feasibility of the lake management techniques available to reduce or eliminate internal loading. Several options could be considered to manage internal sources of nutrients including hypolimnetic withdrawal, alum treatment, vegetation management and hypolimnetic aeration. A technical review should be completed to provide recommendations for controlling internal loading in Ann Lake and Lake Emma.

### 6.4.3 Studies and Biological Management Plans

*Vegetation management.* Curly-leaf pondweed is present in both Ann Lake and Lake Emma at extremely high concentrations. Senescence of the curly-leaf pondweed in summer can be a significant source of internal phosphorus load that often results in a late summer nuisance algal bloom. Vegetation management, such as several successive years of chemical treatment, will be required to keep this exotic invasive species at non-nuisance levels.

*Conduct periodic aquatic plant surveys and prepare and implement vegetation management plans.* As BMPs are implemented and water clarity improves, the aquatic vegetation community will change. Surveys should be updated periodically and vegetation management plans amended to take into account appropriate management activities for that changing community.

*Carp Management.* One activity should be to partner with the DNR to monitor and manage the fish population to maintain a beneficial community. As the aquatic vegetation changes to a more desirable mix of species, it may be possible to restore a more balanced fish community that includes both panfish and top predators. Options to reduce rough fish populations should be evaluated, and the possibility of fish barriers explored to reduce rough fish access to spawning areas and to minimize rough fish migration between lakes.

### 6.4.4 Education

*Provide education and outreach awareness programs.* Provide educational and outreach opportunities in the subwatershed about proper fertilizer use, manure management, low-impact lawn care practices, and other topics to increase awareness of sources of pollutant loadings to the lakes and encourage the adoption of good individual property management practices. Opportunities to better understand aquatic vegetation management practices and how they relate to beneficial biological communities and water quality should also be developed.

## 6.5 MONITORING

The Wright County SWCD plans to continue monitoring Ann Lake on a monthly basis in the summer for total phosphorus, chlorophyll-a, and Secchi depth. The SWCD also plans to continue monitoring County Ditch 10, the primary tributary to Ann Lake for total phosphorus and discharge. Lake Emma will be monitored less frequently, however Ann Lake is a good indicator of progress in the system since the greatest required reductions for Lake Emma are from Ann Lake.

# 7.0 Reasonable Assurance

## 7.1 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 nutrients to Ann Lake and Lake Emma.

The goals outlined in this TMDL study are consistent with objectives outlined in the Wright County Water Plan. This plan has the same objective of developing and implementing strategies to bring impaired waters into compliance with appropriate water quality standards and thereby establish the basis for removing those impaired waters from the 303(d) Impaired Waters List. The plan provides the watershed management framework for addressing water quality issues. In addition, the stakeholder process associated with this TMDL effort as well as the broader planning efforts mentioned previously have generated commitment and support from the local government units affected by this TMDL and will help ensure that this TMDL project is carried successfully through implementation.

Various technical and funding sources will be used to execute measures that will be detailed in the implementation plan that will be developed within one year of approval of this TMDL. Funding resources include a mixture of state and federal programs, including (but not limited to) the following:

- Federal Section 319 Grants for watershed improvements
- Funds ear-marked to support TMDL implementation from the Clean Water, Land, and Legacy constitutional amendment, approved by the state's citizens in November 2008.
- Local government cost-share funds
- Soil and Water Conservation Districts cost-share funds
- NRCS cost-share funds

Although there are not currently any NPDES permits in the Ann Lake or Lake Emma watersheds, it is a reasonable expectation that existing regulatory programs such as those under NDPES will continue to be administered to control discharges from industrial, municipal, and construction sources as well as large animal feedlots that meet the thresholds identified in those regulations.

## 7.2 REGULATORY APPROACHES

Industrial stormwater activities are considered in compliance with provisions of the TMDL if they obtain an industrial stormwater general permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit. There are not currently any industrial dischargers in the watershed, but these regulations would apply to future dischargers.

Stormwater activities from individually permitted, non-MS4 NPDES/SDS stormwater discharges are considered in compliance with provisions of this TMDL if they follow the conditions of the individual permit and implement the appropriate Best Management Practices.

## 7.3 LOCAL MANAGEMENT

### 7.3.1 Crow River Organization of Waters

Portions of ten counties in Central Minnesota make up the Crow River Watershed. From the perspective of the Upper Mississippi River Basin, the Crow River is one of its major tributaries. The effects of rapid urban growth, new and expanding wastewater facilities and erosion from agricultural lands have been common concerns of many citizens, local, state and regional governments in Central Minnesota. As a result, many groups began meeting in 1998 to discuss management of the Crow River basin consisting of the North Fork and South Fork. The Crow River Organization of Water (CROW) was formed in 1999 as a result of heightened interest in the Crow River. A Joint Powers Agreement has been signed between all ten of the Counties with land in the Crow River Watershed. The CROW Joint Powers Board is made up of one representative from each of the County Boards who signed the agreement. The Counties involved in the CROW Joint Powers include Carver, Hennepin, Kandiyohi, McLeod, Meeker, Pope, Renville, Sibley, Stearns and Wright. The CROW currently focuses on identifying and promoting the following:

- Protecting water quality and quantity
- Protect and enhance fish and wildlife habitat and water recreation facilities
- Public education & awareness
- BMP implementation

In summer of 2010, the CROW began working with the Minnesota Pollution Control Agency's new Major Watershed Restoration & Protection Project (MWRPP) approach in the North Fork Crow River Watershed. The idea behind the watershed approach is to provide a more complete assessment of the water quality and facilitates data collection for the development of a Total Maximum Daily Loads (TMDLs) and protection strategies. The watershed approach is to intensively monitor the streams and lakes within a major watershed to determine the overall health of the water resources, identify impaired waters, and identify those waters in need of additional protection efforts to prevent impairments. This process is different because monitoring efforts were previously concentrated in a defined area (a lake or stream reach) and would address one impairment whereas now all impairments are addressed at the same time. Most importantly this process will provide a communication tool that can inform stakeholders, engage volunteers, and help coordinate local/state/federal monitoring efforts. This process will ensure the data necessary for effective water resources planning is available, citizens and stakeholders are engaged in the process, and citizens and governments across Minnesota can evaluate the progress. The MWRPP approach results in a Watershed Management Plan for the North Fork Crow Watershed that covers the Ann Lake and Lake Emma watersheds.

### 7.3.2 Local Comprehensive Water Management Plans

Completion of TMDL assessments of impaired waters within the county was identified as one of the top three priorities in Wright County's Local Comprehensive Water Management Plan. In addition, the implementation section of the plan focuses on a number of areas important in restoring impaired waters to a non-impaired status, including;

1. Support and cooperate with local SWCD, County Water Planners and the Minnesota Pollution Control Agency on on-going TMDL projects.
2. Educate feedlot owners on proper feedlot management, including manure storage and field application, for the purpose of meeting regulatory requirements.
3. Assist and provide information, technical and/or financial assistance to landowners implementing agricultural BMPs on working lands to reduce soil erosion, protect streambanks, and improve water resources.
4. Actively promote and market federal/state/local conservation programs to targeted landowners and help prepare them for eligibility in programs such as CSP and EQIP.
5. Promote and market conservation programs that provide cost-share and assistance to livestock producers for the adoption of comprehensive nutrient management plans.
6. Ensure the proper use and abandonment of manure pits.
7. Support owner/operators to bring their facilities into compliance, with those feedlots that are within identified TMDL watersheds having priority.
8. Promote and establish buffers on public and private ditches.
9. Promote the establishment and maintenance of vegetative buffers.
10. Provide low interest loan dollars to fix failing septic systems.

### 7.3.3 County Soil and Water Conservation Districts

The purpose of the County Soil and Water Conservation District (SWCD) is to plan and execute policies, programs, and projects which conserve the soil and water resources within its jurisdictions. It is particularly concerned with erosion of soil due to wind and water. The SWCD is heavily involved in the implementation of practices that effectively reduce or prevent erosion, sedimentation, siltation, and agricultural-related pollution in order to preserve water and soil as resources. The District frequently acts as local sponsor for many types of projects, including grassed waterways, on-farm terracing, erosion control structures, and flow control structures. The CROW has established close working relationships with the SWCDs on a variety of projects. One example is the conservation buffer strip cash incentives program that provides cash incentives to create permanent grass buffer strips adjacent to water bodies and water courses on land in agricultural use. The CROW currently participates in the program by providing matching grants and will work to target such practices in the Ann and Emma watersheds so that the practices are implemented as cost effectively as possible to achieve the load reduction required in the TMDL.

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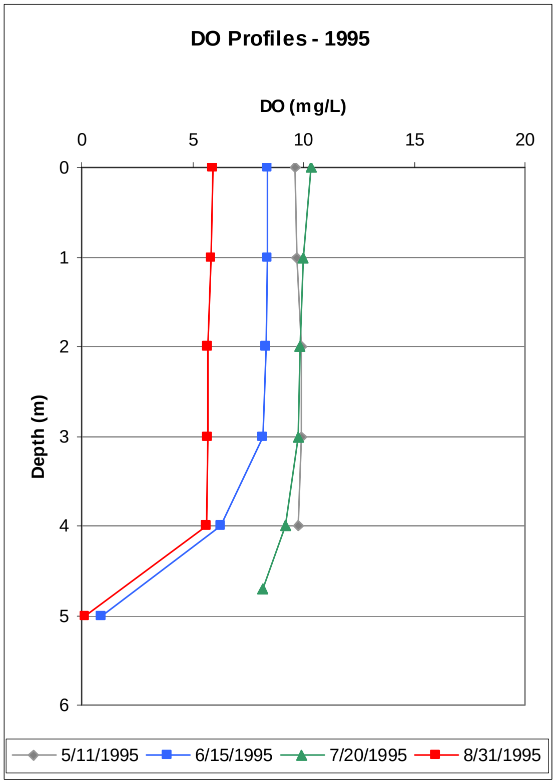
# Appendix A

# Temperature and DO Profiles

# Ann Lake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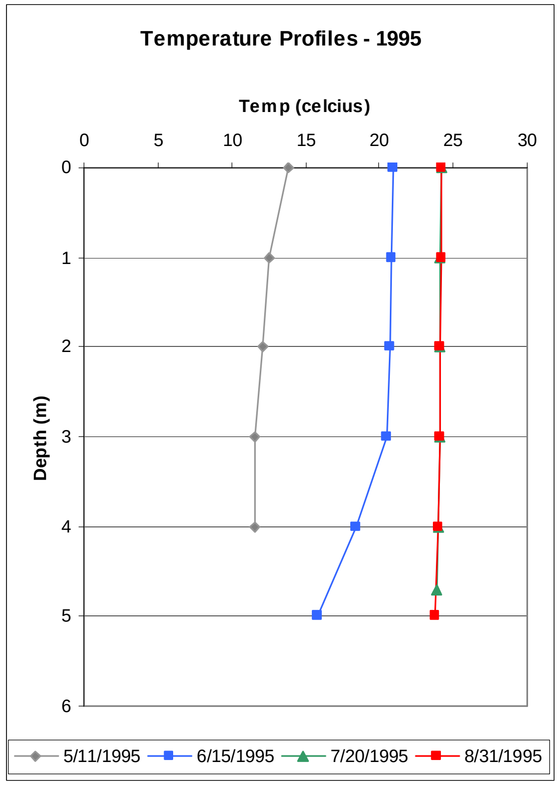
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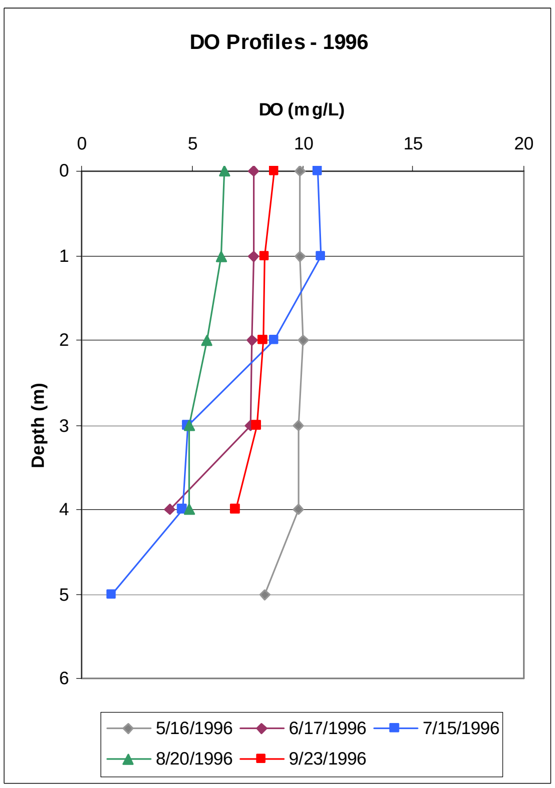
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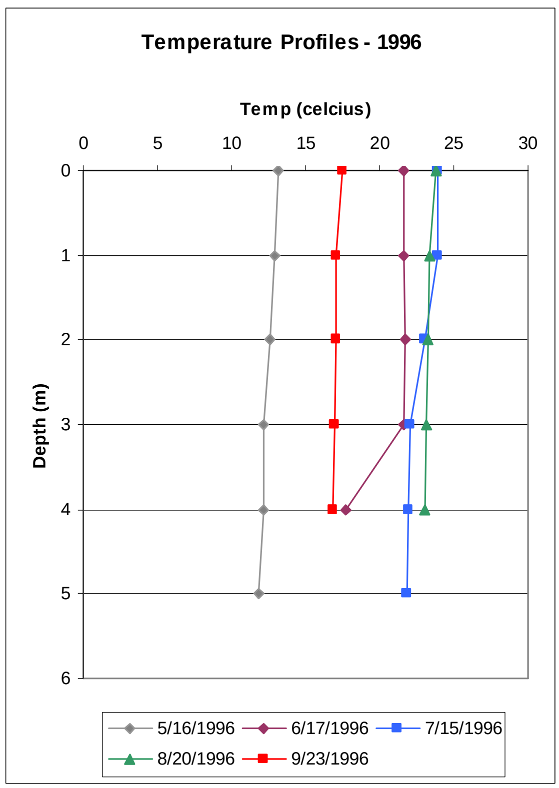
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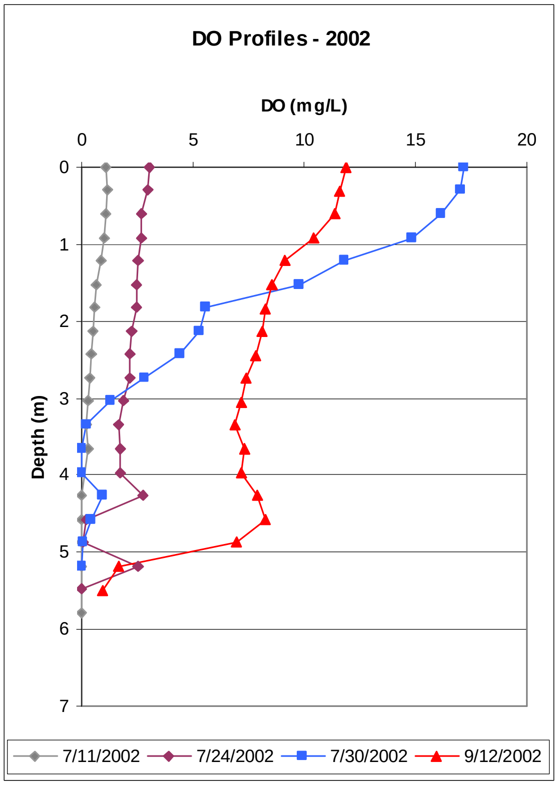
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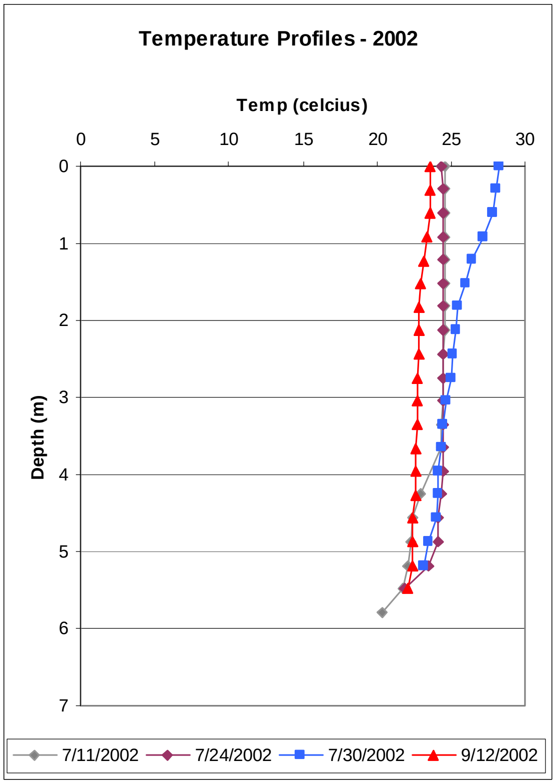
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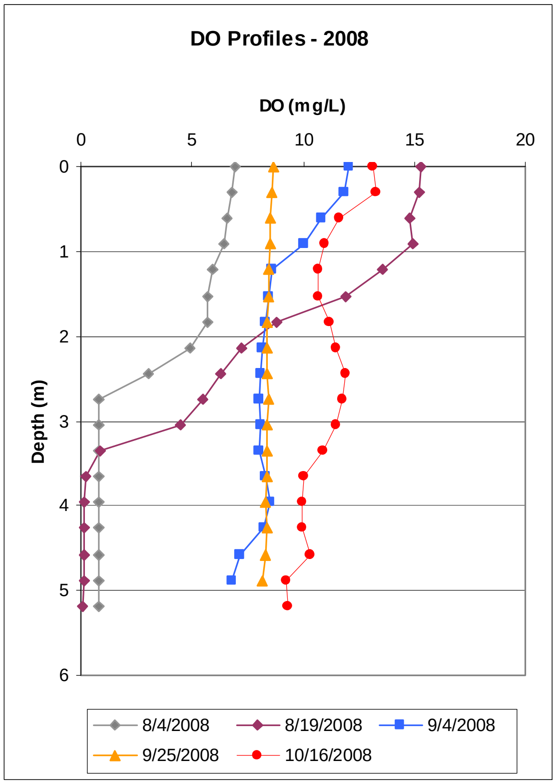
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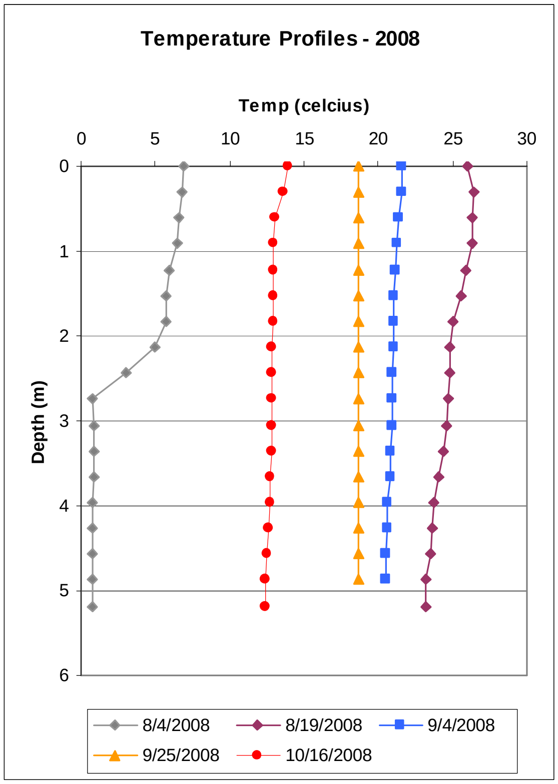
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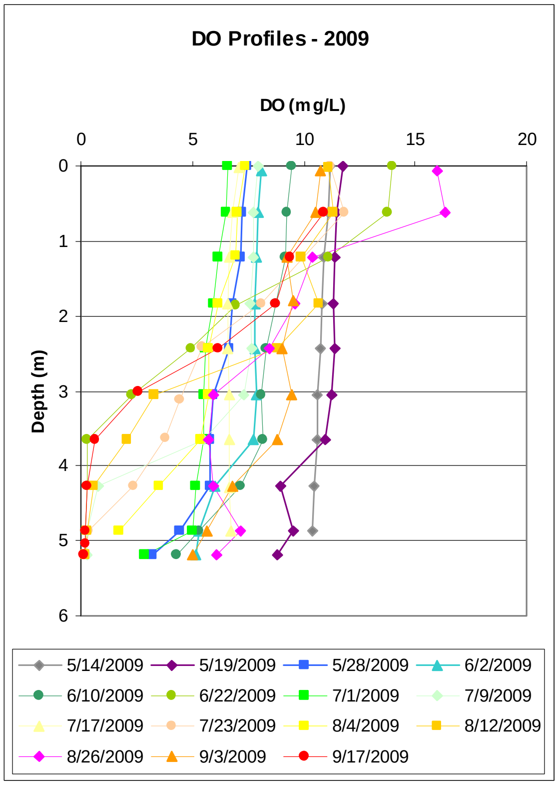
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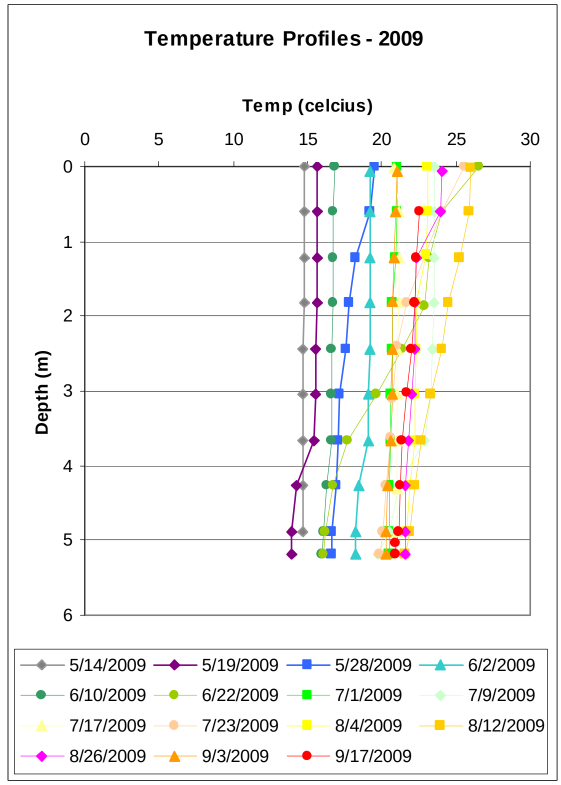
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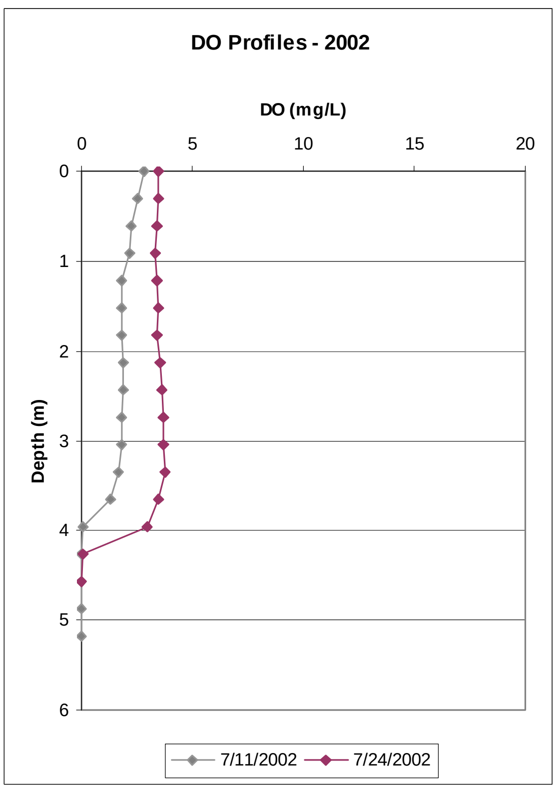
6/22/2009
7/1/2009
7/9/2009
7/17/2009
7/23/2009
8/4/2009
8/12/2009
8/26/2009
9/3/2009
9/17/2009

## Lake Emma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Depth (m)
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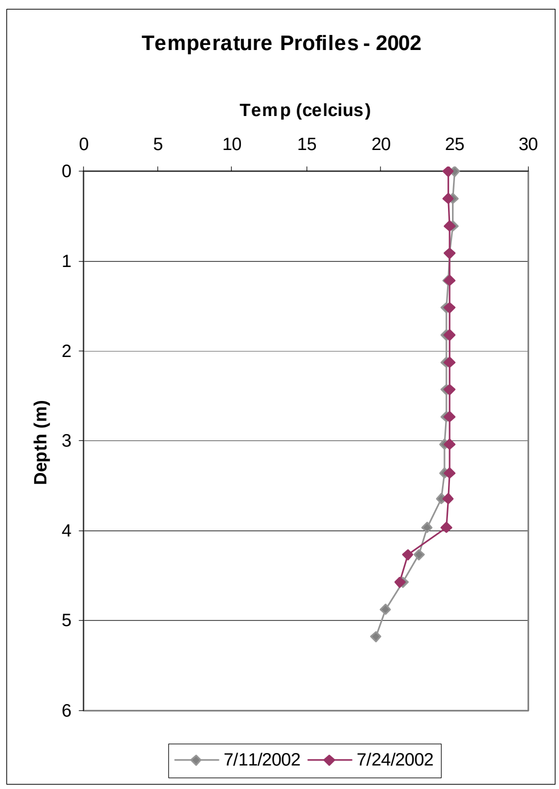
7/24/2002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Temp (celcius)
Depth (m)
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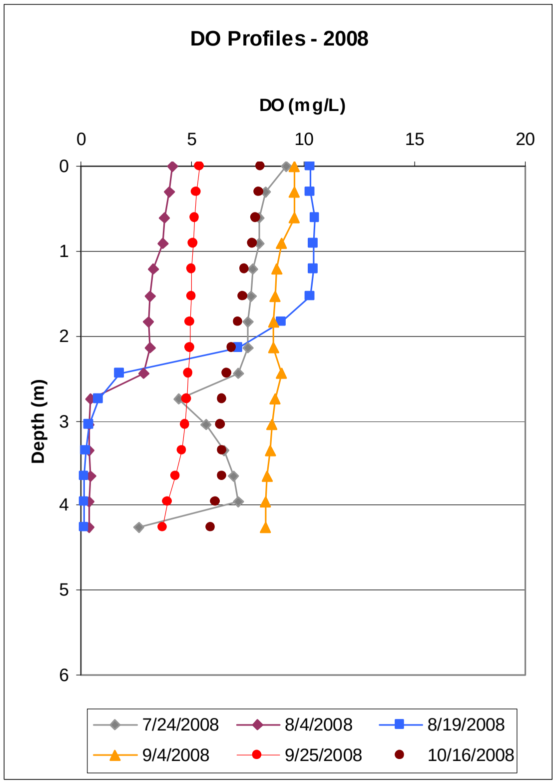
7/24/2002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10
15
20
Depth (m)
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2
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4
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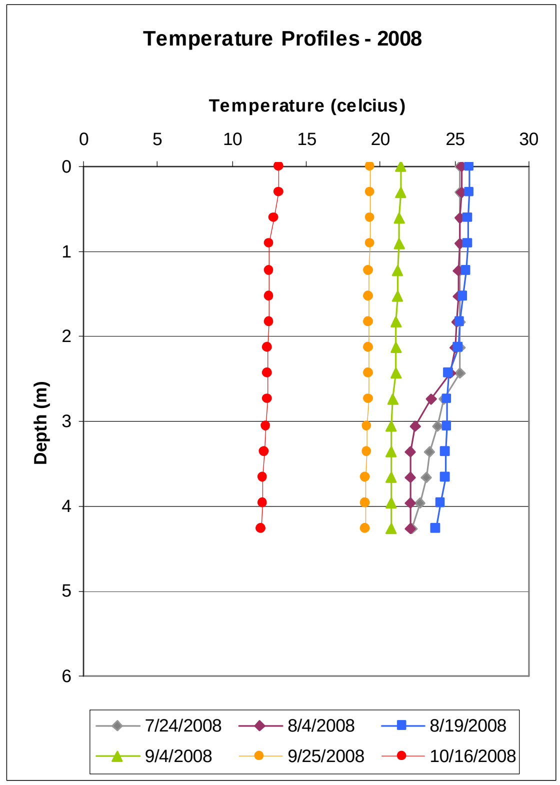
6
7/24/2008
8/4/2008
8/19/2008
9/4/2008
9/25/2008
10/16/2008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15
20
25
30
Depth (m)
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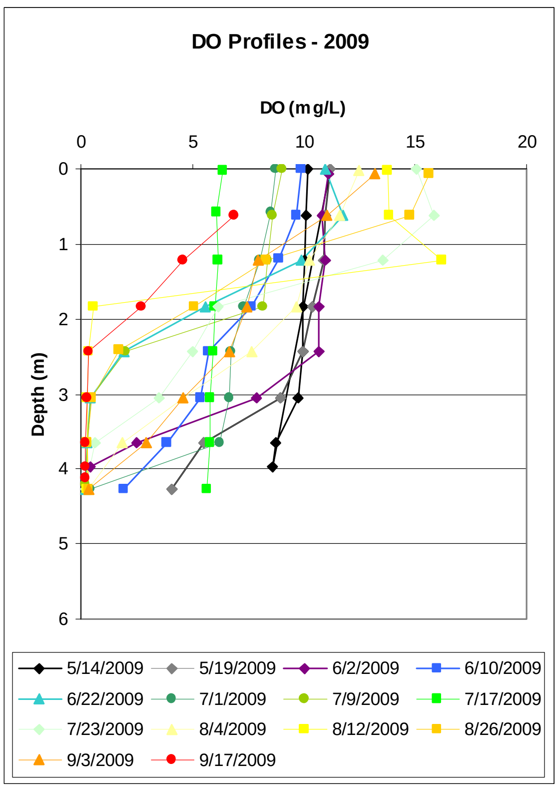
6
7/24/2008
8/4/2008
8/19/2008
9/4/2008
9/25/2008
10/16/2008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20
Depth (m)
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2
3
4
5
6
5/14/2009
5/19/2009
6/2/2009
6/10/2009
6/22/2009
7/1/2009
7/9/2009
7/17/2009
7/23/2009
8/4/2009
8/12/2009
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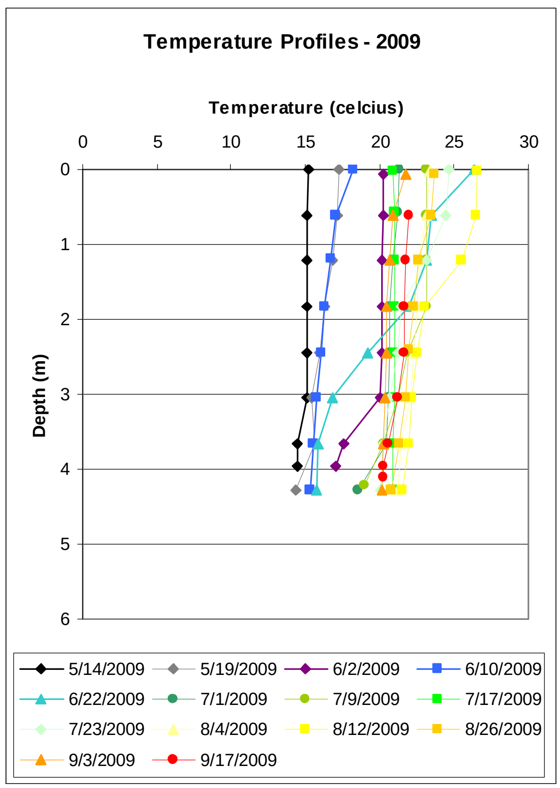
9/3/2009
9/17/2009


Temperature Profiles - 2009
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6/2/2009
6/10/2009
6/22/2009
7/1/2009
7/9/2009
7/17/2009
7/23/2009
8/4/2009
8/12/2009
8/26/2009
9/3/2009
9/17/2009

# Appendix B

## Ann and Emma Internal Release Study

# Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Sediments in Ann, Betsy, Clear, and Emma Lakes, Minnesota

15 June, 2009

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## OBJECTIVES

The objectives of this investigation were to determine rates of phosphorus (P) release from sediments under laboratory-controlled oxic and anoxic conditions and to quantify mobile and refractory P fractions in sediments of Ann, Betsy, clear, and Emma Lakes, Minnesota.

## APPROACH

*Laboratory-derived rates of P release from sediment under oxic and anoxic conditions:* Duplicate sediment cores were collected by Wenck Associates from the lakes in March, 2009, for determination of rates of P release from sediment under oxic and anoxic conditions. All cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water from the lake was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature (20 $^{o}$C) for a three week period. The oxidation-reduction environment in the overlying water was controlled by gently bubbling nitrogen (anoxic) or air (oxic) through an air stone placed just above the sediment surface in each system.

Water samples for soluble reactive P and dissolved iron (Fe) were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 µm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 1998). Dissolved Fe was determined via atomic absorption spectrophotometry (APHA 1998). Rates of P and Fe release from the sediment (mg $m^{-2}$ $d^{-1}$) were calculated as the linear change in mass in the overlying water divided by time (days) and the area ($m^2$) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

*Sediment chemistry:* The upper 10 cm from an additional core collected from each lake was sectioned for analysis of moisture content (%), sediment density (g/mL), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, aluminum-bound P, calcium-bound P, labile and refractory organic P, total P, total iron (Fe), and total calcium (Ca; all expressed at mg/g). A known volume of sediment was dried at 105 $^{o}$C for determination of moisture content and sediment density and ashed at 500 $^{o}$C for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002). Additional sediment was dried to a constant weight, ground, and digested for analysis of total Fe and Ca using standard methods (Plumb 1980; APHA 1998). Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), sodium hydroxide-extractable P (i.e., aluminum-bound P), and hydrochloric acid-extractable P (i.e., calcium-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P. Refractory organic P was estimated as the difference between total phosphorus and the sum of the other fractions.

## RESULTS AND INTERPRETATION

Under anoxic conditions, phosphorus mass in the overlying water column increased linearly between day 0 and day 2 to 3 for all lake sediment incubation systems (Figure 1). The rate of phosphorus release from sediments under anoxic conditions was very high for Betsy Lake sediments at 19 mg $m^{-2}$ $d^{-1}$ (Table 1). Emma, Ann, and Clear Lake sediment exhibited lower anoxic release rates; however, these still fell within ranges reported for eutrophic systems (Table 1). In contrast, phosphorus release was not detected from sediments under oxic conditions for all lakes (Figure 1 and Table 1). Dissolved iron mass was relatively low in the overlying water column throughout the incubation period under both oxic and anoxic conditions for all lakes (Figure 2).

Sediments from all lakes exhibited a high moisture content and low sediment density, indicating fine-grained, flocculent sediment (Table 2). Loss-on-ignition ranged between 9.1 and 20.4%, suggesting moderate organic matter content. Total phosphorus concentrations in the sediment were moderate at ~ 1.3 to 1.4 mg·$g^{-1}$ compared to other eutrophic lakes (Nürnberg 1988). Biologically-labile (i.e., subject to recycling; loosely-bound P, iron-bound P, and labile organic P) phosphorus accounted for a large percentage of the total sediment phosphorus (41 to 56%), suggesting a relatively high recycling potential (Figure 3). Redox-sensitive phosphorus (i.e., loosely-bound and iron-bound P) represented between 24% and 53% of the total sediment phosphorus (Table 2). The redox-sensitive phosphorus concentration was also high in Betsy Lake sediments relative to the other lakes, coinciding with a high rate of phosphorus release under anoxic conditions (Figure 4). Biologically refractory sediment phosphorus (i.e., subject to burial; aluminum-bound P, calcium-bound P, and refractory organic P) accounted for 44% to 58% of the total sediment P. Refractory organic phosphorus dominated refractory forms in Ann, Clear, and Emma Lake sediment (Figure 3). Aluminum-bound phosphorus accounted for most of the refractory phosphorus in Betsy Lake sediment (Figure 3).

Total sediment iron concentrations were moderate for all lakes (Table 2). Total calcium represented between 12.7% and 14.3% of the sediment dry mass, suggesting moderately calcareous conditions. The total iron:total phosphorus ratio ranged between ~ 8 and 11, suggesting a moderate binding capacity for phosphate under oxic conditions (Jensen et al. 1992). This pattern coincided with negligible rates of phosphorus release under oxic conditions, suggesting phosphate adsorption onto iron hydroxide.

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Hjieltjes, A.H., and Lijklema, L. 1980. Fractionation of inorganic phosphorus in calcareous sediments. J. Environ. Qual. 8, 130-132.

Jensen, H.S., Kristensen, P., Jeppesen, E., and Skytthe, A. 1992. Iron:phosphorus ratio in surface sediment as an indicator of phosphate release from aerobic sediments in shallow lakes. Hydrobiol. 235/236:731-743.

Nürnberg, G.K. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. Can. J. Fish. Aquat. Sci. 45:453-462.

Plumb, R.H. 1981. Procedures for handling and chemical analysis of sediment and water samples. Technical Report EPA/CE-81-1. US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Psenner, R., and Puckso, R. 1988. Phosphorus fractionation: Advantages and limits of the method for the study of sediment P origins and interactions. Arch. Hydrobiol. Biel. Erg. Limnol. 30:43-59.

Table 1. Mean (± 1 standard error in parentheses; n=2) rates of phosphorus (P) release and concentrations of biologically labile and refractory P in sediments collected in Ann, Betsy, Clear, and Emma Lakes. DW = dry mass, FW = fresh mass, N.D. = not detected.

| Station | Rates of P Release | | Redox-sensitive and biologically labile P | | | | Refractory P | | |
|---|---|---|---|---|---|---|---|---|---|
| | Oxic ($mg\ m^{-2}\ d^{-1}$) | Anoxic ($mg\ m^{-2}\ d^{-1}$) | Loosely-bound P (mg/g) | Iron-bound P (mg/g DW) | Iron-bound P (mg/g FW) | Labile organic P (mg/g) | Aluminum-bound P (mg/g) | Calcium-bound P (mg/g) | Refractory organic P (mg/g) |
| Ann | N.D. | 5.2 (0.4) | 0.308 | 0.220 | 0.039 | 0.158 | 0.143 | 0.107 | 0.443 |
| Betsy | N.D. | 19.0 (0.9) | 0.118 | 0.635 | 0.127 | 0.045 | 0.465 | 0.097 | 0.132 |
| Clear | N.D. | 2.4 (0.1) | 0.175 | 0.178 | 0.018 | 0.248 | 0.125 | 0.109 | 0.627 |
| Emma | N.D. | 9.1 (2.4) | 0.309 | 0.106 | 0.016 | 0.175 | 0.107 | 0.079 | 0.480 |

Table 2. Textural and chemical characteristics of sediments collected in Ann, Betsy, Clear, and Emma Lakes. P = phosphorus, Fe = iron, Ca = calcium.

| Station | Moisture Content (%) | Density (g/mL) | Loss-on-ignition (%) | Total P (mg/g) | Redox P (mg/g) | Redox P (%) | Total Fe (mg/g) | Total Ca (mg/g) | Fe:P |
|---|---|---|---|---|---|---|---|---|---|
| Ann | 82.7 | 0.218 | 11.6 | 1.379 | 0.528 | 38.3% | 14.19 | 140.6 | 10.3 |
| Betsy | 79.4 | 0.275 | 9.1 | 1.419 | 0.753 | 53.1% | 16.02 | 143.4 | 11.3 |
| Clear | 90.4 | 0.112 | 20.4 | 1.462 | 0.353 | 24.1% | 11.44 | 127.3 | 7.8 |
| Emma | 84.5 | 0.177 | 14.8 | 1.256 | 0.415 | 33.0% | 10.63 | 135.1 | 8.5 |

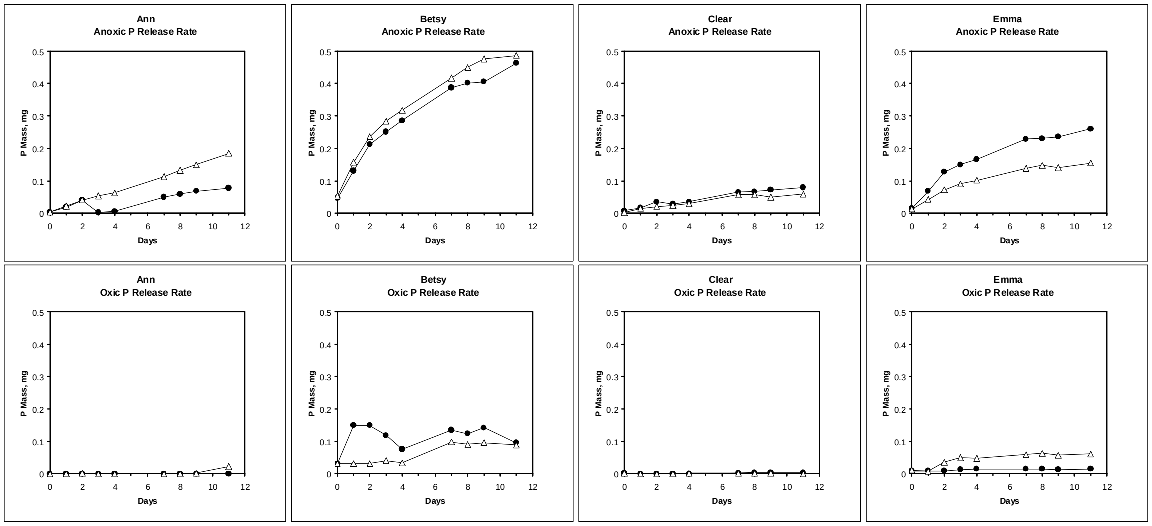



Figure 1. Changes in soluble reactive phosphorus mass in the overlying water column versus time under oxic and anoxic conditions for sediment cores collected in Ann, Betsy, Clear, and Emma Lakes.

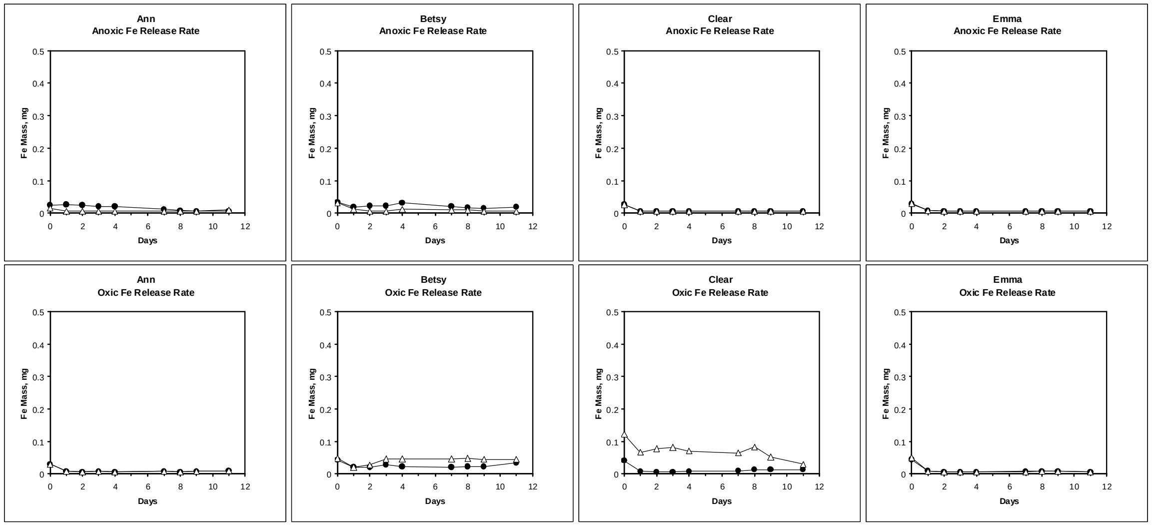



Figure 2. Changes in dissolved iron mass in the overlying water column versus time under oxic and anoxic conditions for sediment cores collected in Ann, Betsy, Clear, and Emma Lakes.

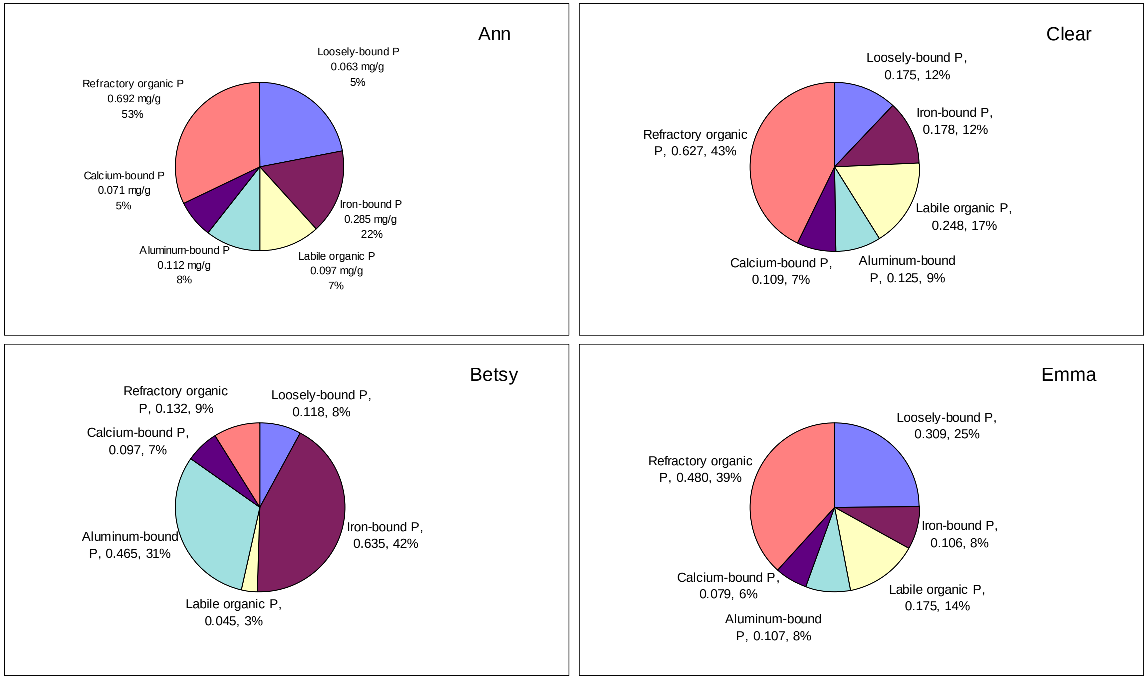



Figure 3. Sediment total phosphorus (P) composition for Ann, Betsy, Clear, and Emma Lake sediment . Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial). Values next to each label represent concentration (mg/g) and percent total P, respectively.

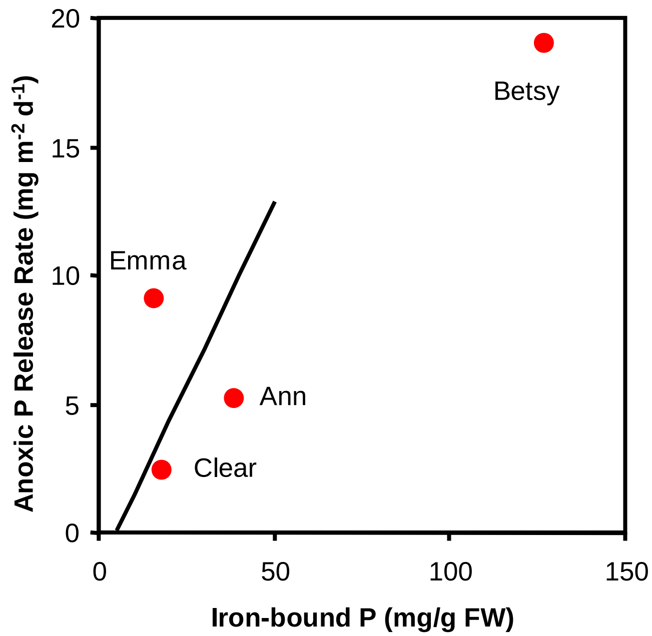
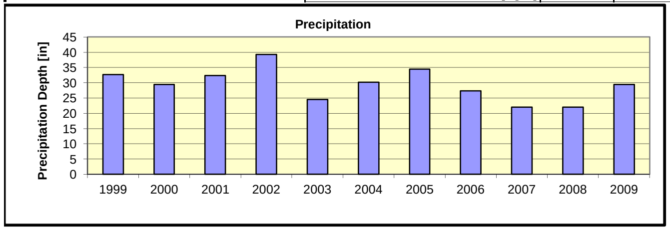


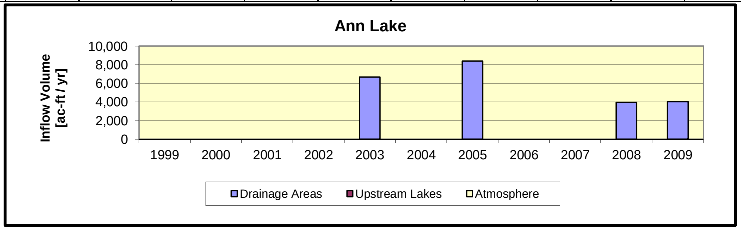

Figure 4. Iron-bound phosphorus (P) versus the anoxic P release rate (regression line) from Nürnburg (1988). The solid red circles represent results for Ann, Betsy, Clear, and Emma Lakes. WW = Fresh or wet weight mass.

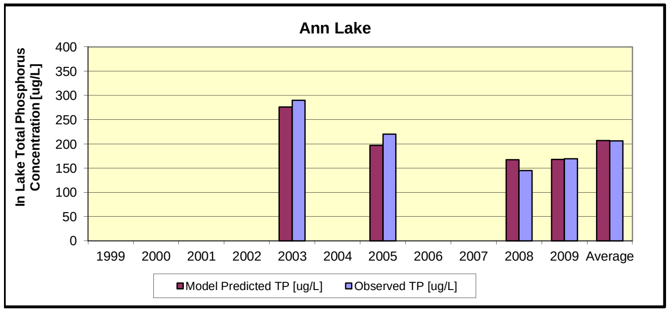
# Appendix C

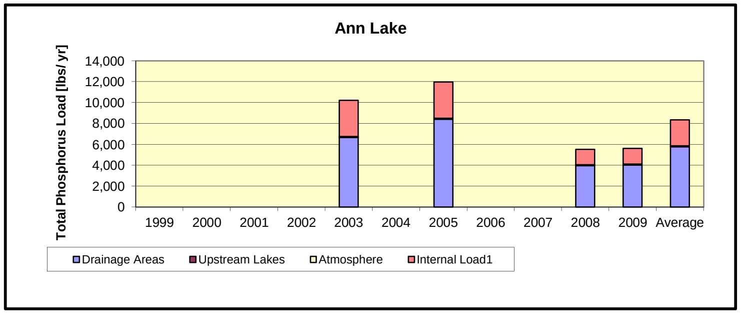
# Lake Response Models

| Ann Lake | Source | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Precipitation Depth [in] | | 30.02 | 32.68 | 29.42 | 32.4 | 39.22 | 24.52 | 30.12 | 34.44 | 27.31 | 22.02 | 22.02 | 29.5 |
| | Residence Time [yr] | | | | | 0.6 | | 0.3 | | | 0.6 | 0.6 | 0.5 |
| Inflow Volume [ac-ft / yr] | Drainage Areas | | | | | 6373.1 | | 6697.3 | | | 6373.1 | 6477.6 | 6,480 |
| | Upstream Lakes | | | | | 0.0 | | 0.0 | | | 0.0 | 0.0 | 0 |
| | Atmosphere | | | | | 0.0 | | 0.0 | | | 0.0 | 0.0 | 0 |
| | **TOTAL =** | | | | | **6373.1** | | **6697.3** | | | **6373.1** | **6477.6** | 6,480 |
| Total Phosphorus Load [lbs/ yr] | Drainage Areas | | | | | 6665 | | 8402 | | | 3955 | 4028 | 5762 |
| | Septic Systems | | | | | 0 | | 0 | | | 0 | 0 | 0 |
| | Upstream Lakes | | | | | 0 | | 0 | | | 0 | 0 | 0 |
| | Atmosphere | | | | | 83 | | 83 | | | 83 | 83 | 83 |
| | Internal Load[1] | | | | | 3479 | | 3479 | | | 1484 | 1484 | 2481 |
| | **TOTAL =** | | | | | **10227** | | **11964** | | | **5522** | **5595** | **8327** |
| Model Results | Model Predicted TP [ug/L] | | | | | 276 | | 197 | | | 167 | 168 | 207 |
| | Observed TP [ug/L] | | | | | 290 | | 220 | | | 145 | 169 | 206 |

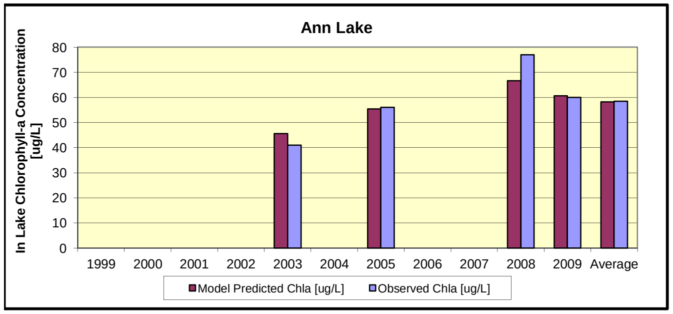


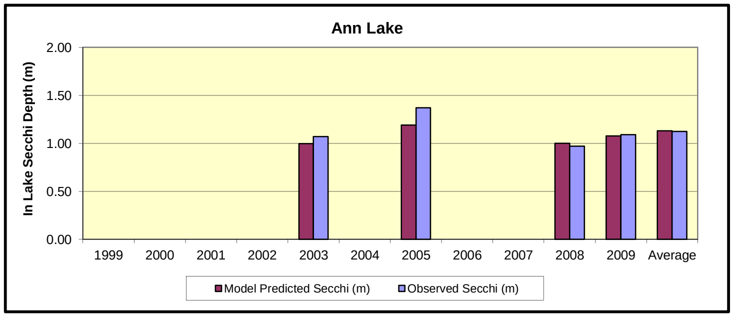




| Ann Lake | | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model Results | Model Predicted Chla [ug/L] | | | | | 46 | | 55 | | | 67 | 61 | 58 |
| | Observed Chla [ug/L] | | | | | 41 | | 56 | | | 77 | 60 | 59 |
| Model Results | Model Predicted Secchi (m) | | | | | 1.00 | | 1.19 | | | 1.00 | 1.08 | 1.13 |
| | Observed Secchi (m) | | | | | 1.07 | | 1.37 | | | 0.97 | 1.09 | 1.13 |



# *Average Loading Summary for Ann Lake*

| Water Budgets | | | | Phosphorus Loading | | |
|---|---|---|---|---|---|---|
| ***Inflow from Drainage Areas*** | | | | | | |
| Name | Drainage Area [acre] | Runoff Depth [in/yr] | Discharge [ac-ft/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [lb/yr] |
| 1 Watershed | 90.20 | 0.0 | 6,480 | 328 | 1.0 | 5,762 |
| 2 | | | | | 1.0 | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| ***Summation*** | ***90*** | ***0*** | ***6,480*** | ***327.5*** | | ***5,762.3*** |
| ***Failing Septic Systems*** | | | | | | |
| Name | Area [ac] | # of Systems | Failure [%] | Load / System | [lb/ac] | [lb/yr] |
| 1 Watershed | 90 | 0 | 0% | 0.0 | 0.0 | 0.0 |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| ***Summation*** | ***90*** | ***0*** | ***0%*** | | ***0.0*** | ***0.0*** |
| ***Inflow from Upstream Lakes*** | | | | | | |
| Name | | | Discharge [ac-ft/yr] | Estimated P Concentration [ug/L] | Calibration Factor [--] | Load [lb/yr] |
| 1 | | | | - | 1.0 | |
| 2 | | | | - | 1.0 | |
| 3 | | | | - | 1.0 | |
| ***Summation*** | | | ***0*** | ***-*** | | ***0*** |
| ***Atmosphere*** | | | | | | |
| Lake Area [acre] | Precipitation [in/yr] | Evaporation [in/yr] | Net Inflow [ac-ft/yr] | Aerial Loading Rate [lb/ac-yr] | Calibration Factor [--] | Load [lb/yr] |
| 375 | 22.0 | 22.0 | 0.00 | 0.22 | 1.0 | 83.3 |
| | | | Dry-year total P deposition = | 0.222 | | |
| | | | Average-year total P deposition = | 0.239 | | |
| | | | Wet-year total P deposition = | 0.259 | | |
| | | | (Barr Engineering 2004) | | | |
| ***Groundwater*** | | | | | | |
| Lake Area [acre] | Groundwater Flux [m/yr] | | Net Inflow [ac-ft/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [lb/yr] |
| 375 | 0.0 | | 0.00 | 0 | 1.0 | 0 |
| ***Internal*** | | | | | | |
| Lake Area [acre] | Anoxic Factor [days] | | | Release Rate [mg/m$^2$-day] | Calibration Factor [--] | Load [lb/yr] |
| 375 | 122 | | | 4.7 | 1.0 | 1,935 |
| 375 | 31.0 | | | 5.2 | 1.0 | 543 |
| | | | **Net Discharge [ac-ft/yr] = 6,480** | | **Net Load [lb/yr] =** | **8,326** |

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.

## *Average Lake Response Modeling for Ann 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) | | |
| | | $C_P$ = | 0.64 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 8,326 | [lb/yr] |
| | | Q (lake outflow) = | 6,483 | [ac-ft/yr] |
| | | V (modeled lake volume) = | 3,756 | [ac-ft] |
| | | T = V/Q = | 0.58 | [yr] |
| | | $P_i$ = W/Q = | 472 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **205.9** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **206.0** | **[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]** | | | **57.6** | **[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) = | 206 | [ug/l] |
| | | N (Total Nitrogen) = | 1670 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 140.3 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 123.4 | [ug/l] |
| | | G (Kinematic factor) = | 0.66 | [--] |
| | | $F_s$ (Flushing Rate) = | 1.73 | [year$^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 14.76 | [ft] |
| | | $C_a$ (non-algal turbity coefficient) = | 0.015 | [-] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - C_a \times [\mathrm{Chl}a]$ | a (Non algal turbidity) = | 0.01 | [m$^{-1}$] |
| | | S (Secchi Depth) = | 3.69 | [ft] |
| | | Maximum lake depth = | 18.79 | [ft] |
| **Model Predicted In-Lake [Chl-a]** | | | **58.3** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **27.9** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\mathrm{a} + C_a \times [\mathrm{Chl}\ a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.01 | [m$^{-1}$] |
| **Model Predicted In-Lake SD** | | | **1.13** | **[m]** |
| **Observed In-Lake SD** | | | **1.43** | **[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) =** | **4,697** | **[lb/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **3,629** | **[lb/yr]** |

# TMDL Loading Summary for Ann Lake

| Water Budgets | | | | Phosphorus Loading | | |
|---|---|---|---|---|---|---|

## Inflow from Drainage Areas

| Name | Drainage Area [acre] | Runoff Depth [in/yr] | Discharge [ac-ft/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [lb/yr] |
|---|---|---|---|---|---|---|
| 1 Watershed | 90.20 | 0.0 | 6,480 | 73 | 1.0 | 1,278 |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| ***Summation*** | ***90*** | ***0*** | ***6,480*** | ***72.7*** | | ***1,278.3*** |

## Failing Septic Systems

| Name | Area [ac] | # of Systems | Failure [%] | Load / System | [lb/ac] | [lb/yr] |
|---|---|---|---|---|---|---|
| 1 Watershed | 90 | 0 | 0% | 0.0 | 0.0 | 0.0 |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| ***Summation*** | ***90*** | ***0*** | ***0%*** | | ***0.0*** | ***0.0*** |

## Inflow from Upstream Lakes

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

## Atmosphere

| Lake Area [acre] | Precipitation [in/yr] | Evaporation [in/yr] | Net Inflow [ac-ft/yr] | Aerial Loading Rate [lb/ac-yr] | Calibration Factor [--] | Load [lb/yr] |
|---|---|---|---|---|---|---|
| 375 | 22.0 | 22.0 | 0.00 | 0.22 | 1.0 | 83.3 |

Dry-year total P deposition = 0.222
Average-year total P deposition = 0.239
Wet-year total P deposition = 0.259
(Barr Engineering 2004)

## Groundwater

| Lake Area [acre] | Groundwater Flux [m/yr] | Net Inflow [ac-ft/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [lb/yr] |
|---|---|---|---|---|---|
| 375 | 0.0 | 0.00 | 0 | 1.0 | 0 |

## Internal

| Lake Area [acre] | Anoxic Factor [days] | Release Rate [$mg/m^2$-day] | Calibration Factor [--] | Load [lb/yr] |
|---|---|---|---|---|
| 375 | 122 | 0.5 | 1.0 | 204 |
| 375 | 15.0 | 0.50 | 1.0 | 25 |

**Net Discharge [ac-ft/yr] = 6,480** | **Net Load [lb/yr] = 1,591**

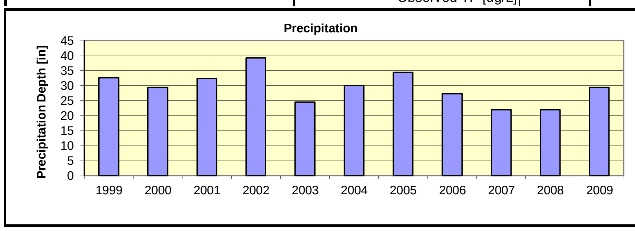
NOTES

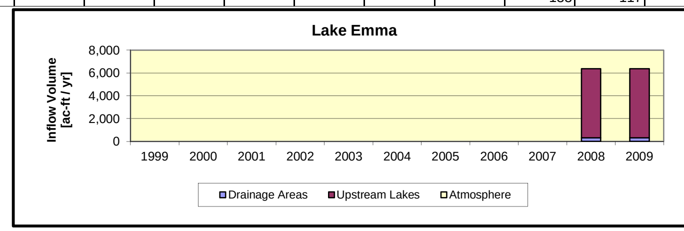
[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

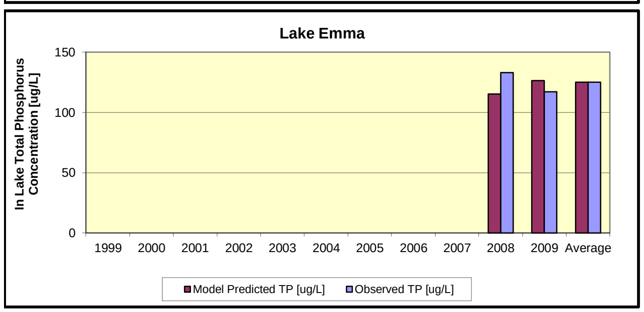
# *TMDL Lake Response Modeling for Ann Lake*

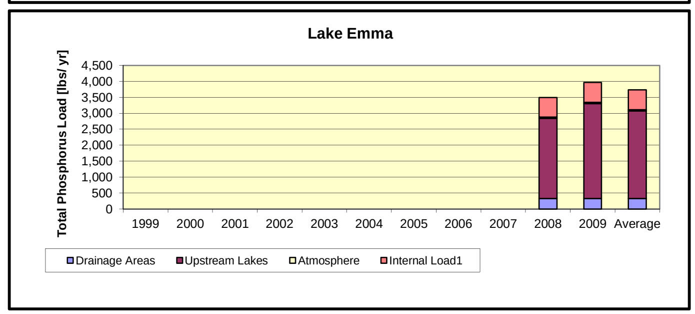
| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 0.53 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 1,591 | [lb/yr] |
| | | Q (lake outflow) = | 6,483 | [ac-ft/yr] |
| | | V (modeled lake volume) = | 3,756 | [ac-ft] |
| | | T = V/Q = | 0.58 | [yr] |
| | | $P_i$ = W/Q = | 90 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **60.1** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **60.0** | **[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]** | | | **16.8** | **[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) = | 1670 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 37.5 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\dfrac{N-150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 45.8 | [ug/l] |
| | | G (Kinematic factor) = | 0.75 | [--] |
| | | $F_s$ (Flushing Rate) = | 1.73 | [year$^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 16.73 | [ft] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - C_a \times [\mathrm{Chl}a]$ | $C_a$ (non-algal turbity coefficient) = | 0.015 | [-] |
| | | a (Non algal turbidity) = | 0.70 | [m$^{-1}$] |
| | | S (Secchi Depth) = | 3.28 | [ft] |
| | | Maximum lake depth = | 18.79 | [ft] |
| **Model Predicted In-Lake [Chl-a]** | | | **17.3** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **20.0** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\mathrm{a} + C_a \times [\mathrm{Chl}\ a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.70 | [m$^{-1}$] |
| **Model Predicted In-Lake SD** | | | **1.04** | **[m]** |
| **Observed In-Lake SD** | | | **1.43** | **[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) =** | **532** | **[lb/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **1,059** | **[lb/yr]** |

| Lake Emma | Source | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Precipitation Depth [in] | | 30.02 | 32.68 | 29.42 | 32.4 | 39.22 | 24.52 | 30.12 | 34.44 | 27.31 | 22.02 | 22.02 | 29.5 |
| | Residence Time [yr] | | | | | | | | | | 0.2 | 0.2 | 0.2 |
| Inflow Volume [ac-ft / yr] | Drainage Areas | | | | | | | | | | 527 | 527 | 527 |
| | Upstream Lakes | | | | | | | | | | 6049 | 6049 | 6,049 |
| | Atmosphere | | | | | | | | | | 0 | 0 | 0 |
| | **TOTAL =** | | | | | | | | | | **6576** | **6576** | 6,576 |
| Total Phosphorus Load [lbs/ yr] | Drainage Areas | | | | | | | | | | 327 | 327 | 327 |
| | Septic Systems | | | | | | | | | | 0 | 0 | 0 |
| | Upstream Lakes | | | | | | | | | | 2513 | 2978 | 2746 |
| | Atmosphere | | | | | | | | | | 42 | 42 | 42 |
| | Internal Load[1] | | | | | | | | | | 617 | 617 | 617 |
| | **TOTAL =** | | | | | | | | | | **3499** | **3964** | **3731** |
| Model Results | Model Predicted TP [ug/L] | | | | | | | | | | 115 | 126 | 125 |
| | Observed TP [ug/L] | | | | | | | | | | 133 | 117 | 125 |

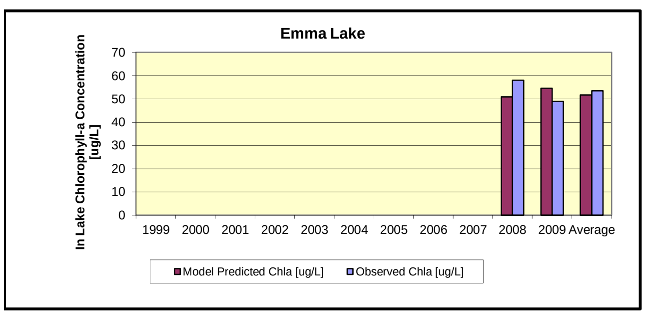


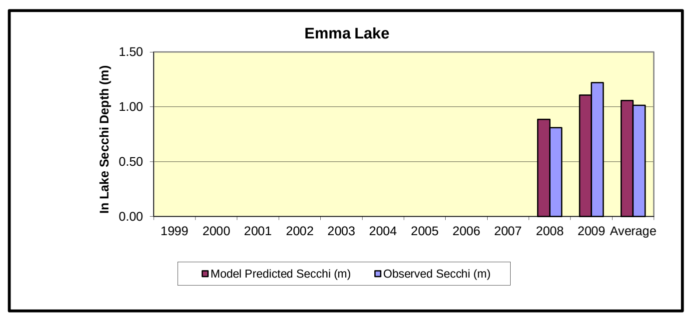




| Lake Emma | | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model Results | Model Predicted Chla [ug/L] | | | | | | | | | | 51 | 55 | 52 |
| | Observed Chla [ug/L] | | | | | | | | | | 58 | 49 | 54 |
| Model Results | Model Predicted Secchi (m) | | | | | | | | | | 0.89 | 1.11 | 1.06 |
| | Observed Secchi (m) | | | | | | | | | | 0.81 | 1.22 | 1.02 |



## *Average Loading Summary for Emma*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Water Budgets** | | | | **Phosphorus Loading** | | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | Direct | 1803.00 | 3.5 | 527 | 228 | 1.0 | 327 |
| 2 | | | | | 0.0 | | |
| 3 | | | | | 0.0 | | |
| 4 | | | | | 0.0 | | |
| 5 | | | | | 0.0 | | |
| | ***Summation*** | ***1,803*** | ***4*** | ***527*** | ***45.6*** | | ***326.6*** |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Area [ac] | # of Systems | Failure [%] | Load / System | [lb/ac] | [lb/yr] |
| 1 | Direct | 1,803 | #N/A | #N/A | #N/A | #N/A | #N/A |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | ***Summation*** | ***1,803*** | ***#N/A*** | ***#N/A*** | | ***0.0*** | |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | Ann | | | 6,049 | 169.0 | 1.0 | 2,746 |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| | ***Summation*** | | | ***6,049*** | ***169.0*** | | ***2,746*** |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 188 | 22.0 | 22.0 | 0.00 | 0.22 | 1.0 | 41.8 |
| | | | | Dry-year total P deposition = | 0.222 | | |
| | | | | Average-year total P deposition = | 0.239 | | |
| | | | | Wet-year total P deposition = | 0.259 | | |
| | | | | (Barr Engineering 2004) | | | |
| ***Groundwater*** | | | | | | | |
| | Lake Area | Groundwater Flux | | Net Inflow | Phosphorus Concentration | Calibration Factor | Load |
| | [acre] | [m/yr] | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| | 188 | 0.0 | | 0.00 | 0 | 1.0 | 0 |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [acre] | [days] | | | [mg/m$^2$-day] | [--] | [lb/yr] |
| | 188 | 122 | | | 1.3 | | 266 |
| | 188 | 18.5 | | | 9.10 | 1.0 | 351 |
| | | | **Net Discharge [ac-ft/yr] =** | **6,576** | | **Net Load [lb/yr] =** | **3,731** |

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.

## *Average Lake Response Modeling for Emma*

| 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) | | |
| | | $C_P$ = | 0.82 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 3,732 | [lb/yr] |
| | | Q (lake outflow) = | 6,579 | [ac-ft/yr] |
| | | V (modeled lake volume) = | 1,422 | [ac-ft] |
| | | T = V/Q = | 0.22 | [yr] |
| | | $P_i$ = W/Q = | 209 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **125.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **125.0** | **[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]** | | | **35.0** | **[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) = | 125 | [ug/l] |
| | | N (Total Nitrogen) = | 1670 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 113.4 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 105.1 | [ug/l] |
| | | G (Kinematic factor) = | 0.58 | [--] |
| | | $F_s$ (Flushing Rate) = | 4.63 | [year$^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 12.14 | [ft] |
| | | $C_a$ (non-algal turbity coefficient) = | 0.015 | [-] |
| | $F_s = \frac{Q}{V}$ ; $a = \frac{1}{SD} - C_a \times [\mathrm{Chl}a]$ | a (Non algal turbidity) = | 0.17 | [m$^{-1}$] |
| | | S (Secchi Depth) = | 3.35 | [ft] |
| | | Maximum lake depth = | 16.25 | [ft] |
| **Model Predicted In-Lake [Chl-a]** | | | **51.7** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **54.0** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \frac{CS}{(\mathrm{a} + C_a \times [\mathrm{Chl}\ a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.17 | [m$^{-1}$] |
| **Model Predicted In-Lake SD** | | | **1.06** | **[m]** |
| **Observed In-Lake SD** | | | **1.43** | **[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) =** | **1,495** | **[lb/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **2,237** | **[lb/yr]** |

## *TMDL Loading Summary for Emma*

| Water Budgets | | | | Phosphorus Loading | | |
|---|---|---|---|---|---|---|

### *Inflow from Drainage Areas*

| Name | Drainage Area [acre] | Runoff Depth [in/yr] | Discharge [ac-ft/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [lb/yr] |
|---|---|---|---|---|---|---|
| 1 Direct | 1803.00 | 3.5 | 527 | 228 | 1.0 | 327 |
| 2 | | | | 0.0 | | |
| 3 | | | | 0.0 | | |
| 4 | | | | 0.0 | | |
| 5 | | | | 0.0 | | |
| ***Summation*** | ***1,803*** | ***4*** | ***527*** | ***45.6*** | | ***326.6*** |

### *Failing Septic Systems*

| Name | Area [ac] | # of Systems | Failure [%] | Load / System | [lb/ac] | [lb/yr] |
|---|---|---|---|---|---|---|
| 1 Direct | 1,803 | #N/A | #N/A | #N/A | #N/A | #N/A |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| ***Summation*** | ***1,803*** | ***#N/A*** | ***#N/A*** | | ***0.0*** | |

### *Inflow from Upstream Lakes*

| Name | Discharge [ac-ft/yr] | Estimated P Concentration [ug/L] | Calibration Factor [--] | Load [lb/yr] |
|---|---|---|---|---|
| 1 Ann | 6,049 | 60.0 | 1.0 | 2,746 |
| 2 | | - | 1.0 | |
| 3 | | - | 1.0 | |
| ***Summation*** | ***6,049*** | ***60.0*** | | ***985*** |

### *Atmosphere*

| Lake Area [acre] | Precipitation [in/yr] | Evaporation [in/yr] | Net Inflow [ac-ft/yr] | Aerial Loading Rate [lb/ac-yr] | Calibration Factor [--] | Load [lb/yr] |
|---|---|---|---|---|---|---|
| 188 | 22.0 | 22.0 | 0.00 | 0.22 | 1.0 | 41.8 |
| | | | Dry-year total P deposition = | 0.222 | | |
| | | | Average-year total P deposition = | 0.239 | | |
| | | | Wet-year total P deposition = | 0.259 | | |
| | | | (Barr Engineering 2004) | | | |

### *Groundwater*

| Lake Area [acre] | Groundwater Flux [m/yr] | Net Inflow [ac-ft/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [lb/yr] |
|---|---|---|---|---|---|
| 188 | 0.0 | 0.00 | 0 | 1.0 | 0 |

### *Internal*

| Lake Area [acre] | Anoxic Factor [days] | Release Rate [mg/m$^2$-day] | Calibration Factor [--] | Load [lb/yr] |
|---|---|---|---|---|
| 188 | 122 | 0.7 | 1.0 | 143 |
| 188 | 18.5 | 1.40 | 1.0 | 54 |

| | | | |
|---|---|---|---|
| **Net Discharge [ac-ft/yr] =** | **6,576** | **Net Load [lb/yr] =** | **1,551** |

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 Emma

| 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) | | |
| | | $C_P$ = | 0.82 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 1,553 | [lb/yr] |
| | | Q (lake outflow) = | 6,579 | [ac-ft/yr] |
| | | V (modeled lake volume) = | 1,422 | [ac-ft] |
| | | T = V/Q = | 0.22 | [yr] |
| | | $P_i$ = W/Q = | 87 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **60.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **60.0** | **[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]** | | | **16.8** | **[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) = | 1670 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 37.5 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 45.8 | [ug/l] |
| | | G (Kinematic factor) = | 0.58 | [--] |
| | | $F_s$ (Flushing Rate) = | 4.63 | [year$^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 12.14 | [ft] |
| | | $C_a$ (non-algal turbity coefficient) = | 0.015 | [-] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - C_a \times [\mathrm{Chl}a]$ | a (Non algal turbidity) = | 0.68 | [m$^{-1}$] |
| | | S (Secchi Depth) = | 3.35 | [ft] |
| | | Maximum lake depth = | 16.25 | [ft] |
| **Model Predicted In-Lake [Chl-a]** | | | **20.2** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **27.9** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\mathrm{a} + C_a \times [\mathrm{Chl}\ a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.68 | [m$^{-1}$] |
| **Model Predicted In-Lake SD** | | | **1.02** | **[m]** |
| **Observed In-Lake SD** | | | **1.43** | **[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) =** | **480** | **[lb/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **1,073** | **[lb/yr]** |