# Cedar Island, Pike, and Eagle Lakes Nutrient TMDL Final

Wenck

Prepared for

Shingle Creek Watershed Management Commission

Minnesota Pollution Control Agency

February 2010

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**Wenck File #1240-22**

Prepared for:

**SHINGLE CREEK WATERSHED MANAGEMENT COMMISSION**

**MINNESOTA POLLUTION CONTROL AGENCY**

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# TMDL Summary

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<tr><td>303(d) Listing Information</td><td>Cedar Island Lake 27-0119-00<br>Pike Lake 27-0111-02<br>Eagle Lake 27-0111-01<br><br>Pike Lake was added to the 303(d) list in 2002, Cedar Island in 2004, and Eagle in 2008 because of excess nutrient concentrations impairing aquatic recreation, as set forth in Minnesota Rules 7050.0150. The Pike and Cedar Island TMDLs were prioritized to start in 2008 and be completed by 2012, and the Eagle Lake TMDL to start in 2012 and be completed by 2016.</td><td>2-1</td></tr>
<tr><td>Applicable Water Quality Standards/ Numeric Targets</td><td>Criteria set forth in Minn. R. 7050.0150 (3) and (5). For Eagle Lake, the numeric target is a total phosphorus concentration of 40 µg/L or less. For Pike and Cedar Island Lakes, which are shallow lakes, the target is a total phosphorus concentration of 60 µg/L or less.</td><td>2-1 – 2-2</td></tr>
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<table>
<tr><th colspan="2">Total maximum daily total phosphorus load (kg/day)</th></tr>
<tr><td>Cedar Island Lake</td><td>0.208</td></tr>
<tr><td>Pike Lake</td><td>0.402</td></tr>
<tr><td>Eagle Lake</td><td>0.909</td></tr>
</table></td><td>7-1 – 7-3</td></tr>
<tr><td>Wasteload Allocation</td><td>Portion of the loading capacity allocated to existing and future permitted sources.
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<tr><td>Permitted Stormwater: Cedar Island</td><td>MS400102 – Maple Grove<br>MS400138 – Hennepin Cnty<br>MS400170 – MnDOT</td><td>0.133</td></tr>
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<tr><td>Permitted Stormwater: Eagle</td><td>MS400102 – Maple Grove<br>MS400112 - Plymouth<br>MS400138 – Hennepin Cnty<br>MS400170 – MnDOT</td><td>0.810</td></tr>
</table></td><td>7-1 – 7-3</td></tr>
</table>

# TMDL Summary

<table>
<tr><td>Load Allocation</td><td>The portion of the loading capacity allocated to existing and future non-permitted sources.
<table>
<tr><th>Source</th><th>Load Allocation (kg/day)</th></tr>
<tr><td>Atmospheric Load</td><td></td></tr>
<tr><td>Cedar Island Lake</td><td>0.024</td></tr>
<tr><td>Pike Lake</td><td>0.017</td></tr>
<tr><td>Eagle Lake</td><td>0.085</td></tr>
<tr><td>Internal Load</td><td></td></tr>
<tr><td>Cedar Island Lake</td><td>0.051</td></tr>
<tr><td>Pike Lake</td><td>0.035</td></tr>
<tr><td>Eagle Lake</td><td>0.014</td></tr>
</table></td><td>7-1 – 7-3</td></tr>
<tr><td>Margin of Safety</td><td>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.</td><td>7-2</td></tr>
<tr><td>Seasonal Variation</td><td>Seasonal variation is accounted for by developing targets for the summer critical period when the frequency and severity of nuisance algal growth is greatest. Although the critical period is the summer, lakes are not sensitive to short-term changes but rather respond to long-term changes in annual load.</td><td>7-9</td></tr>
<tr><td>Reasonable Assurance</td><td>Reasonable assurance is provided by the cooperative efforts of the Shingle Creek Watershed Commission, a joint powers organization with statutory responsibility to protect and improve water quality of the water resources in the Shingle Creek watershed in which these lakes are located, and by the member cities of this organization. In addition, the entire contributing area to these lakes is regulated under the NPDES program and Minnesota’s General Permit requires MS4s to amend their NPDES permit’s Storm Water Pollution Prevention Program within 18 months after adoption of a TMDL to set forth a plan to meet the TMDL wasteload allocation.</td><td>Section 10</td></tr>
<tr><td>Monitoring</td><td>The Shingle Creek Watershed Management Commission periodically monitors these lakes and will continue to do so through the implementation period.</td><td>10-3</td></tr>
<tr><td>Implementation</td><td>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.</td><td>Section 9</td></tr>
<tr><td>Public Participation</td><td>Public comment period: 9/28/09 – 10/28/09<br>Comments: Four comment letters were received<br>Meetings: See Section 8-1</td><td>8-1</td></tr>
</table>

# Executive Summary

This Total Maximum Daily Load (TMDL) study addresses nutrient impairments in the Eagle Lake chain of lakes. The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients in Cedar Island (27-0119-00), Pike (27-0111-02), and Eagle (27-0111-01) Lakes.

The Eagle Lake chain of lakes is a regional water resource located in Hennepin County, Minnesota, in the Shingle Creek watershed, specifically in the cities of Maple Grove and Plymouth. Eagle Lake is a highly used recreational water body that provides opportunities for fishing and swimming as well as aesthetic values. Pike and Cedar Island Lakes provide fishing opportunities. Eagle Lake Regional Park, managed by the Three Rivers Park District, is located on Eagle and Pike Lakes. The drainage area to the lake chain is 2,880 acres of fully developed urban and suburban land. Pike and Eagle Lakes are connected to each other by a channel through a large wetland. Cedar Island Lake has no natural outlet. A pumped outlet discharges into Eagle Lake. The lake system discharges into Eagle Creek, which is a tributary of Shingle Creek, which ultimately discharges into the Mississippi River.

Water quality in Cedar Island and Pike Lakes is considered poor with frequent algal blooms while Eagle Lake has more moderately degraded water quality. Both Cedar Island Lake and Pike Lake drain into Eagle Lake and likely have a large influence on water quality in Eagle Lake. The most severe algal blooms in Eagle Lake occur in late summer. Cedar Island Lake is shallow and has extremely high total phosphorus concentrations and extremely severe algal blooms. Cedar Island Lake has a large internal load that is exacerbated by the presence of curly-leaf pondweed in nuisance densities. Pike Lake is also shallow and has high total phosphorus concentrations throughout the summer with severe algal blooms.

A 67 percent decrease in phosphorus load would be required for Cedar Island Lake to consistently meet water quality standards. Pike Lake would require a 49 percent decrease and Eagle Lake a 40 percent decrease. Pike Lake contributes a substantial load downstream to Eagle Lake, thus improvements to that lake should result in improvement in Eagle Lake. Internal load management, biologic management, and reduction of nonpoint sources of phosphorus in the watershed by retrofitting Best Management Practices (BMPs) would have the most impact on reducing phosphorus load and improving water quality in the chain of lakes.

Aquatic plant management will target in-lake sources of nutrients and fishery management will be coordinated with the Department of Natural Resources (DNR) to manage and maintain a beneficial community. The Shingle Creek Watershed Management Commission will work in partnership with the cities with land that drains to the lakes and other agencies to prepare a more detailed Implementation Plan that will set forth specific strategies and priorities for achieving nutrient load reduction goals.

# 1.0 Introduction

## 1.1 PURPOSE

This Total Maximum Daily Load (TMDL) study addresses a nutrient impairment in Eagle Lake and two lakes in its contributing watershed: Cedar Island and Pike Lakes. The goal of this TMDL is to quantify the pollutant reductions needed to meet the water quality standards for nutrients. The Cedar Island, Pike, and Eagle Lakes 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 these lakes exceed the State-established standards for nutrients.

This TMDL provides waste load allocations (WLAs) and load allocations (LAs) for these three lakes. Based on the current State standard for nutrients, the TMDL establishes a numeric target of 40 µg/L total phosphorus concentration for Eagle Lake and 60 µg/L total phosphorus concentration for Cedar Island and Pike Lakes.

## 1.2 PROBLEM IDENTIFICATION

Pike Lake, located in the cities of Plymouth and Maple Grove, was placed on the 2002 State of Minnesota’s 303(d) list of impaired waters. Cedar Island, which is located in the city of Maple Grove, was placed on the 2004 list and Eagle Lake, which is also in Maple Grove, on the 2008 list. Each was identified for impairment of aquatic recreation. Eagle Lake is highly used for fishing, provides aesthetic values, and Three Rivers Park District plans an expansion of the Eagle Lake Regional Park to include a swimming and picnicking area on the south end of the lake. Pike and Cedar Island Lakes are smaller lakes with limited public access. Pike Lake is directly connected to Eagle Lake by a large wetland through which a channel has been dredged. Water quality in all three lakes does not meet state standards for nutrient concentrations.

Water quality is eutrophic and moderately degraded in Eagle Lake and eutrophic in Pike and hypereutrophic in Cedar Island Lake, which are more severely degraded. The average Carlson’s Trophic State Index (TSI) for phosphorus is 59 for Eagle, 68 for Pike, and 80 for Cedar Island. A TSI value of less than 57 is generally regarded as suitable water quality for swimming.

# 2.0 Target Identification and Determination of Endpoints

## 2.1 IMPAIRED WATERS

The Minnesota Pollution Control Agency (MPCA) first included Pike Lake on the 2002 303(d) list of impaired waters, Cedar Island on the 2004 list and Eagle Lake on the 2008 list (Table 2.1). The lakes are impaired by excess nutrient concentrations, which inhibit aquatic recreation. The MPCA's projected schedule for TMDL completions, as indicated on the 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. The projects were scheduled to be completed in 2012 and 2016. Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

**Table 2.1. Impaired waters in the Eagle Lake chain of lakes.**

| Lake | DNR Lake # | Listing Year | Affected use | Pollutant or stressor | Target TMDL Start | Target TMDL Completion |
|---|---|---|---|---|---|---|
| Cedar Island | 27-0119-00 | 2004 | Aquatic recreation | Excess nutrients | 2008 | 2012 |
| Pike | 27-0111-02 | 2002 | Aquatic recreation | Excess nutrients | 2008 | 2012 |
| Eagle | 27-0111-01 | 2008 | Aquatic recreation | Excess nutrients | 2012 | 2016 |

## 2.2 MINNESOTA WATER QUALITY STANDARDS AND ENDPOINTS

### 2.2.1 State of Minnesota Standards

Minnesota's standards for nutrients limit the quantity of nutrients which may enter waters. Minnesota's standards at the time of listing (Minnesota Rules 7050.0150(3)) stated that in all Class 2 waters of the State (i.e., "…waters…which do or may support fish, other aquatic life, bathing, boating, or other recreational purposes…") "…there shall be no material increase in undesirable slime growths or aquatic plants including algae…". In accordance with Minnesota Rules 7050.0150(5), to evaluate whether a waterbody is in an impaired condition the MPCA developed "numeric translators" for the narrative standard for purposes of determining which lakes should be included in the section 303(d) list as being impaired for nutrients. The numeric translators established numeric thresholds for phosphorus, chlorophyll-a, and clarity as measured by Secchi depth. Table 2.2 lists the thresholds for listing lakes on the 303(d) list of impaired waters in Minnesota that were in place when these lakes were listed.

**Table 2.2. Trophic status thresholds for determination of use support for lakes.**
Thresholds applicable at the time of listing are highlighted in bold.

| **305(b) Designation** | **Full Support** | | | **Partial Support to Potential Non-Support** | | | |
|---|---|---|---|---|---|---|---|
| **303(d) Designation** | **Not Listed** | | | **Review** | **Listed** | | |
| **Ecoregion** | **TP (ppb)** | **Chl-a (ppb)** | **Secchi (m)** | **TP Range (ppb)** | **TP (ppb)** | **Chl-a (ppb)** | **Secchi (m)** |
| North Central Hardwood Forests | **≤ 40** | **≤ 14** | **≥ 1.2** | 40 - 45 | > 45 | > 18 | < 1.1 |
| (Carlson's TSI) | **(<57)** | **(<57)** | **(<57)** | (57 – 59) | (> 59) | (> 59) | (> 59) |

### 2.2.2 End Points Used in this TMDL

The numeric target used to list these three lakes was the numeric translator threshold phosphorus standard for Class 2B waters in the North Central Hardwood Forest ecoregion (40 µg/L) prior to the adoption of new standards in 2008. However, since that time the state has adopted new standards for lakes meeting shallow lakes criteria. Cedar Island and Pike Lakes are now considered shallow lakes and are subject to the revised total phosphorus target of 60 µg/L or greater (Minnesota Rules 7050). Eagle Lake is a deep lake and is subject to the 40 µg/L deep lake standard. Therefore, this TMDL calculates load and wasteload allocations and estimated load reductions based on the end points presented in Table 2.3.

Although the TMDL is set for the total phosphorus standard, one of the other two eutrophication standards must be met: chlorophyll-a and Secchi depth (see Table 2.3). All three of these parameters were assessed to assure that the TMDL will result in compliance with State standards.

**Table 2.3. Target total phosphorus concentration end points used in this TMDL.**

| | **Total Phosphorus Standard (µg/L)** | **Chlorophyll-a Standard (µg/L)** | **Secchi Depth Standard (m)** |
|---|---|---|---|
| Cedar Island Lake | ≤60 | ≤20 | ≥1.0 |
| Pike Lake | ≤60 | ≤20 | ≥1.0 |
| Eagle Lake | ≤40 | ≤14 | ≥1.4 |

## 2.3 PRE-SETTLEMENT CONDITIONS

Another consideration when evaluating nutrient loads to lakes is the natural background load. Ultimately, the background load represents the load the lake would be expected to receive under natural, undisturbed conditions. This load can be determined using ecoregion pre-settlement nutrient concentrations as determined by diatom fossil reconstruction. Diatom inferred total phosphorus concentrations are presented in Table 2.4.

**Table 2.4. Pre-settlement total phosphorus concentrations based on water quality reconstructions from fossil diatoms.**

| | **Ecoregions** | | | |
|---|---|---|---|---|
| | **North Central Hardwood Forest** | | **Western Corn Belt Plains** | |
| **Parameters** | **Shallow[1]** | **Deep** | **Shallow[1]** | **Deep** |
| Total phosphorus concentration (µg/L) | **47** | **26** | 89 | 56 |

All are the concentration at the 75th percentile (MPCA 2002).

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

A 2002 MPCA study reconstructed pre-settlement lake conditions based on diatom assemblages in soil cores from many different representative lakes across the state. None of the Eagle Lake chain lakes were included in the study. Based on the diatom fossils, pre-settlement concentrations were approximately 26 µg/L for deep lakes in the North Central Hardwood Forests ecoregion, and 47 µg/L for shallow lakes. Another benchmark that may be useful in determining goals and load reductions are expected stream concentrations under natural or undisturbed conditions. Table 2.5 provides data from minimally impacted streams in the North Central Hardwood Forest ecoregion.

**Table 2.5. Interquartile range of summer mean concentrations by ecoregion for minimally impacted streams in Minnesota for 1970-1992.**

| Region | Total Phosphorus (µg/L) | | |
|---|---|---|---|
| | 25$^{th}$ Percentile | 50$^{th}$ Percentile | 75$^{th}$ Percentile |
| North Central Hardwood Forest | 70 | 100 | 170 |

(McCollor and Heiskary 1993).

To achieve the predicted background load, average in-stream concentrations for Cedar Island, Pike, and Eagle Lakes would need to be approximately 85 to 100 µg/L, 80 to 95 µg/L, and 45 to 55 µg/L, respectively. The values for Cedar Island and Pike are between the 25$^{th}$ and 50$^{th}$ percentiles shown in Table 2.5 but the values for Eagle is significantly lower than the low end of the interquartile range (70 µg/L).

# 3.0 Watershed and Lake Characterization

## 3.1 LAKE AND WATERSHED DESCRIPTION

Much of the drainage area of these lakes is located within the City of Maple Grove; about half of the Pike Lake drainage area is located within the City of Plymouth (see Figure 3.1 and Figure 3.2). Cedar Island Lake discharges through a pumped outlet into a storm sewer system to Eagle Lake, while Pike Lake is connected to Eagle Lake by a large wetland through which a short channel has been dredged. The area is almost fully developed, with a 2000 Census population of about 18,000.

Cedar Island Lake is approximately 79 acres in size with an average depth of 4.6 feet. The lake is entirely littoral (i.e., less than 15 feet in depth) and, therefore, aquatic vegetation has a significant impact on the water quality in this shallow lake. The residence time indicates that runoff from the watershed in an average year displaces lake volume in just over half a year, providing a significant supply of nutrients to the lake regularly. There are about 10 storm sewer outfalls discharging into the lake.  Additional details for Cedar Island Lake are provided in Table 3.1.

Pike Lake is approximately 60 acres in size with an average depth of 7 feet. Approximately 95% of the surface area is littoral and, therefore, aquatic vegetation has a significant impact on the water quality in this shallow lake. The residence time indicates that runoff from the watershed in an average year displaces the lake volume twice per year. There are about 5 storm sewer outfalls discharging into the lake or its extensive wetland fringe.  Additional details for Pike Lake are provided in Table 3.1.

Eagle Lake is approximately 287 acres in size with an average depth of 12.5 feet. Approximately 68% of the surface area is littoral and, therefore, aquatic vegetation has an impact on the water quality in this deep lake. The residence time indicates that runoff from the watershed displaces the lake volume approximately once every 4 years which indicates that nutrients washed off from the watershed are used to feed several growing seasons of aquatic organisms. There are about 15 storm sewer outfalls discharging into the lake or its extensive wetland fringe.  Additional details for Eagle Lake are provided in Table 3.1.

**Table 3.1. Morphometric characteristics of the Eagle Lake chain of lakes.**

| Parameter | Cedar Island | Pike Lake | Eagle Lake |
|---|---|---|---|
| Surface Area (ac) | 79 | 60 | 287 |
| Average Depth (ft) | 3.6 | 8.6 | 10.4 |
| Maximum Depth (ft) | 7 | 22 | 34 |
| Volume (ac-ft) | 285 | 514 | 2,991 |
| Residence Time (years) | 0.6 | 0.5 | 0.64 |
| Littoral Area (ac) | 79 (100%) | 55 (95%) | 199 (68%) |
| Watershed (ac) | 642 | 1,071 | 2,879 |

### 3.1.1 Cedar Island Lake

The Cedar Island Lake subwatershed is developed with typical suburban low density residential land use dominating and lies within the City of Maple Grove. The subwatershed includes parts of the drainage system for the I-494/94 Fish Lake Interchange. There are several ponds in the subwatershed that provide pretreatment of drainage prior to discharge into the lake. The lake has a pumped outlet to storm sewer that ultimately drains to Eagle Lake.

### 3.1.2 Pike Lake

The Pike Lake subwatershed is mostly developed, although some vacant land remains for commercial development (see Table 3.2 and Figure 3.3). The subwatershed is drained by Pike Creek. A stream restoration project completed in 2001 corrected severe erosion along 1,300 feet of channel downstream of Hemlock Lane to Pike Lake. There are several large wetlands in the subwatershed. Eagle Lake Regional Park and its nine-hole golf course are located on the east side of Pike Lake. Old aerial photos show a road crossing the isthmus between Pike and Eagle Lakes; that crossing has been replaced by a trail and trail bridge that are part of the park. Construction of a 200-acre industrial park in the southeast corner of the subwatershed in the city of Plymouth during the late 1980s altered the subwatershed’s historic drainage pattern, removing some drainage area from Pike Lake and draining it directly to Bass Creek.

### 3.1.3 Eagle Lake

The Eagle Lake subwatershed is almost entirely developed and includes portions of the drainage system for I-94. Riparian wetlands surround the lake, and several channels have been cleared through the emergent vegetation to provide boat access for lakeshore properties. Eagle Lake discharges through Eagle Creek to the east. Shingle Creek is formed about one-half mile to the east, at the confluence of Eagle Creek and Bass Creek.

## 3.2 LAND USE

**Table 3.2. 2000 land use in the Cedar Island Lake, Pike Lake and Eagle Lake watersheds.**

| Land Use Class | Cedar Island Lake | | Pike Lake | | Eagle Lake | |
|---|---|---|---|---|---|---|
| | Area (acres) | Percent | Area (acres) | Percent | Area (acres) | Percent |
| Single Family Residential | 185 | 29% | 318 | 30% | 938 | 33% |
| Undeveloped | 61 | 10% | 179 | 17% | 358 | 12% |
| Park, Rec, Preserve, Golf | 12 | 2% | 228 | 21% | 328 | 11% |
| Agriculture, Farmstead | -- | -- | -- | -- | -- | -- |
| Water | 94 | 14% | 62 | 6% | 453 | 16% |
| Highway | 152 | 24% | 38 | 4% | 243 | 8% |
| Multi-Family Residential | 72 | 11% | 51 | 5% | 196 | 7% |
| Commercial/Industrial | 40 | 6% | 182 | 16% | 244 | 9% |
| Institutional | 25 | 4% | 13 | 1% | 119 | 4% |
| Total Area | 641 | 100% | 1,071 | 100% | 2,878 | 100% |

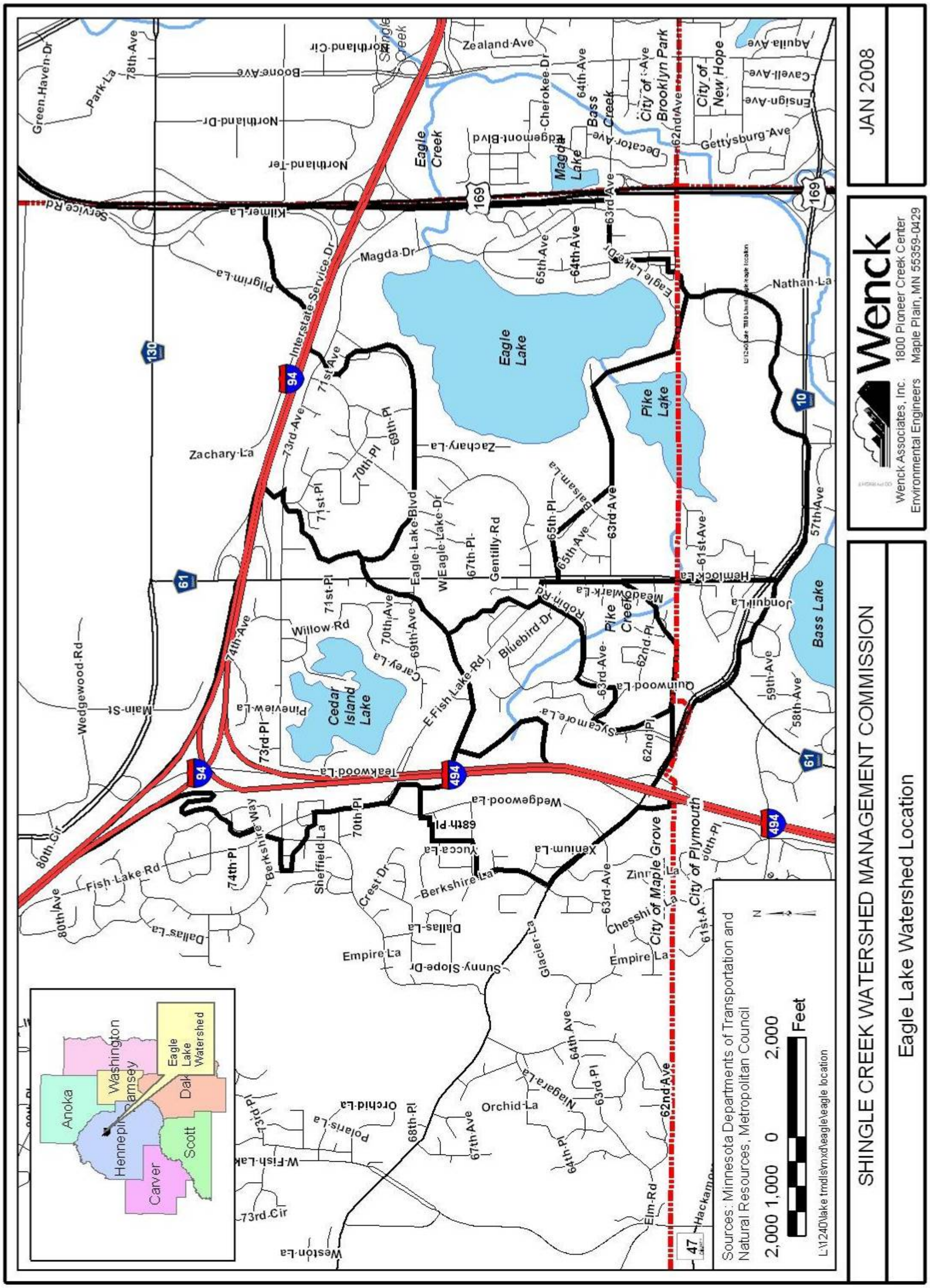



**Figure 3.1. Location map.**

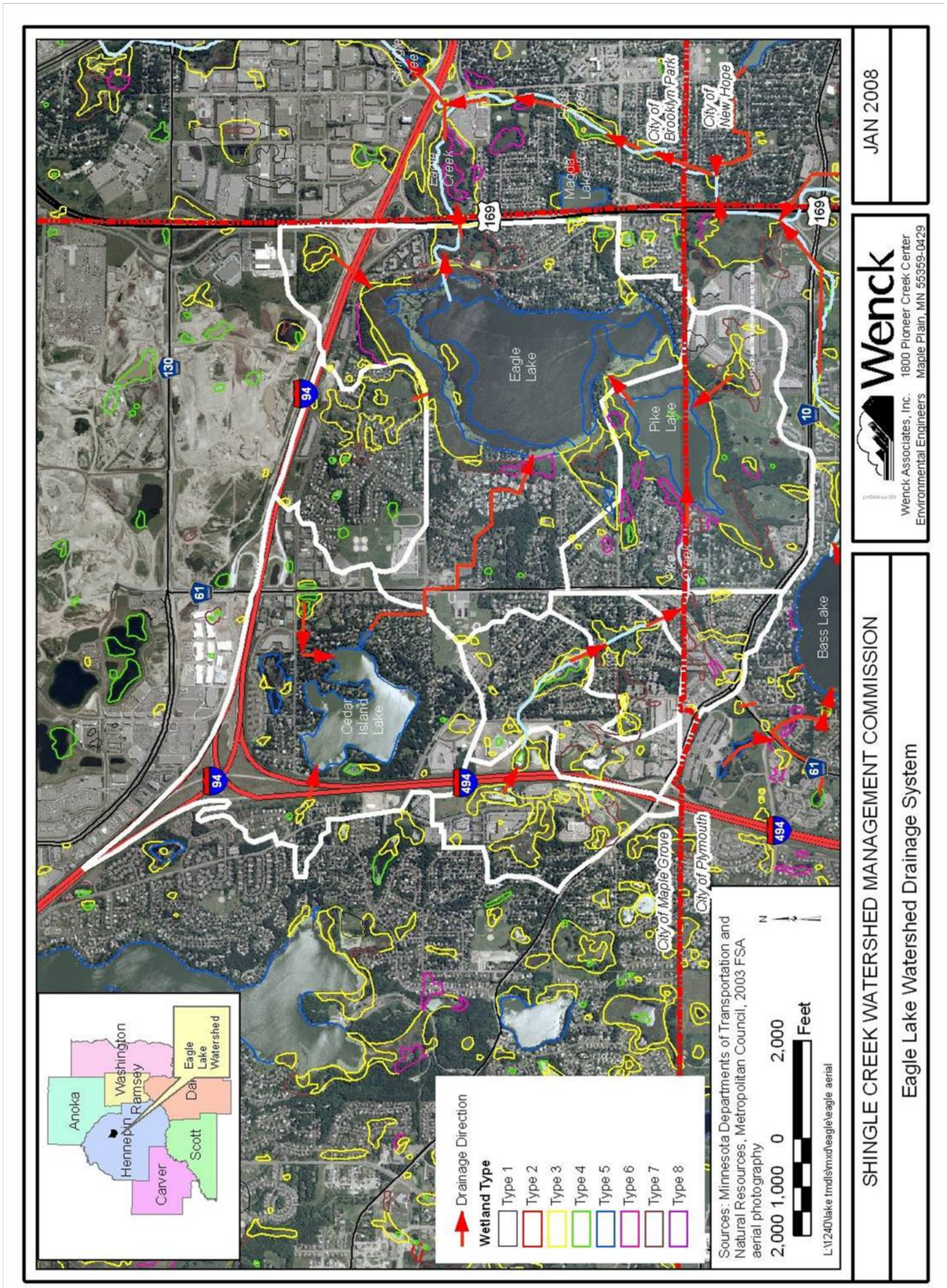



**Figure 3.2. General drainage system.**

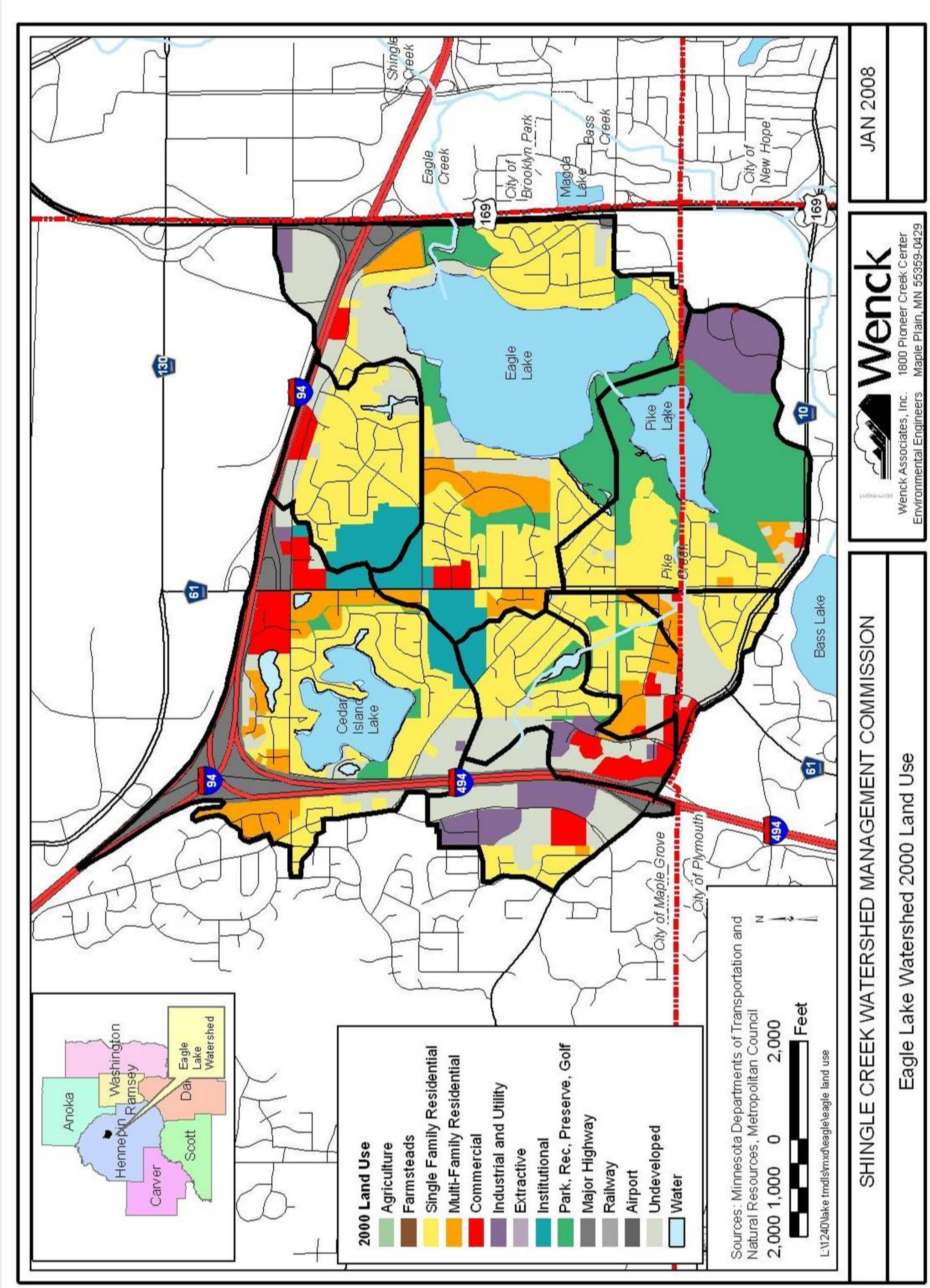



**Figure 3.3. 2000 land use.**

## 3.3 RECREATIONAL USES

### 3.3.1 Parks and Open Space

The largest park in the watershed is the Eagle Lake Regional Park, owned and operated by the Three Rivers Park District. The park's primary recreation facility is a nine hole golf course, although the park also contains paved and unpaved hiking trails and cross country ski trails. The park's long range master plan includes a potential swimming, picnicking, and boating area on the south shore of Eagle Lake, on the isthmus between Eagle and Pike Lakes.

The City of Maple Grove operates Thoresen and Woodcrest Parks on the east shore of Eagle Lake. Several community parks and playlots are located within the watershed. There is city-owned open space on both Eagle and Cedar Island Lakes.

### 3.3.2 Other

The Three Rivers Park District maintains both paved and unpaved trails at Eagle Lake Regional Park, including a trail crossing of the channel between Pike and Eagle Lakes.

Boat access to Eagle Lake is available at Woodcrest Park on the northeast shore. A shallow dredged channel connects Eagle and Pike Lakes. Cedar Island Lake does not have a public boat access.

A fishing pier is available on Eagle Lake in the Eagle Lake Regional Park, while shore fishing is possible at Thoresen Park. No public swimming access is available.

## 3.4 WATER CONDITION

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

### 3.4.1 Historic Water Quality

Historic water quality is presented in Figure 3.4, Figure 3.6, and Figure 3.8. Historic summer average total phosphorus (TP) concentration in Cedar Island, Pike, and Eagle Lakes ranges from

20 µg/L to 121 µg/L with the highest concentration occurring in Cedar Island Lake and the lowest concentration occurring in Eagle Lake. The standards for Eagle Lake are 40 µg/L TP and 14 µg/L chlorophyll-a, and for Pike and Cedar Island 60 µg/L TP and 20 µg/L chlorophyll-a.

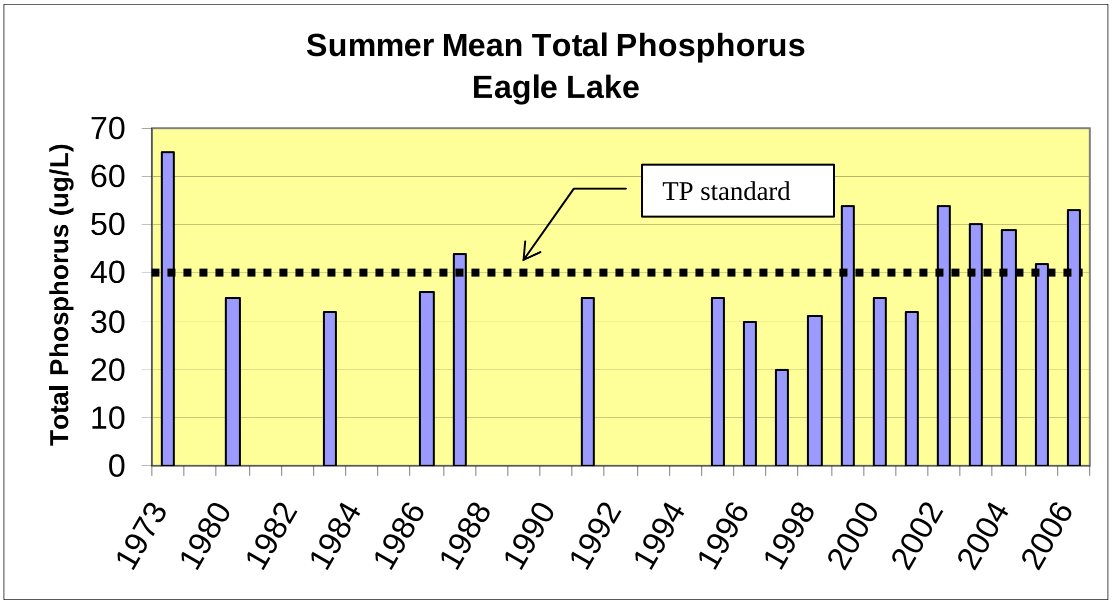



**Figure 3.4. Summer (June 1 –September 30) mean total phosphorus concentrations for Eagle Lake.**

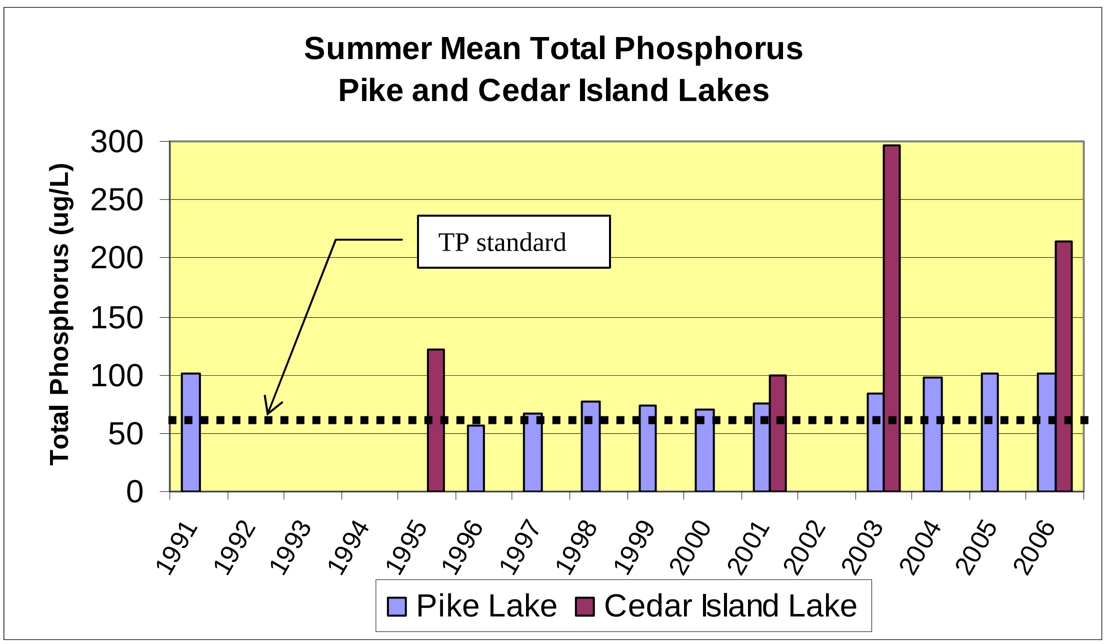



**Figure 3.5. Summer (June 1 –September 30) mean total phosphorus concentrations for Cedar Island and Pike Lakes.**

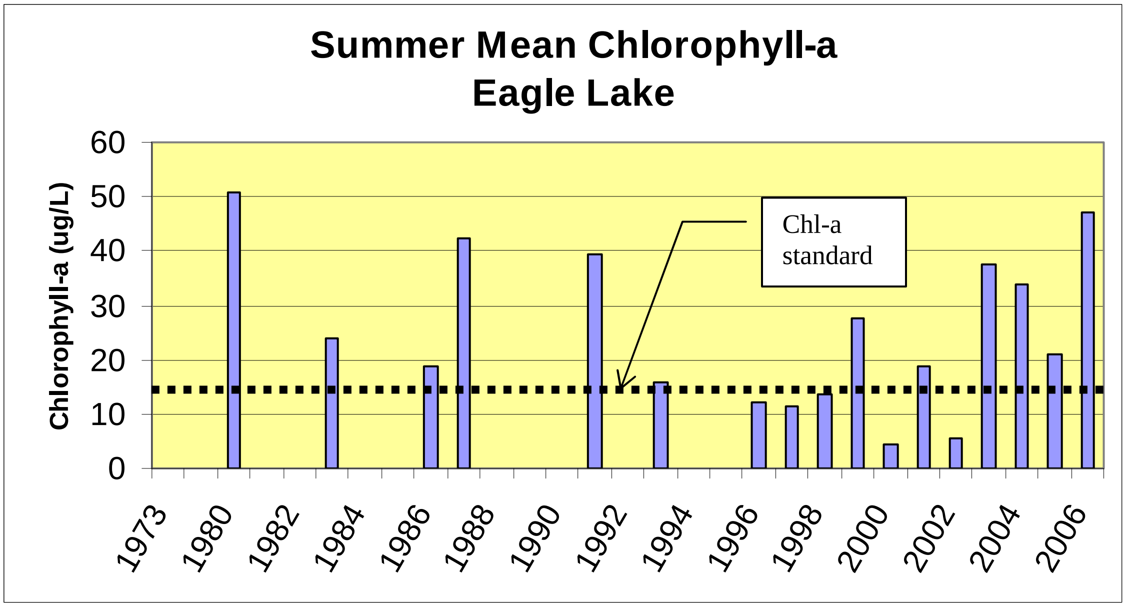



**Figure 3.6. Summer (June 1 –September 30) mean chlorophyll-a concentrations for the chain of lakes.**

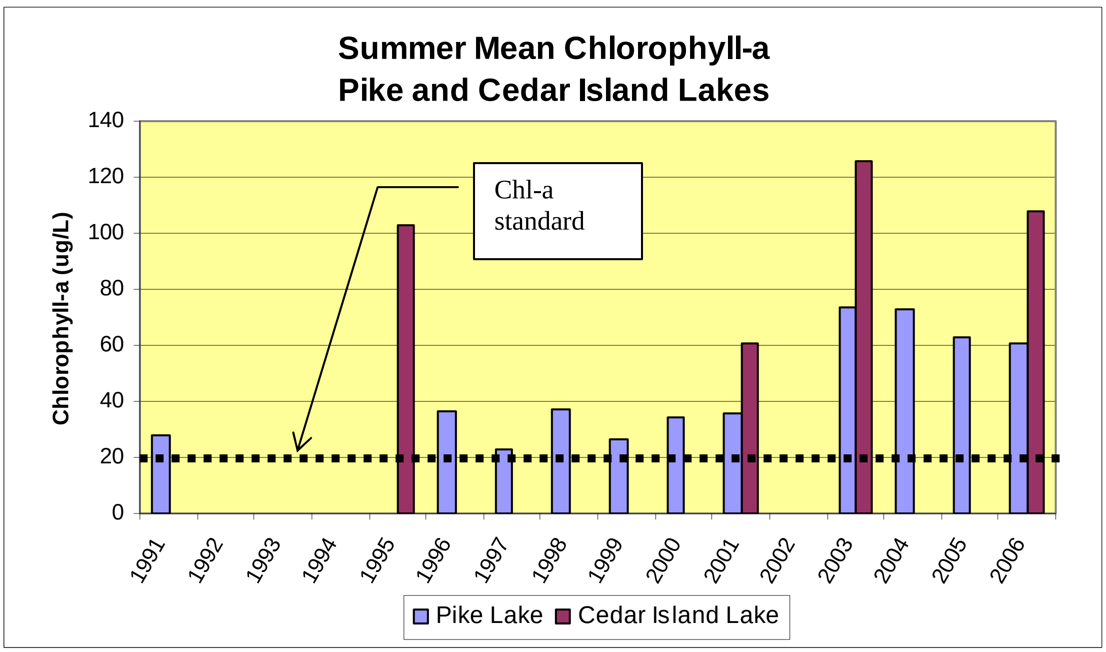
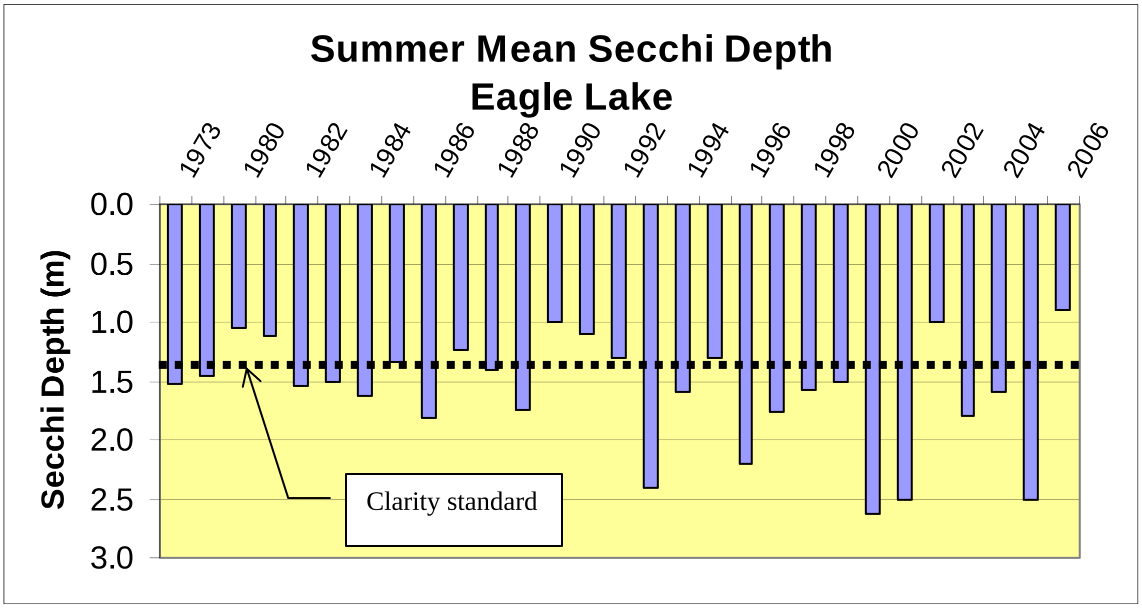



**Figure 3.7. Summer (June 1–September 30) mean chlorophyll-a concentrations for Cedar Island and Pike Lakes.**

Water clarity, as measured by Secchi depth measurements, was observed to follow similar trends as total phosphorus and chlorophyll-a concentrations. The Secchi depth standard for Eagle Lake is 1.4 meters and for Pike and Cedar Island is 1.0 meter.



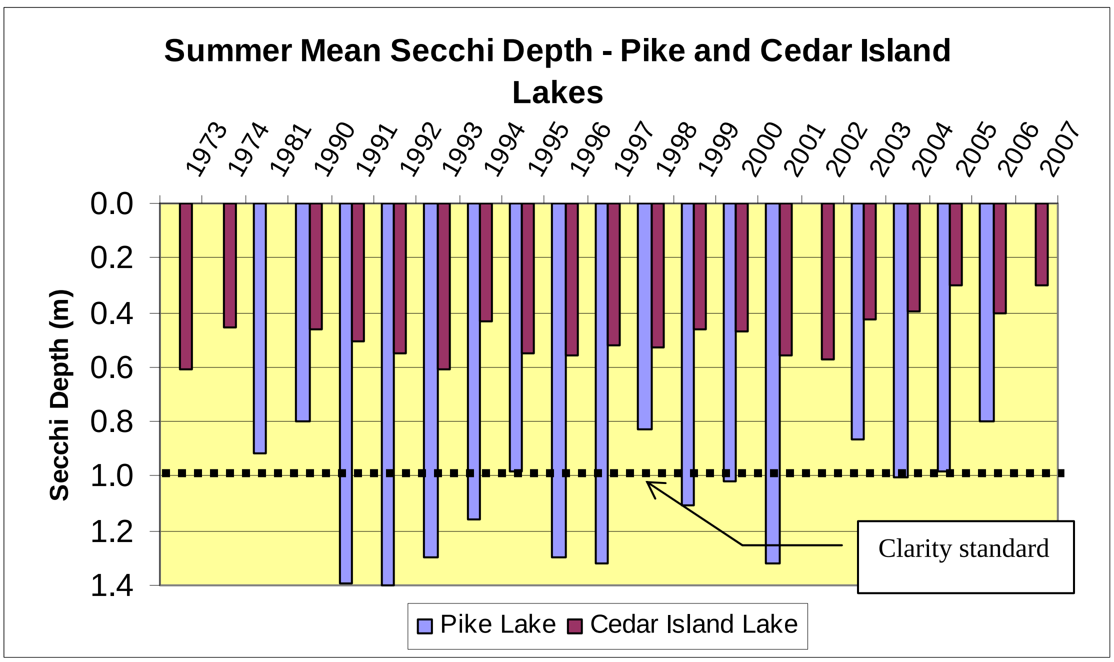




**Figure 3.8. Summer (June 1 –September 30) mean Secchi depth (meters) for the chain of lakes.**

## 3.5 FISH POPULATIONS AND FISH HEALTH

### 3.5.1 Fish Populations

The Minnesota DNR conducted fish population surveys on Eagle Lake in 2004 and on Pike Lake in 1993. There are no data available from the DNR for Cedar Island Lake. Fish species captured during the survey at each lake are shown below (Table 3.3, Figure 3.9, and Figure 3.10).

**Table 3.3. Fish species represented in DNR lake surveys.**

| Fish Species | Pike Lake | Eagle Lake | Fish Species | Pike Lake | Eagle Lake |
|---|---|---|---|---|---|
| Black Bullhead | X | | Hybrid Sunfish | | X |
| Black Crappie | X | X | Largemouth Bass | X | X |
| Bluegill | X | X | Northern Pike | X | X |
| Bowfin | | X | Pumpkinseed Sunfish | X | X |
| Brown Bullhead | X | | Walleye | | X |
| Common Carp | X | X | White Sucker | | X |
| Golden Shiner | X | X | Yellow Bullhead | X | X |
| Green Sunfish | | X | Yellow Perch | X | X |

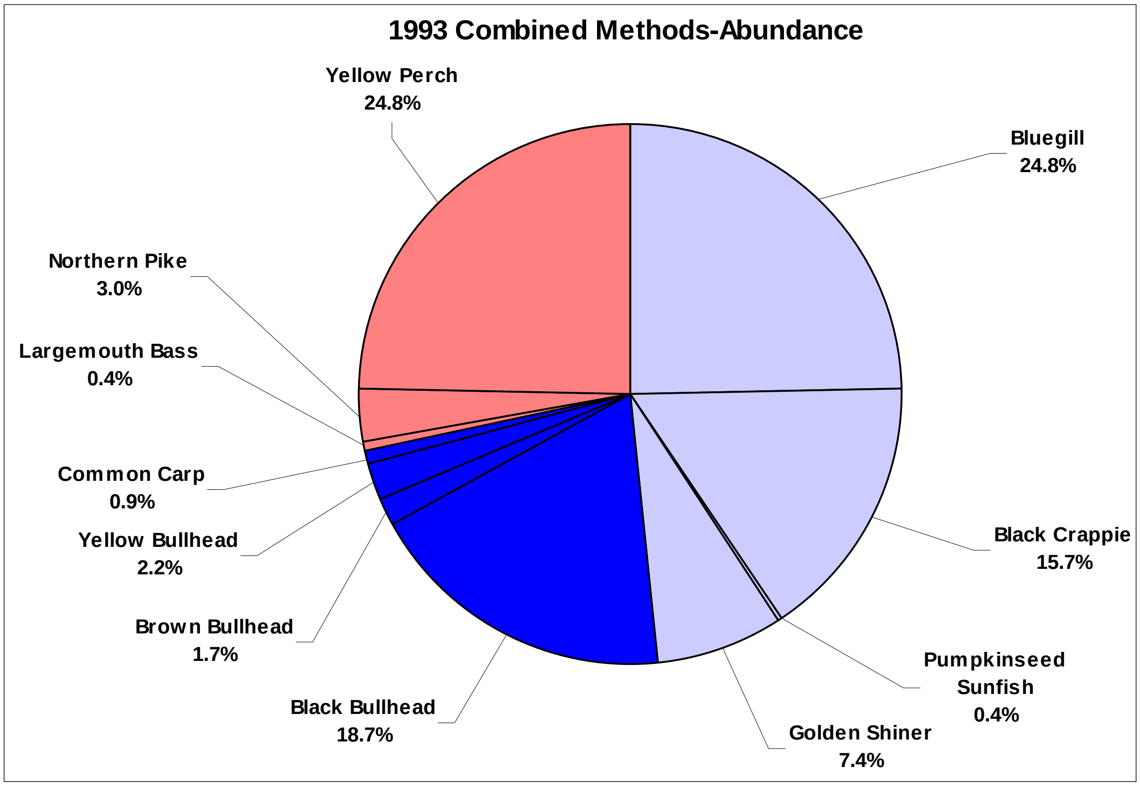
The Eagle Lake fish population contains many of the typical game species found in metro area lakes including such predator species as walleye, largemouth bass, and northern pike, and pan fish species such as bluegill, black crappie, pumpkinseed sunfish and yellow perch. The walleye population in Eagle Lake appears to be down compared to the 1996 sampling, but the northern pike population in the lake is healthy with large numbers of fish over 28 inches in size. The largemouth bass collected were small. Bluegills and perch are present in large numbers in Eagle Lake, but the average individuals are small. Black crappies are less abundant than perch or bluegills. No muskies were collected during the 2004 population survey conducted by the Minnesota DNR, but electrofishing crews noted 10 large muskies in shallow water.
Predator species such as largemouth bass and northern pike are less abundant in Pike Lake as compared to Eagle Lake. However, the observed growth rates for both species were good and the numbers of fish collected were typical for this lake class. Panfish species such as bluegill and black crappie are present in normal numbers for this lake class but the majority of individuals collected were small. Important prey species such as yellow perch and golden shiner are present in large numbers but individuals collected were small. Both yellow and black bullheads are present in normal abundance for this lake class.

### 3.5.2 Fish Stocking

Since 2000 the Minnesota DNR has routinely stocked Eagle Lake with walleye and muskellunge fingerlings, annually alternating the two species. In 2000 over 1,000 walleye adult fish were stocked in Eagle Lake.

### 3.5.3 Fish Kills

Fish kills occur when dissolved oxygen (D.O.) levels are so low that fish begin to die from the lack of oxygen. Fish kills commonly occur during the summer or winter. Summer kills are the result of high productivity (algae and macrophytes) that eventually senesce, and are subsequently broken down by bacteria. The breakdown by bacteria demands oxygen, which depletes D.O. in the water column. These conditions can result in a summer fish kill. Winter fish kills are the result of snow-covered ice that shades out photosynthesis under the ice. These conditions, coupled with a high sediment oxygen demand, can deplete the D.O. under the ice and result in a fish kill. Information from the Minnesota DNR indicates that winter fish kills happen periodically in Pike Lake. The fish population in Pike Lake is restocked by fish that move in from Eagle Lake, which does not experience winter kill due to deep water areas present in the lake. There is no historical record of fish kills in Cedar Island Lake.



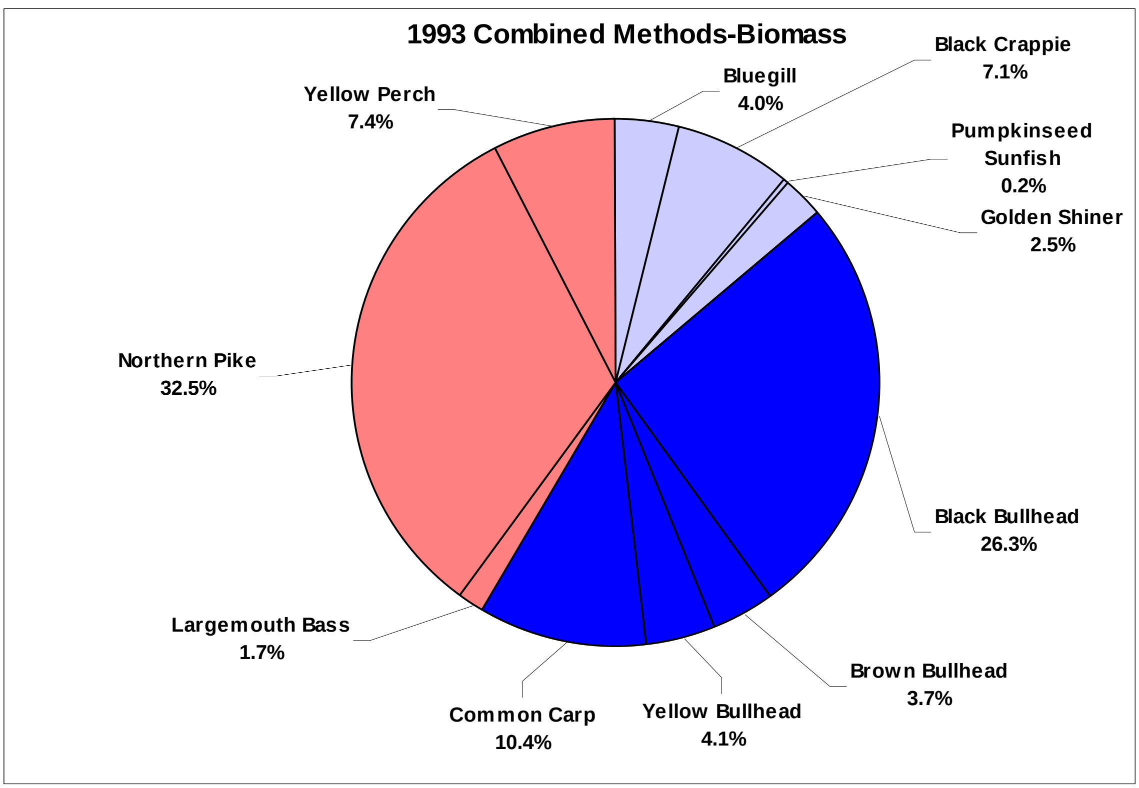
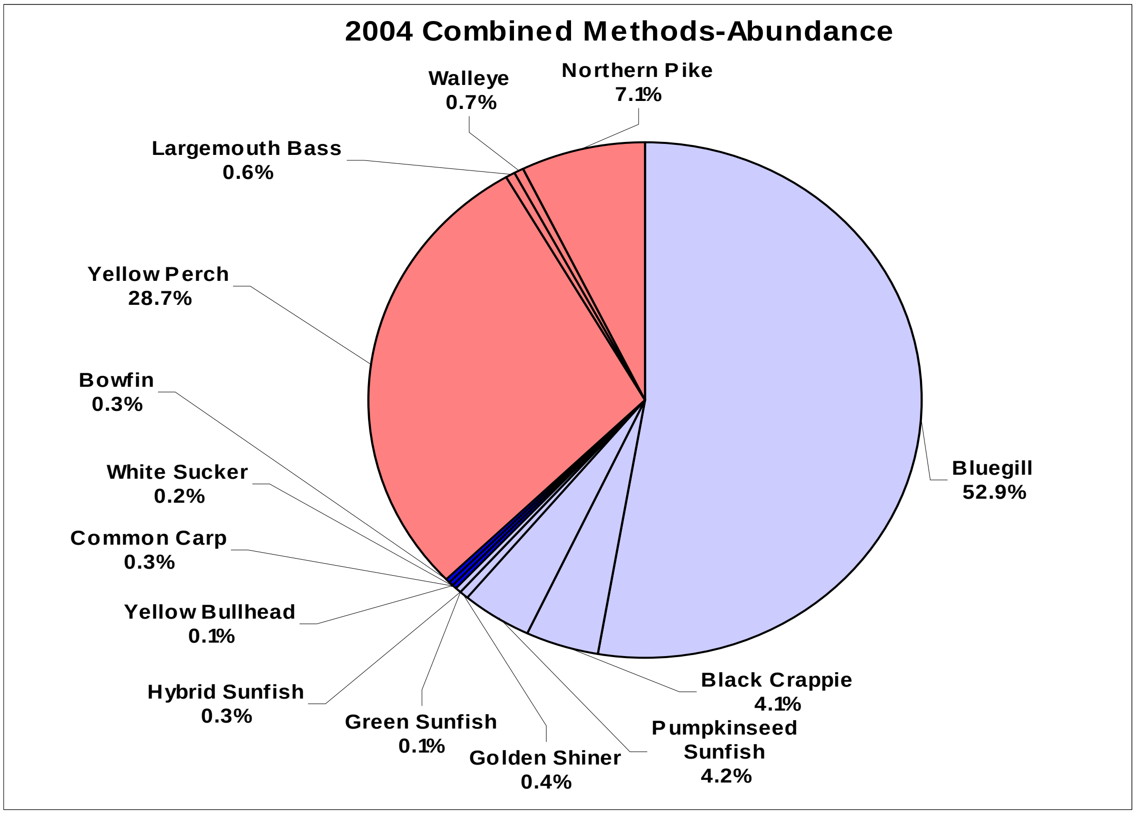




**Figure 3.9. Fish abundance and biomass results from a 1993 fish survey for Pike Lake.**



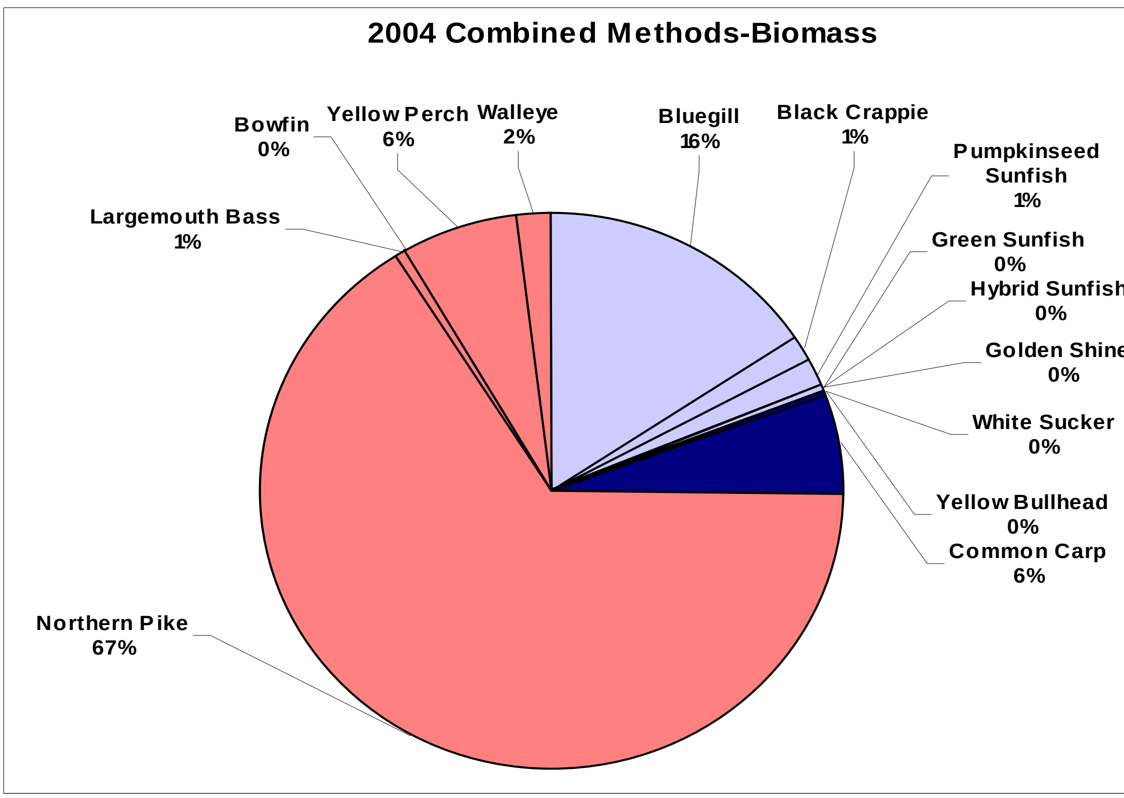




**Figure 3.10. Fish abundance and biomass results from a 2004 fish survey for Eagle Lake.**

### 3.5.4 Carp and Rough Fish

Common carp and other rough fish have both direct and indirect effects on aquatic environments. Carp uproot aquatic macrophytes during feeding and spawning re-suspending bottom sediments and nutrients. These activities can lead to increased nutrients in the water column, ultimately resulting in increased nuisance algal blooms. Fish surveys conducted by the Minnesota DNR collected common carp and various species of bullhead from both Eagle and Pike Lakes. The number of fish caught from each lake was relatively low but the individuals captured were large, ranging from 6 to 10 pounds in Eagle Lake and from 3 to 4.5 pounds in Pike Lake. The large carp present in these lakes have the potential to disturb macrophyte beds and nutrient rich sediments.

## 3.6 AQUATIC PLANTS

### 3.6.1 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 excess they limit recreational activities such as boating and swimming. 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, Eurasian watermilfoil can reduce plant biodiversity in a lake because it grows in great densities and outcompetes 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 in the aquatic plant community in any lake ecosystem.

### 3.6.2 Littoral Zone

The littoral zone is defined as that portion of the lake that is less than 15 feet in depth and is where the majority of the aquatic plants are found. The littoral zone of the lake also provides the essential spawning habitat for most warmwater fish (e.g. bass, walleye, and panfish). As shown in Table 3.1, the littoral area in Cedar Island, Pike, and Eagle Lakes are 100%, 95%, and 68%, of the surface area, respectively. Therefore, the aquatic vegetation will have a significant impact on the water quality in all three lakes.

### 3.6.3 Aquatic Plants in the Eagle Lake Chain

Limited data is available on aquatic plants. A survey conducted in 1999 for Cedar Island Lake found that about 74 percent of the lake bottom was colonized with submerged aquatic plants, with curly-leaf pondweed the dominant plant. About 65 acres were colonized with curly-leaf, with about 10 acres classified as nuisance coverage. Later that season, after the curly-leaf die-back, water lilies and softstem and hardstem bulrush were found, and no submergent vegetation was observed. The Cedar Island Lake Association contracts for aquatic plant chemical treatment to target curly-leaf pondweed. Eagle Lake is on the DNR's list of lakes infested with Eurasian watermilfoil.

## 3.7 SHORELINE HABITAT AND CONDITIONS

The shoreline areas are defined as the areas adjacent to the lake edge with hydrophytic vegetation and water up to 1.5 feet deep or a water table within 1.5 feet from the surface. Shoreline areas should not be confused with shoreland areas which are defined as 1,000 feet upland from the Ordinary High Water (OHW). Natural shorelines provide water quality treatment, wildlife habitat, and increased biodiversity of plants and aquatic organisms. Natural shoreline areas also provide aesthetic values and important habitat to fisheries including spawning areas and refugia.

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

About 60 percent of the Eagle Lake shoreline is dominated by cattails. The remainder is single-family residential with turfed lawns and little native vegetation. Pike Lake is surrounded by cattail wetlands. Except for some small riparian wetlands, the shoreline of Cedar Island Lake is developed as single family residential featuring turfed lawns and little native vegetation. Limited data is available on shoreline conditions, as no shoreline condition surveys have been performed.

# 4.0 Nutrient Source Assessment

## 4.1 INTRODUCTION

Understanding the sources of nutrients to a lake is a key component in developing a TMDL for lake nutrients. This section provides a brief description of the potential sources of phosphorus to the lakes.

## 4.2 PERMITTED SOURCES

### 4.2.1 Wastewater

Permitted sources can range from industrial effluent to municipal wastewater treatment plants. There are no wastewater treatment plant effluent discharges in the watershed. No known permitted wastewater sources are present in the Eagle Lake subwatershed.

### 4.2.2 Stormwater

Phosphorus transported by stormwater represents one of the largest contributors of phosphorus to lakes in Minnesota. In fact, phosphorus export from urban watersheds rivals that of agricultural watersheds. Impervious surfaces in the watershed improve the efficiency of water moving to streams and lakes resulting in increased transport of phosphorus into local water bodies. Phosphorus in stormwater is a result of transporting organic material such as leaves, grass clippings, fertilizers, and sediments to the water body. All of these materials contain phosphorus which can impair local water quality. Consequently, stormwater is a high priority pollution concern in urban and urbanizing watersheds.

There are permitted stormwater sources in the Eagle Lake subwatershed. National Pollution Discharge Elimination System (NPDES) Phase II permits for small municipal separate storm sewer systems (MS4s) have been issued to the member cities in the Shingle Creek watershed as well as Hennepin County and the Minnesota Department of Transportation (MnDOT). The MS4 cities, Hennepin County and MnDOT Metro District, are covered under the Phase II General NPDES Stormwater Permit – MNR040000. Not all the MS4s in the Shingle Creek watershed drain to the Eagle Lake chain. The unique permit numbers assigned to the MS4s that discharge to the Eagle Lake chain are as follows:

- Maple Grove – MS400102
- Plymouth – MS400112
- Hennepin County – MS400138
- MnDOT Metro District – MS400170

Storm sewer information was used to develop the lakeshed boundaries as shown in Figure 3.1. The following MS4s, while located in the Shingle Creek watershed, do not drain to the Eagle Lake chain, and thus are not part of the Categorical Wasteload Allocation:

- Brooklyn Center – MS400006
- Brooklyn Park – MS400007
- Crystal – MS400012
- Minneapolis – MN0061018
- New Hope – MS400039
- Osseo – MS400043
- Robbinsdale – MS400046
- New Hope – MS400039

## 4.3 NON-PERMITTED SOURCES

### 4.3.1 Atmospheric Deposition

Precipitation contains phosphorus that can ultimately end up in the lakes as a result of direct input on the lake surface or as a part of stormwater running off of impervious surfaces in the watershed. Although atmospheric inputs must be accounted for in development of a nutrient budget, direct inputs to the lake surface are impossible to control.

### 4.3.2 Internal Phosphorus Release

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. Large internal loads are the result of significant amounts of phosphorus in lake-bottom sediments that are released under specific conditions. Phosphorus can build up in lake-bottom sediments as part of the eutrophication process which can be accelerated and exacerbated by an increase in phosphorus load export from developing watersheds. Internal loading can be a result of sediment anoxia where poorly bound phosphorus is released in a form readily available for phytoplankton production. Internal loading can also result from sediment resuspension that may result from rough fish activity or propeller wash from boat activity. Additionally, curly-leaf pondweed can increase internal loading because it senesces and releases phosphorus during the summer growing season (late June to early July). All of these factors affect internal phosphorus cycling in these lakes.

# 5.0 Assessment of Water Quality Data

## 5.1 INTRODUCTION

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

## 5.2 PREVIOUS STUDIES AND MONITORING ON THE EAGLE LAKE CHAIN

### 5.2.1 Citizen Assisted Monitoring Program (CAMP)

All three lakes have been periodically monitored by volunteers sponsored and trained by the Shingle Creek Watershed Management Commission (SCWMC) through the Citizen Assisted Monitoring Program (CAMP) operated by Metropolitan Council Environmental Services (MCES). The CAMP program is a volunteer monitoring program where volunteers collect data and samples biweekly including samples for total phosphorus, total Kjeldahl nitrogen, and Secchi depth. The SCWMC has no professional monitoring program at this time. However, some of the member cities have conducted their own monitoring periodically on some of the lakes in the watershed.

### 5.2.2 Three Rivers Park District

The Three Rivers Park District has conducted routine monitoring on Eagle and Pike Lakes since 1999. This data includes monitoring for nutrients as well as both dissolved oxygen and temperature profiles.

### 5.2.3 City of Maple Grove

The City of Maple Grove conducted monitoring of Cedar Island Lake in 1998 and has conducted aquatic plant surveys on the lake in 1999. Water quality monitoring conducted included Secchi disk transparency and total phosphorus concentrations.

## 5.3 MONITORING PARAMETERS

### 5.3.1 Temperature and Dissolved Oxygen

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

No temperature and dissolved oxygen data is available for Cedar Island Lake, but since it is so shallow it most likely mixes several times a year. Limited data for Pike Lake indicates weak summer stratification. Eagle Lake is dimictic.

### 5.3.2 Phosphorus and Nitrogen

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

### 5.3.3 Chlorophyll-a and Secchi Depth

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

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

## 5.4 LAKE MONITORING RESULTS

Following is a discussion of the lake monitoring results for Cedar Island, Pike and Eagle Lakes. The discussion is focused on specific monitoring years to present nutrient cycling dynamics in the lakes.

### 5.4.1 Cedar Island Lake

#### 5.4.1.1 Historical Data

Summer average water quality for Cedar Island Lake is presented in Table 5.1. Data suggests that Cedar Island Lake exhibited poor water clarity as far back as the 1970s. Data in 1995 and 2003 demonstrated severe algal bloom conditions, suggesting little has changed in water quality for Cedar Island Lake in the past 10 to 15 years. Total Kjeldahl nitrogen concentrations in Cedar Island Lake were relatively high in recently monitored years.

**Table 5.1. Historical summer average water quality for Cedar Island Lake.**

| Year | Total Phosphorus (µg/L) | | Chlorophyll-a (µg/L) | | Secchi Depth (m) | |
|---|---|---|---|---|---|---|
| | N | Mean | N | Mean | N | Mean |
| 1973 | | | | | 15 | 0.6 |
| 1974 | | | | | 15 | 0.5 |
| 1990 | | | | | 3 | 0.5 |
| 1991 | | | | | 10 | 0.5 |
| 1992 | | | | | 10 | 0.6 |
| 1993 | | | | | 4 | 0.6 |
| 1994 | | | | | 7 | 0.4 |
| 1995 | 9 | 121 | 9 | 103 | 21 | 0.6 |
| 1996 | | | | | 15 | 0.6 |
| 1997 | | | | | 12 | 0.5 |
| 1998 | | | | | 14 | 0.5 |
| 1999 | | | | | 12 | 0.5 |
| 2000 | | | | | 12 | 0.5 |
| 2001 | 9 | 99 | 8 | 61 | 21 | 0.6 |
| 2002 | | | | | 13 | 0.6 |
| 2003 | 7 | 296 | 7 | 126 | 19 | 0.4 |
| 2004 | | | | | 12 | 0.4 |
| 2005 | | | | | 12 | 0.3 |
| 2006 | 7 | 214 | 7 | 108 | 13 | 0.4 |
| 2007 | | | | | 9 | 0.3 |
| Average | | 173 | | 98 | | 0.5 |
| Standard | 60 or less | | 20 or less | | 1.0 or more | |

N=number of sample
All data collected through the Citizen Assisted Monitoring Program (CAMP)

### 5.4.1.2 Temperature and Dissolved Oxygen

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

### 5.4.1.3 Phosphorus

Looking at the 2001 and 2003 data in more detail (see Figures 5.1 and 5.2), total phosphorus concentrations in Cedar Island Lake demonstrated a dramatic increase in July with total phosphorus increasing by almost 100 µg/L. This increase coincides well with typical curly-leaf pondweed senescence which is the likely cause of the increase in phosphorus concentration. Curly-leaf pondweed dominates the plant community in Cedar Island Lake and has more than 10 acres in nuisance densities.

In addition to the senescence of curly-leaf pondweed, there was a dramatic dry period over the summer. The increase in total phosphorus can be attributed to both an internal loading from the sediments and from curly-leaf pondweed die-off.

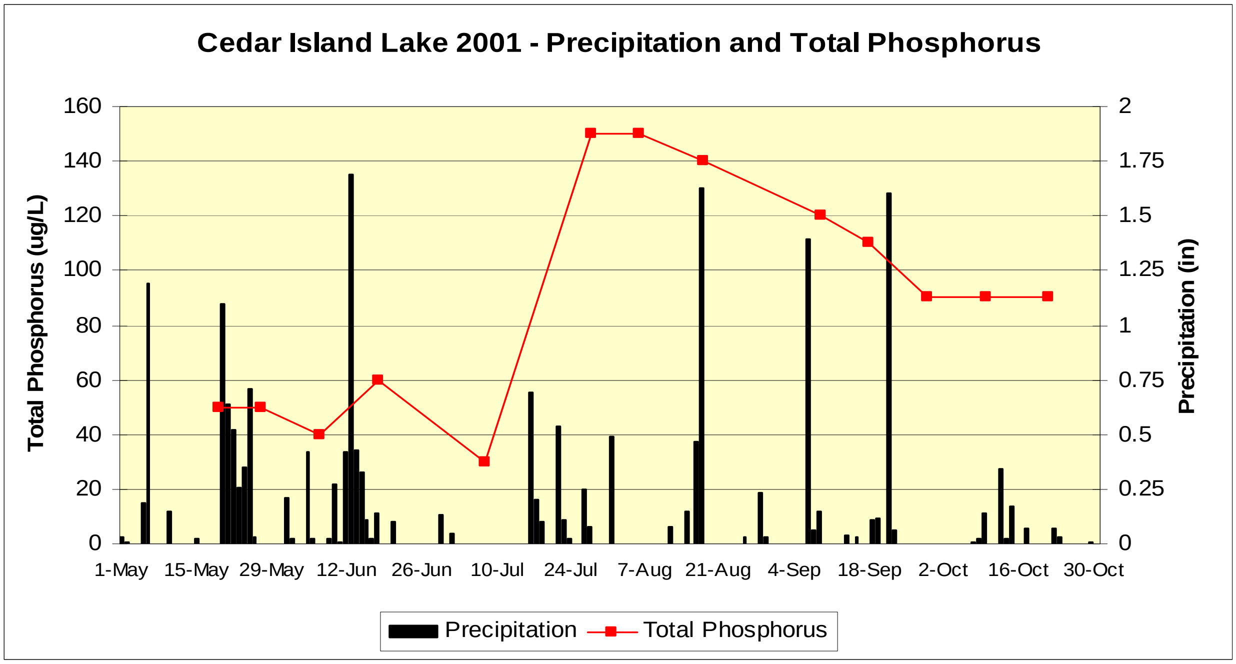



**Figure 5.1. Surface total phosphorus concentrations and precipitation for Cedar Island Lake in 2001.**

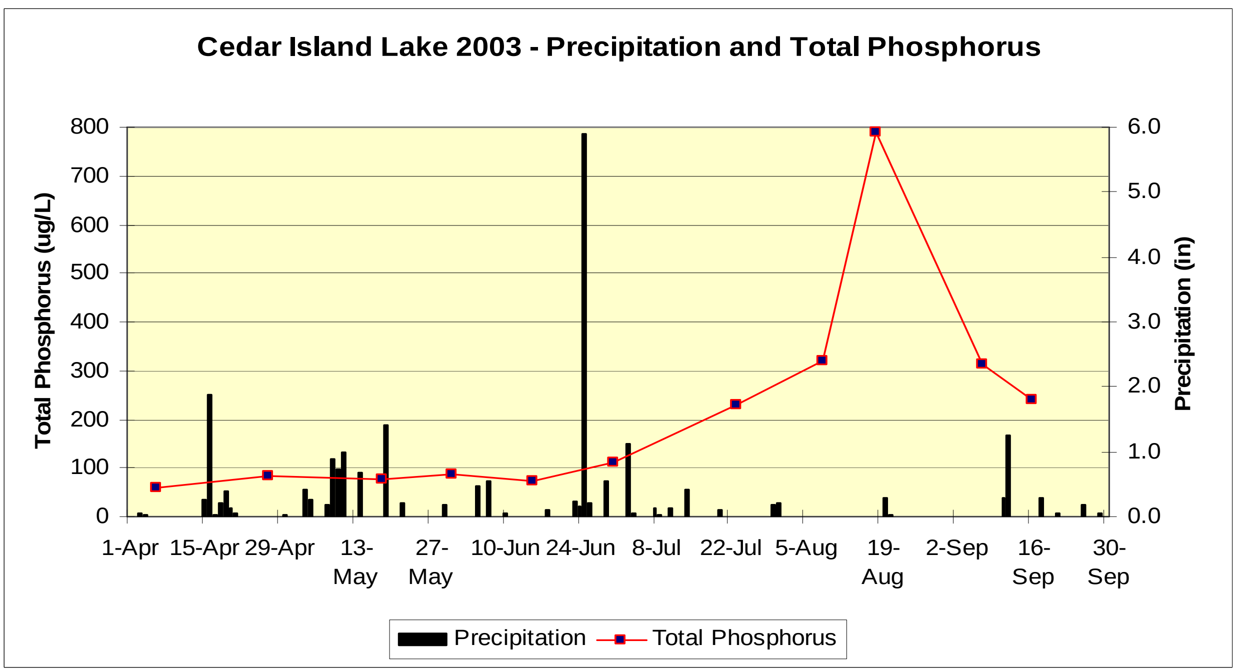



**Figure 5.2. Surface total phosphorus concentrations and precipitation for Cedar Island Lake in 2003.**

### 5.4.1.4 Chlorophyll-a

In 2001 (Figure 5.3) chlorophyll-a concentrations in Cedar Island Lake followed a seasonal pattern similar to total phosphorus concentrations. Prior to curly-leaf senescence, chlorophyll-a concentrations were relatively low (below 40 µg/L). Once the curly-leaf pondweed died off, releasing phosphorus into the water column and reducing shading in the water column, the algae population grew dramatically. Although phosphorus concentrations remained high, chlorophyll-a concentrations decreased as light began to limit algal productivity.

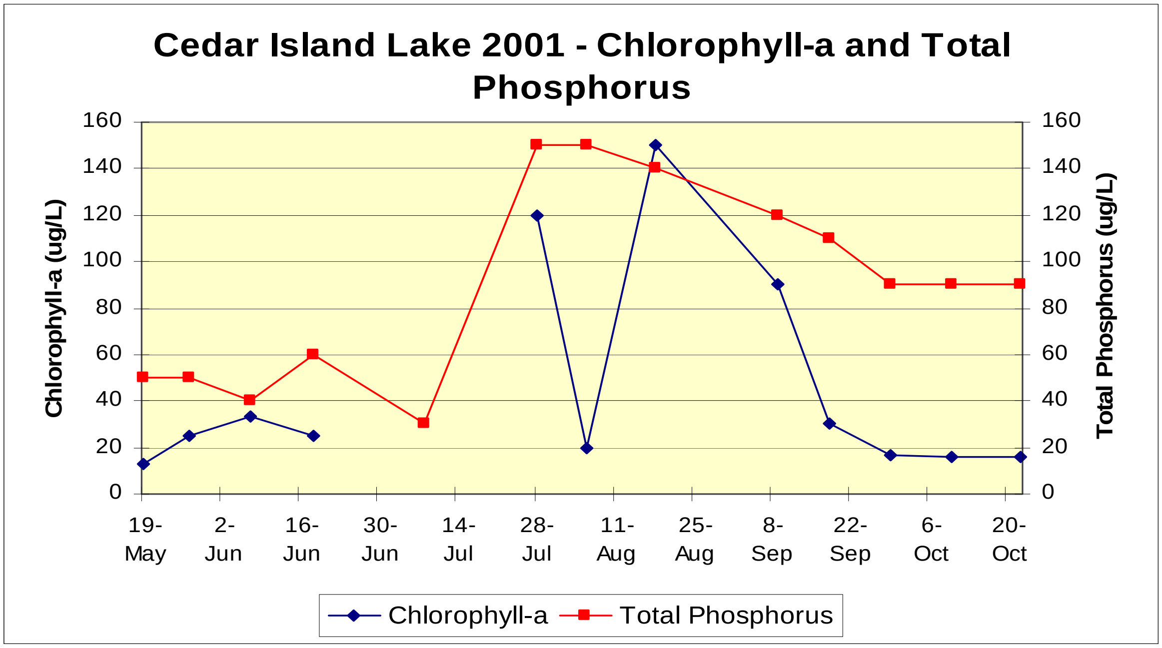



**Figure 5.3. Surface total phosphorus concentrations and chlorophyll-a for Cedar Island Lake in 2001.**

Chlorophyll-a concentrations in 2003 (Figure 5.4) had similar patterns, with concentrations remaining relatively low prior to late season total phosphorus increases associated with curly-leaf senescence and increase in internal loading. Phosphorus and chlorophyll-a dynamics in Cedar Island are strongly influenced by internal loading and the presence of curly-leaf pondweed.

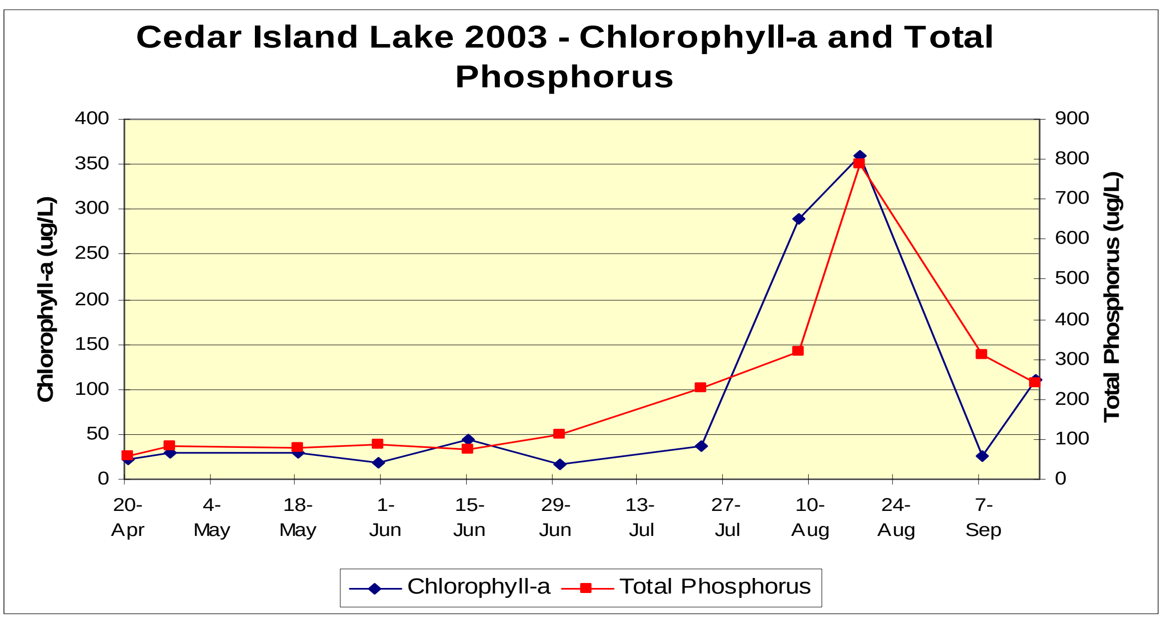



**Figure 5.4. Surface total phosphorus concentrations and chlorophyll-a for Cedar Island Lake in 2003.**

## 5.4.2 Pike Lake

### 5.4.2.1 Historical Data

Historical summer average water quality for Pike Lake is presented in Table 5.2. Water quality conditions have remained relatively similar over the past 15 years with high total phosphorus concentrations and severe algal blooms. More recently, the conditions have been considerably worse with summer average chlorophyll-a concentrations at approximately 70 µg/L (the State water quality standard for a shallow lake is less than 20 µg/L).

**Table 5.2. Historical summer average water quality for Pike Lake.**

| Year | Total Phosphorus (µg/L) | | Chlorophyll-a (µg/L) | | Secchi Depth (m) | |
|---|---|---|---|---|---|---|
| | N | Mean | N | Mean | N | Mean |
| 1981[2] | | | | | 3 | 0.9 |
| 1990[1] | | | | | 13 | 0.8 |
| 1991[1] | 7 | 101 | 9 | 28 | 21 | 1.4 |
| 1991[2] | | | | | 7 | 1.4 |
| 1992[1] | | | | | 5 | 1.4 |
| 1992[2] | | | | | 6 | 1.5 |
| 1993[1] | | | | | 7 | 1.3 |
| 1993[2] | | | | | 8 | 1.6 |
| 1994[1] | | | | | 5 | 1.2 |
| 1994[2] | | | | | 5 | 1.7 |
| 1995[1] | | | | | 4 | 1.0 |
| 1995[2] | | | | | 4 | 1.0 |
| 1996[1] | | | | | 5 | 1.3 |
| 1996[2] | 10 | 56 | 10 | 36 | 15 | 1.0 |
| 1997[2] | 9 | 67 | 9 | 23 | 9 | 1.3 |
| 1998[2] | 10 | 77 | 10 | 37 | 10 | 0.8 |
| 1999[1] | 7 | 73 | 8 | 26 | 12 | 1.1 |
| 2000[2] | 9 | 70 | 9 | 34 | 9 | 1.0 |
| 2001[1] | 7 | 77 | 6 | 36 | 13 | 1.3 |
| 2003[1] | 7 | 84 | 7 | 74 | 14 | 0.9 |
| 2004[1] | 8 | 98 | 8 | 73 | 16 | 1.0 |
| 2005[1] | 8 | 101 | 8 | 63 | 16 | 1.0 |
| 2006[1] | 7 | 101 | 7 | 61 | 10 | 0.8 |
| Average | | 81 | | 43 | | 1.1 |
| Standard | 60 or less | | 20 or less | | 1.0 or more | |

N=number of samples
[1] Three Rivers Park District monitoring data
[2] Citizen Assisted Monitoring Program (CAMP) data

### 5.4.2.2 Temperature and Dissolved Oxygen

The Three Rivers Park District collected temperature and dissolved oxygen profiles in 2003, 2004, and 2005. Pike Lake demonstrates weak summer stratification (Figure 5.5). Dissolved oxygen in 2005 demonstrates a similar pattern with anoxia occurring as shallow as 4 meters in depth (Figure 5.6). The anoxia occurs very early in the spring and late into the fall allowing for long periods of sediment phosphorus loading. Similar patterns were observed in other years.

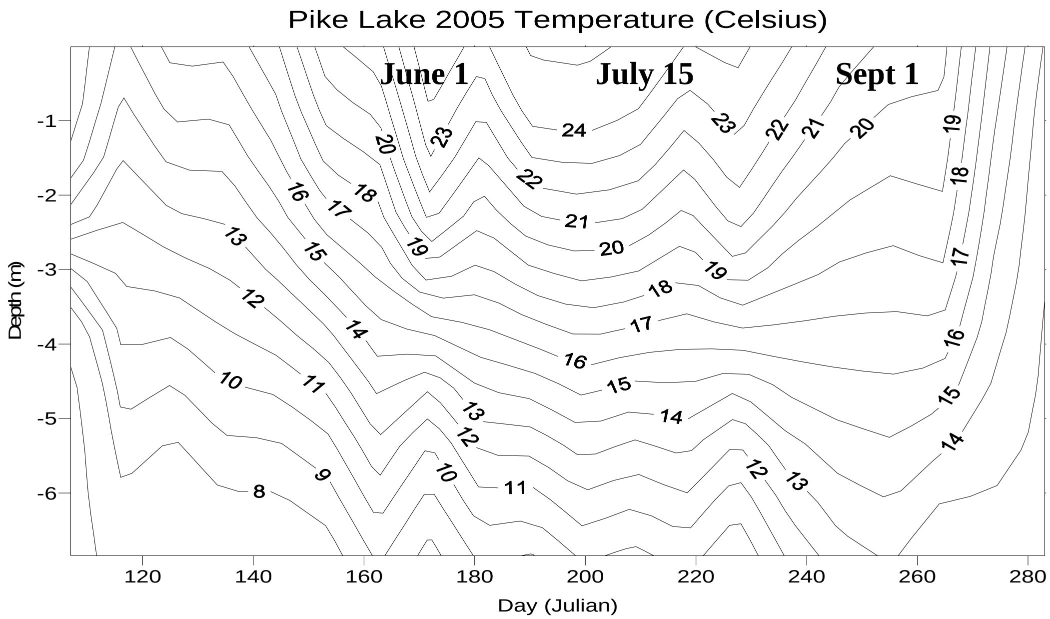



**Figure 5.5. Temperature isoplot for Pike Lake, biweekly sampling May-October 2005.**

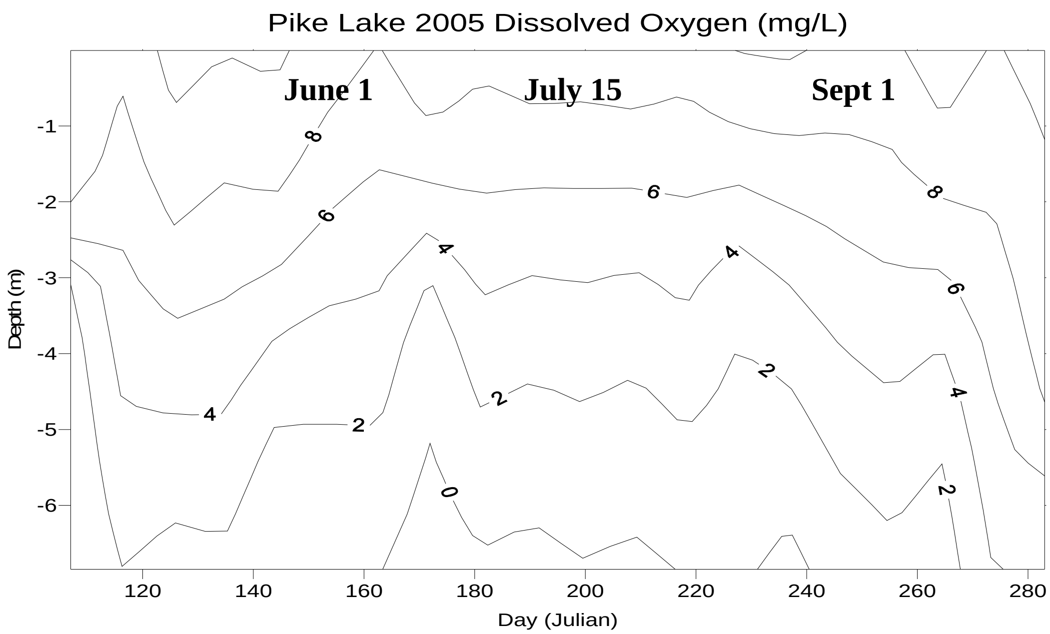



**Figure 5.6. Dissolved oxygen isoplot for Pike Lake, biweekly sampling May-October 2005.**

### 5.4.2.3 Phosphorus

Total phosphorus concentrations remained relatively high throughout the 2004 season with the highest concentrations during the drier summer period, suggesting that internal loading is occurring in Pike Lake (Figure 5.7). It is important to note that early spring concentrations in Pike Lake were quite high, with concentrations well above 80 µg/L. Additionally, Pike Lake demonstrated anoxia over the sediments early in the spring which may be the source of phosphorus during this period.

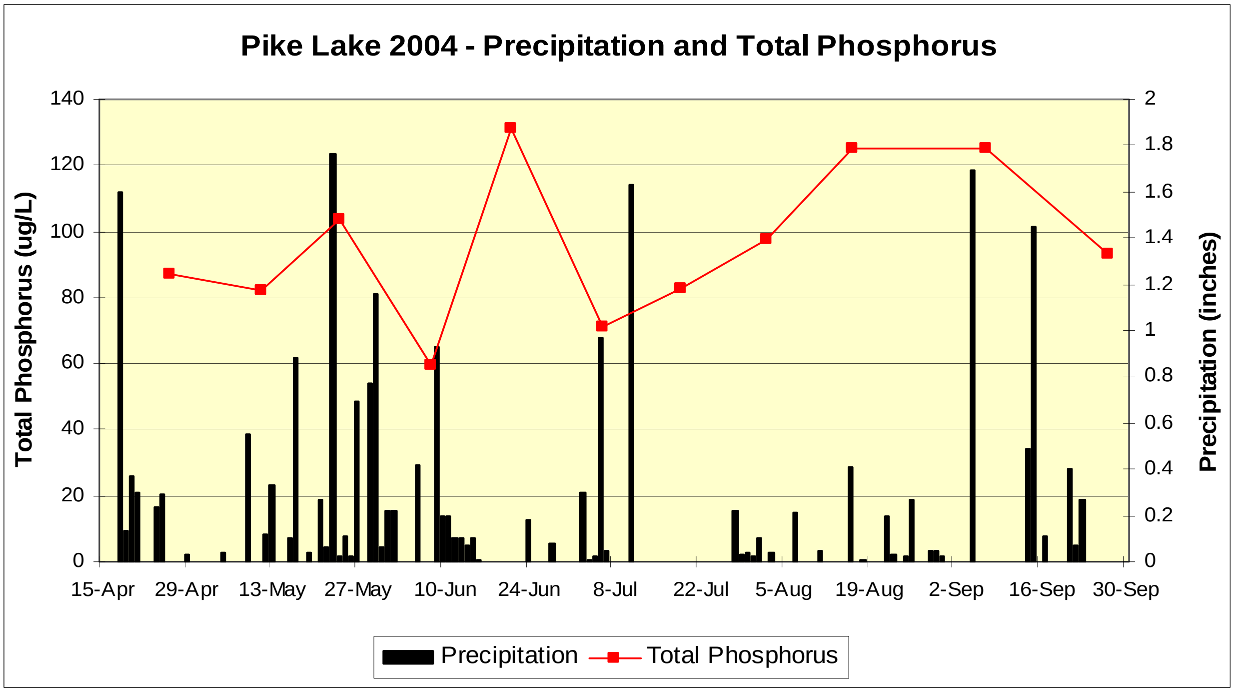



**Figure 5.7. Total phosphorus concentrations and precipitation for Pike Lake in 2004.**

Total phosphorus concentrations in 2005 demonstrated a steady increase over the entire summer period, reaching concentrations well over 120 µg/L (Figure 5.8). These patterns suggest internal loading has a strong influence on phosphorus cycling in Pike Lake.

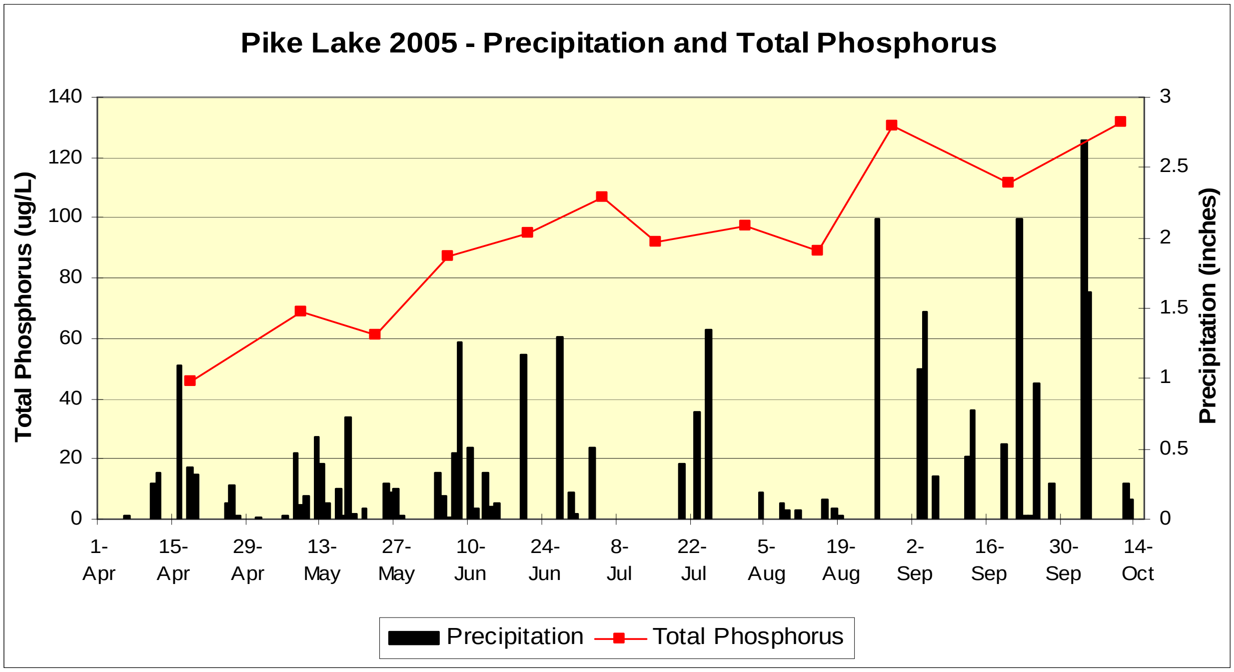



**Figure 5.8. Total phosphorus concentrations and precipitation for Pike Lake in 2005.**

### 5.4.2.4 Chlorophyll-a

Chlorophyll-a concentrations in Pike Lake in 2004 demonstrated a steady increase starting as early as May and continuing through late fall (Figure 5.9). Chlorophyll-a concentrations demonstrated severe algal blooms in early June and maintained these conditions throughout the summer with concentrations well above 60 µg/L throughout the summer.

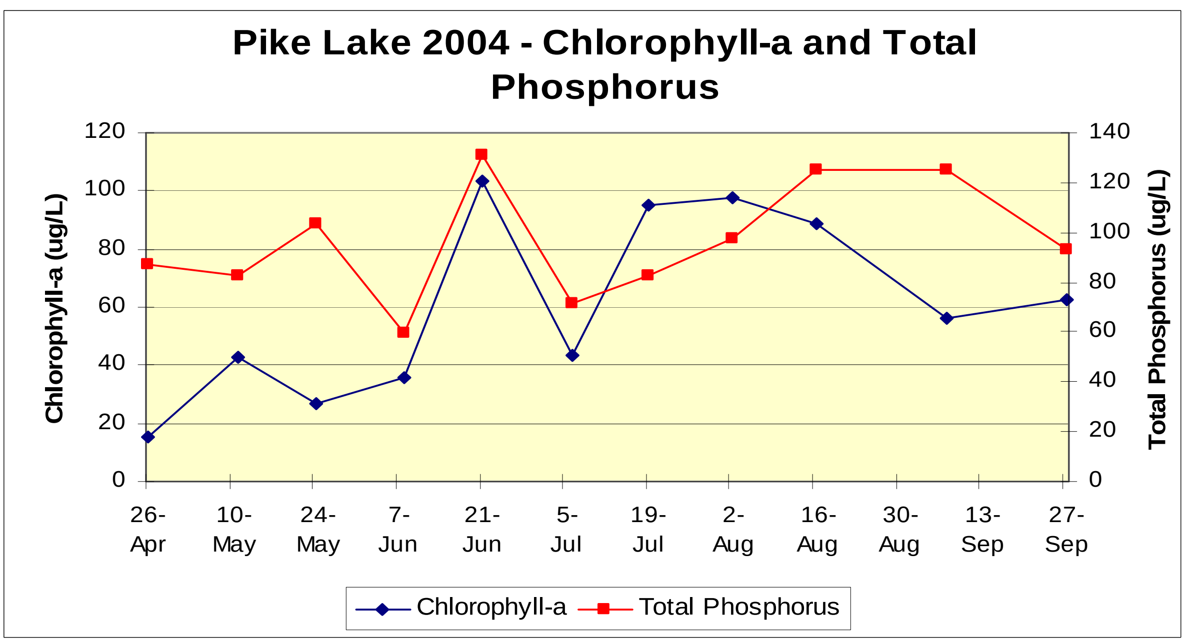



**Figure 5.9. Chlorophyll-a and phosphorus concentrations in Pike Lake in 2004.**

Similar patterns were observed in 2005 with a steady increase in chlorophyll-a concentrations beginning in spring and continuing throughout the summer (Figure 5.10). These patterns suggest that internal loading is providing an increasing supply of phosphorus for algal production resulting in severe algal bloom conditions throughout the summer.

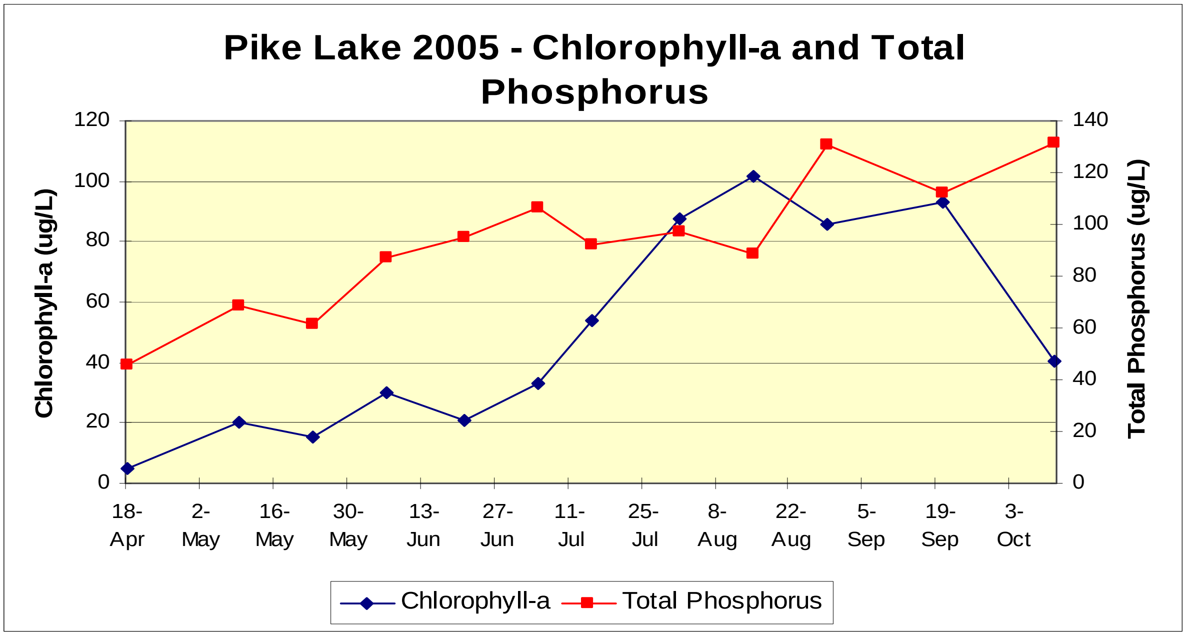



**Figure 5.10. Chlorophyll-a and phosphorus concentrations in Pike Lake in 2005.**

### 5.4.3 Eagle Lake

#### 5.4.3.1 Historical Data

Historical data for Eagle Lake are presented in Table 5.3. Data in the 1980s and 1990s suggest that at that time water quality was relatively good with reasonable total phosphorus concentrations.

**Table 5.3. Historical summer average water quality for Eagle Lake.**

| Year | Total Phosphorus (µg/L) | | Chlorophyll-a (µg/L) | | Secchi Disk (m) | |
|---|---|---|---|---|---|---|
| | N | Mean | N | Mean | N | Mean |
| 1973[2] | 1 | 65 | | | 1 | 1.5 |
| 1978[2] | | | | | 1 | 1.5 |
| 1980[2] | 10 | 35 | 4 | 51 | 20 | 1.1 |
| 1981[2] | | | | | 3 | 1.1 |
| 1982[2] | | | | | 7 | 1.6 |
| 1983[2] | 4 | 33 | 4 | 24 | 9 | 1.5 |
| 1984[2] | | | | | 5 | 1.6 |
| 1985[2] | | | | | 5 | 1.3 |
| 1986[2] | 9 | 36 | 9 | 19 | 14 | 1.8 |
| 1987[2] | 9 | 44 | 9 | 42 | 14 | 1.2 |
| 1988[2] | | | | | 15 | 1.4 |

| Year | Total Phosphorus (μg/L) | | Chlorophyll-a (μg/L) | | Secchi Disk (m) | |
|---|---|---|---|---|---|---|
| | N | Mean | N | Mean | N | Mean |
| 1989[2] | | | | | 19 | 1.8 |
| 1990[2] | | | | | 20 | 1.1 |
| 1991[1] | | | | | 10 | 1.0 |
| 1991[2] | 7 | 35 | 7 | 39 | 31 | 1.1 |
| 1992[1] | | | | | 6 | 1.3 |
| 1992[2] | | | | | 20 | 1.3 |
| 1993[1] | | | | | 7 | 2.4 |
| 1993[2] | 8 | 35 | 8 | 16 | 25 | 2.2 |
| 1994[1] | | | | | 5 | 1.6 |
| 1994[2] | | | | | 16 | 1.5 |
| 1995[1] | | | | | 4 | 1.3 |
| 1995[2] | | | | | 15 | 1.4 |
| 1996[1] | | | | | 5 | 2.2 |
| 1996[2] | 9 | 30 | 9 | 12 | 23 | 1.6 |
| 1997[2] | 7 | 20 | 7 | 11 | 15 | 1.8 |
| 1998[2] | 9 | 31 | 9 | 14 | 18 | 1.6 |
| 1999[1] | 8 | 54 | 8 | 28 | 8 | 1.5 |
| 1999[2] | | | | | 9 | 1.1 |
| 2000[2] | 4 | 35 | 4 | 5 | 14 | 2.6 |
| 2001[1] | 6 | 32 | 6 | 19 | 7 | 2.5 |
| 2001[2] | | | | | 3 | 4.1 |
| 2002[2] | 2 | 55 | 2 | 6 | 3 | 1.0 |
| 2003[1] | 9 | 50 | 9 | 38 | 9 | 1.8 |
| 2004[1] | 8 | 49 | 8 | 34 | 8 | 1.6 |
| 2005[1] | 8 | 42 | 8 | 21 | 8 | 2.5 |
| 2006[1] | 8 | 53 | 8 | 47 | 10 | 0.9 |
| Average | | 39 | | 26 | | 1.6 |
| Standard | 40 or less | | 14 or less | | 1.4 or more | |

N = number of samples
[1] Three Rivers Park District monitoring data
[2] Citizen Assisted Monitoring Program (CAMP) data

### 5.4.3.2 Temperature and Dissolved Oxygen

The Three Rivers Park District collected temperature and dissolved oxygen profiles in 2003, 2004, and 2005. Eagle Lake is a relatively deep, dimictic lake that demonstrates stratification in early June that lasts throughout the summer (Figure 5.11).

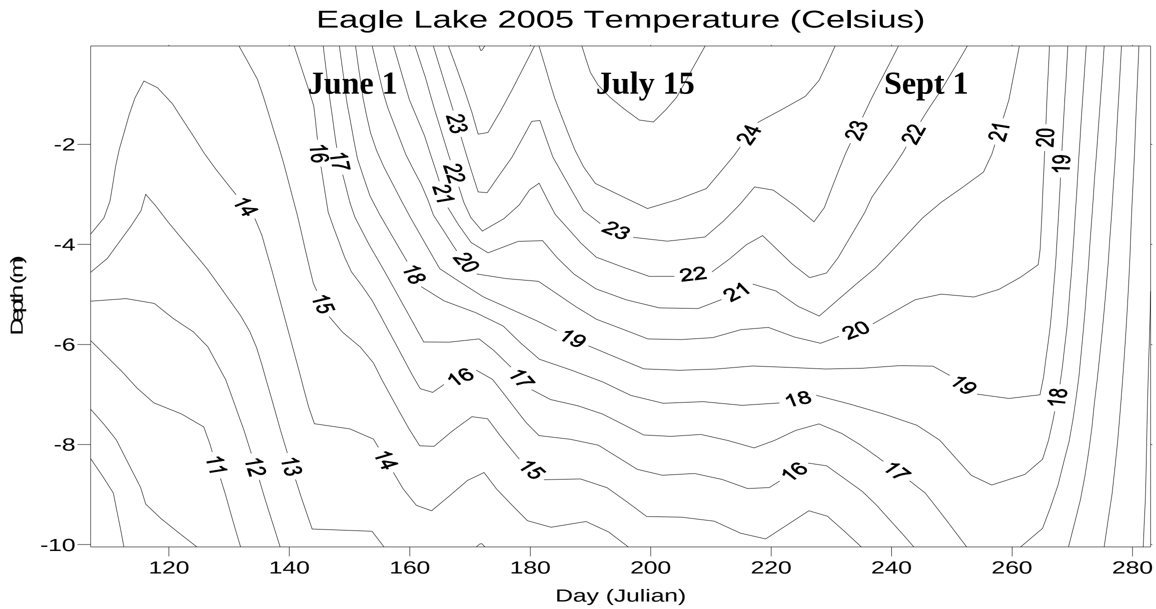


**Figure 5.11. Temperature isoplot for Eagle Lake, biweekly sampling May-October 2005.**

During the stratification period, significant anoxia occurs over the sediments as shallow as 6 meters in depth (Figure 5.12). The anoxia allows for sediment release of phosphorus. The effects of this are less pronounced in dimictic lakes since the phosphorus is trapped in the hypolimnion. However, internal loading can still play an important role in eutrophication of deep, dimictic lakes.

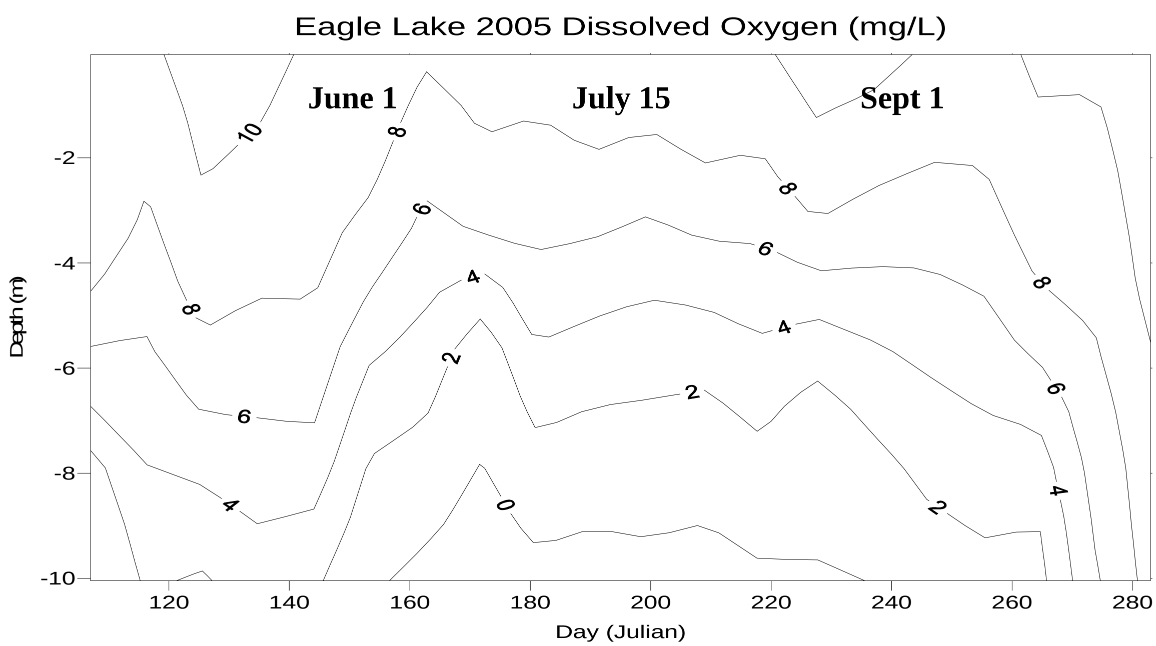


**Figure 5.12. Dissolved oxygen isoplot for Eagle Lake, biweekly sampling May-October 2005.**

### 5.4.3.3 Phosphorus

Total phosphorus concentrations in both 2004 and 2005 demonstrated a steady increase over the summer (Figure 5.13 and Figure 5.14). In-lake total phosphorus concentrations did not appear to respond directly to precipitation events. In 2005, total phosphorus concentrations decreased slightly during two summer dry periods. In 2004, total phosphorus concentrations continued to rise through the dry summer period suggesting that internal loading may be providing some phosphorus to the epilimnion.

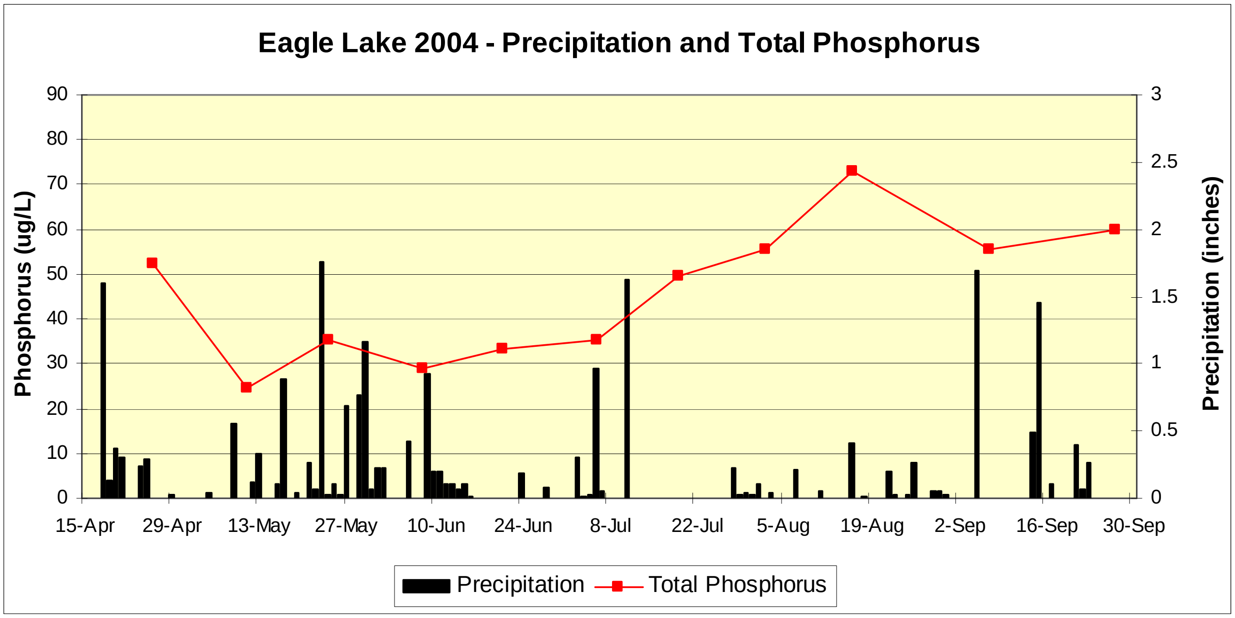



**Figure 5.13. Surface total phosphorus concentrations and precipitation in Eagle Lake during 2004.**

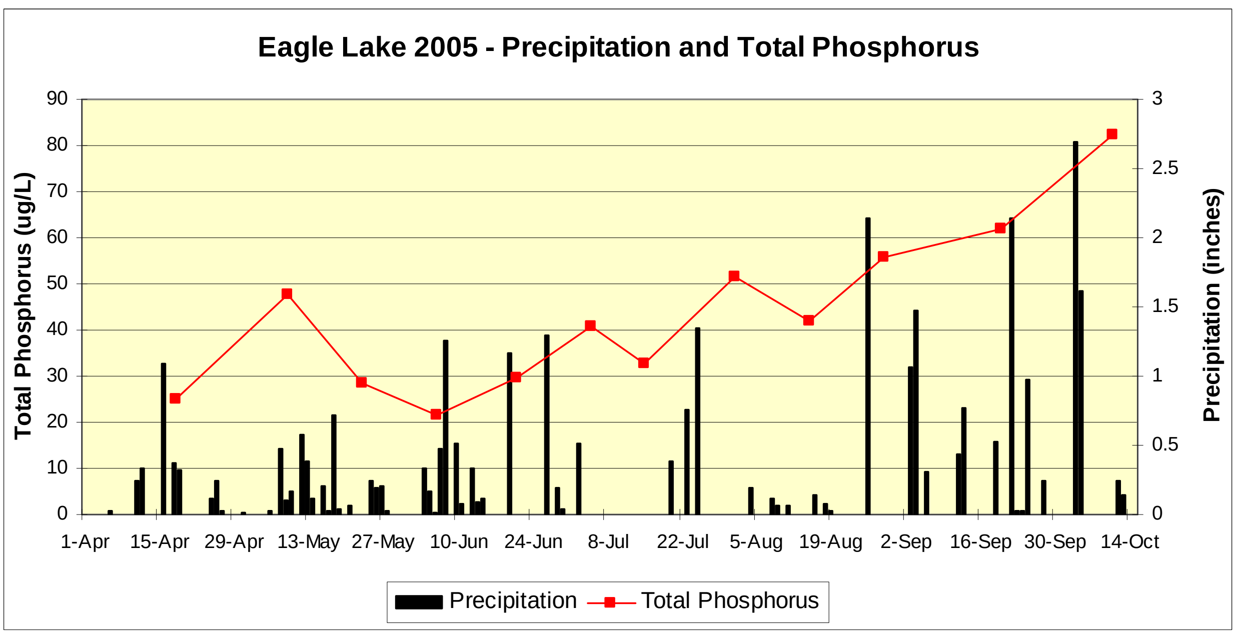



**Figure 5.14. Surface total phosphorus concentrations and precipitation in Eagle Lake in 2005.**

### 5.4.3.4 Chlorophyll-a

Chlorophyll-a concentrations in Eagle Lake demonstrated a steady increase throughout the summer in 2004 (Figure 5.15). In 2005, chlorophyll-a concentrations were low through late July before exhibiting a severe algal bloom with concentrations reaching 60 µg/L (Figure 5.16). The most severe algal blooms occurred in mid to late summer.

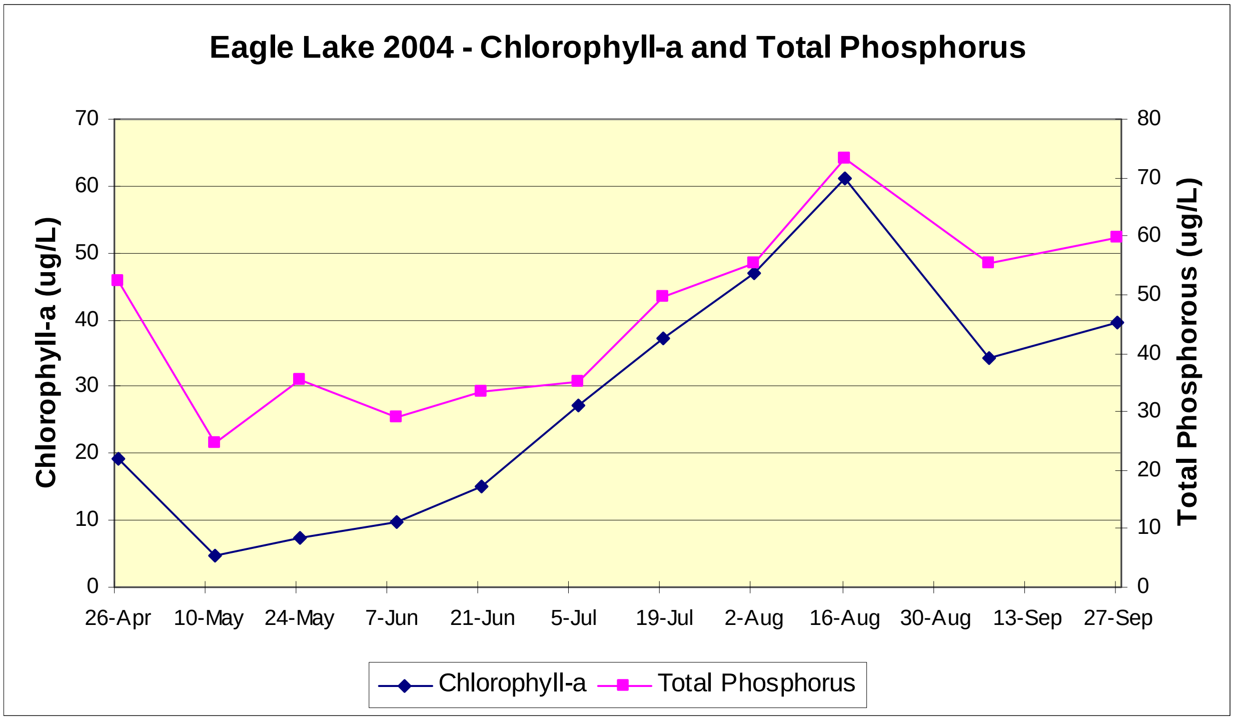



**Figure 5.15. Chlorophyll-a and phosphorus concentrations in the surface waters of Eagle Lake in 2004.**

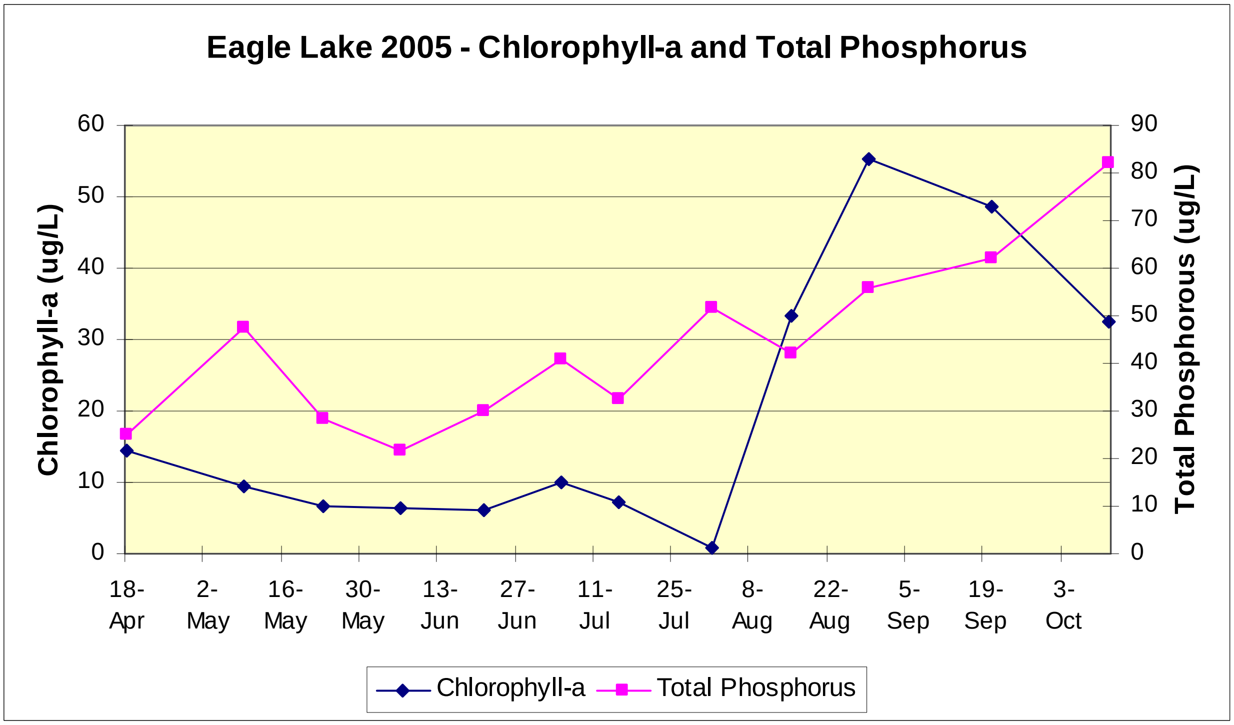



**Figure 5.16. Chlorophyll-a and phosphorus concentrations in the surface waters of Eagle Lake in 2005.**

## 5.5 CONCLUSIONS

Both Cedar Island Lake and Pike Lake drain into Eagle Lake and likely have a large influence on water quality in Eagle Lake. Cedar Island Lake demonstrates extremely high total phosphorus concentrations and extremely severe algal blooms. Cedar Island Lake likely has a large internal load that is exacerbated by the presence of curly-leaf pondweed in nuisance densities.

Pike Lake also demonstrates high total phosphorus concentrations throughout the summer with severe algal blooms. It is likely that Pike Lake has a large internal phosphorus load as demonstrated by anoxia over the sediments throughout the summer and even extending into spring and fall when the lake does not demonstrate temperature stratification.

Eagle Lake water quality is likely controlled by inputs from both Cedar Island Lake and Pike Lake, which have relatively high total phosphorus concentrations. Additionally, Eagle Lake demonstrates the potential for internal loading with anoxic sediments and total phosphorus increases through summer dry periods. However, external loads need to be addressed prior to addressing internal loads on Eagle Lake. The most severe algal blooms in Eagle Lake occur in late summer.

# 6.0 Linking Water Quality Targets and Sources

## 6.1 INTRODUCTION

A detailed nutrient budget for Cedar Island, Pike, and Eagle Lakes can be a useful tool for identifying management options and their potential effects on water quality. Additionally, lake response models can be developed to understand how different lake variables respond to changes in nutrient loads. Through this knowledge, managers can make educated decisions about how to allocate restoration dollars and efforts as well as understand the resultant effect of such efforts. At the time this report was written, only data through 2005 was available for model calibration.

## 6.2 SELECTION OF MODELS AND TOOLS

Modeling was completed using three independent platforms including SWMM, P8, and model equations extracted from BATHTUB.

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

P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles, & Ponds) is a public domain (http://wwwalker.net/p8/), industry standard model developed to assess pollutant loading in urban watersheds. P8 was developed using National Urban Runoff Program (NURP) data and provides loading estimates based on data collected as a part of the NURP program.

The U.S. Army Corps of Engineers' BATHTUB model predicts eutrophication-related water quality conditions (e.g., phosphorus, nitrogen, chlorophyll- a, and transparency) using empirical relationships previously developed and tested for reservoir applications. The Canfield-Bachmann natural lake model, which was developed for northern temperate lakes, was selected from the suite of BATHTUB relationships to model lake phosphorus concentration response. Other models from the suite were used to predict chlorophyll-a and transparency.

SWMM was used to develop watershed hydraulics and runoff volumes through calibration to collected data. The P8 model was subsequently calibrated to match the watershed runoff volumes developed from the SWMM model. Watershed loads were calculated using P8 ($50^{th}$ percentile particle file) for each of the subwatersheds. Watershed loads were entered into the BATHTUB model equations in a spreadsheet to predict lake effects and exchange between the tributary lakes and Eagle Lake.

### 6.2.1 SWMM Modeling

The Shingle Creek Watershed Management Commission developed the XP-SWMM model during the development of the Shingle Creek Chloride TMDL (Wenck 2007). The calibrated model was used to predict annual runoff volumes for each of the lake watersheds. More details on the calibration of the XP-SWMM model can be found in the *Shingle Creek Chloride TMDL* report (http://www.pca.state.mn.us/water/tmdl/project-shinglecreek-chloride.html).

### 6.2.2 P8 Modeling

Watershed loads were estimated using the P8 model for urban watersheds (Walker 1990). The model is based on National Urban Runoff Program studies and is widely used in the State of Minnesota for assessing runoff from urban watersheds. The P8 model was calibrated to match annual runoff volumes predicted by the calibrated XP-SWMM model as reported in the *Shingle Creek Chloride TMDL* (Wenck 2007). No ponds or wetlands were explicitly included in the model but, since the model is calibrated to in-lake data, it implicitly reflects all the BMPs in place in the watershed at the time the in-lake data was collected. Some of the lake load is a result of internal loading, which has been estimated externally of the model. The P8 results give a relative sense of watershed nutrient dynamics and provide a tool for future evaluation of watershed BMPs.

## 6.3 CURRENT PHOSPHORUS BUDGET COMPONENTS

A phosphorus budget that sets forth the current phosphorus load contributions from watershed, atmospheric, and internal loads was developed using the modeling and collected data described above. Following is a brief description of the budget components and how these values were developed.

### 6.3.1 Tributary or Watershed Load

The tributary load from stormwater runoff from the watershed was developed using the P8 model calibrated to the SWMM runoff volumes (see Section 6.2). Particle data that represents the median for particle sedimentation developed during the National Urban Runoff Program studies was used for development of the loads.

### 6.3.2 Atmospheric Load

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

Table 6.1. Estimated total phosphorus load from atmospheric deposition by lake.

| Lake | Lake Area ($km^2$) | TP Deposition Rate ($kg/km^2/yr$) | Annual Atmospheric Load (kg) |
|---|---|---|---|
| Cedar Island | 0.320 | 26.8 | 8.6 |
| Pike | 0.242 | 26.8 | 6.5 |
| Eagle | 1.162 | 26.8 | 31.1 |

### 6.3.3 Internal Loads

Internal phosphorus loading from lakes has been demonstrated to be an important aspect of the phosphorus budgets of lakes. However, measuring or estimating internal loads can be difficult, especially in shallow lakes that may mix many times throughout the year. Internal loads were estimated independently for each of the basins. Internal load was calculated from an anoxic factor (Nürnberg 2004), which estimates the period where anoxic conditions exist over the sediments. In the case of shallow lakes, this can be estimated from lake geomorphology and lake TP concentrations (Nürnberg 2004). The anoxic factor is expressed in days but is normalized over the area of the lake. For example, if the depth of oxygen depletion (<2 mg/L D.O.) was 6 meters, then the number of days was multiplied by the anoxic area at that depth and divided by the entire area of the lake. A release rate was then selected based upon the eutrophic state of the lake. The selected release rates were a range based on previous lake studies (Figure 6.1; Nürnberg 1997).

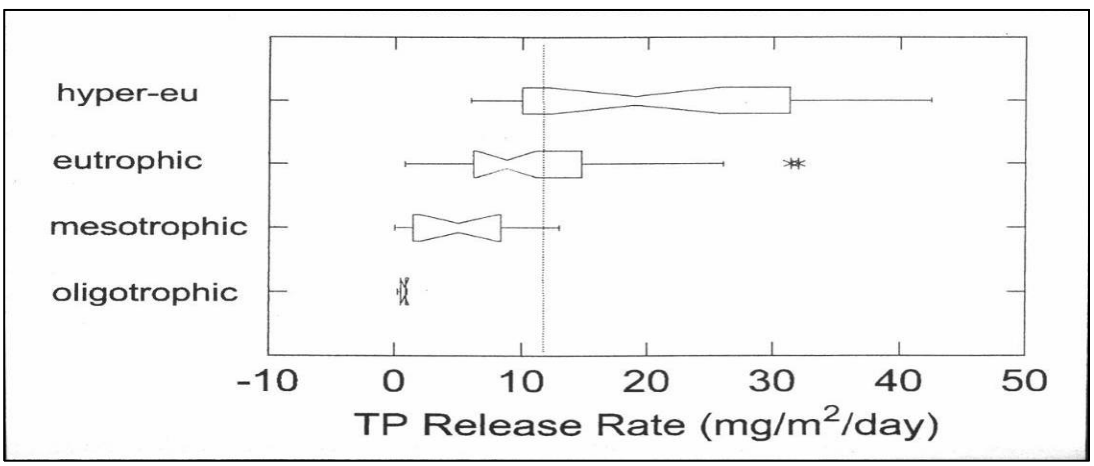



**Figure 6.1. Sediment phosphorus release rates by trophic condition (Nürnberg 1997).**

However, it is important to note that these estimates are used to give an estimate of the role of internal loading in lakes. The Canfield-Bachmann model used to estimate lake response in this TMDL is likely based on empirical relationships with lakes that demonstrate some internal loading. Consequently, the external load estimated is partially in lieu of internal loading. As an additional margin of safety, this TMDL is developed with load reductions applied to the watershed to meet the standard and a load reduction estimated for the internal loading.

### 6.3.3.1 Cedar Island Lake Internal Loads

No dissolved oxygen profile data was available for Cedar Island Lake. Consequently, we predicted the anoxic factor for Cedar Island Lake using a relationship with water quality and lake morphology (Nürnberg 2004, Figure 6.1). Based on these estimates, internal loading from Cedar Island Lake's own sediments has the potential to load 113 to 280 kilograms of phosphorus into the water column of the lake each year (Table 6.1). As will be seen later in this report, in an average year, the lake can only assimilate up to an estimated 76 kilograms of phosphorus annually without exceeding the State standard for TP concentration. Based on these estimates, even if there was no phosphorus load from the watershed at all, the lake would exceed the State TP standard just from internal loading.

**Table 6.2. Results of the internal load assessment for Cedar Island Lake.**

| Year | Release Rate ($mg/m^2/day$)[1] | Anoxic Factor (days) | Gross Load ($mg/m^2$/summer) | Gross Load (kg) |
|---|---|---|---|---|
| Shallow Lake[2] | 6 | 59 | 351 | 113 |
| | 9 | 59 | 527 | 168 |
| | 15 | 59 | 878 | 280 |

[1]Estimated from Figure 6.1 (Nürnberg 2002).
[2]Anoxic factor predicted based on lake phosphorus concentration and lake morphology.

### 6.3.3.2 Pike Lake Internal Loads

Anoxia occurs over the sediments in Pike Lake for almost the entire summer, suggesting that internal loading is a significant source of phosphorus to the lake (Table 6.3). The long periods can be seen in the estimated anoxic factor that demonstrates that an area equal to the entire area of lake is anoxic for 68 to 76 days in the summer. It is likely that internal loading is an important process in Pike Lake.

**Table 6.3. Results of the internal load assessment for Pike Lake.**

| Year | Release Rate ($mg/m^2/day$)[1] | Anoxic Factor (days)[2] | Gross Load ($mg/m^2$/summer) | Gross Load (kg) |
|---|---|---|---|---|
| 2004 | 6 | 68 | 410 | 99 |
| | 9 | 68 | 615 | 149 |
| | 15 | 68 | 1025 | 248 |
| | | | | |
| 2005 | 6 | 76 | 453 | 110 |
| | 9 | 76 | 680 | 165 |
| | 15 | 76 | 1133 | 274 |
| | | | | |
| Shallow Lake[3] | 6 | 53 | 318 | 77 |
| | 9 | 53 | 477 | 116 |
| | 15 | 53 | 796 | 193 |

[1]Estimated from Figure 6.1 (Nürnberg 2002).
[2]Calculated from dissolved oxygen profiles.
[3]Anoxic factor predicted based on lake phosphorus concentration and lake morphology.

### 6.3.3.3 Eagle Lake Internal Loads

Eagle Lake demonstrates a potential for internal loading, however water quality suggests that it may be a relatively unimportant process in Eagle Lake. In deep lakes such as Eagle Lake, the majority of the phosphorus is trapped below the thermocline and unavailable for phytoplankton production. For purposes of establishing the current phosphorus budget the internal load was assumed to be 0 because the estimated watershed load was sufficient to account for in-lake phosphorus concentrations. The import of phosphorus from upstream water bodies likely plays a larger role in controlling water quality in Eagle Lake.

**Table 6.4. Results of the internal load assessment for Eagle Lake.**

| Year | Release Rate ($mg/m^2/day$)[1] | Anoxic Factor (days)[2] | Gross Load ($mg/m^2/summer$) | Gross Load (kg) |
|---|---|---|---|---|
| 2004 | 3 | 35 | 106 | 123 |
| | 6 | 35 | 211 | 246 |
| | 9 | 35 | 317 | 369 |
| | | | | |
| 2005 | 3 | 33 | 98 | 113 |
| | 6 | 33 | 195 | 227 |
| | 9 | 33 | 293 | 340 |

[1]Estimated from Figure 6.1 (Nürnberg 2002).
[2]Calculated from dissolved oxygen profiles.

### 6.3.4 Lake Exchange

Lakes or bays can exchange nutrients through either advective exchange (water moving through) or diffusive exchange (molecules moving along a gradient). The three lakes in the Eagle Lake chain are connected by pipes or channels so advective exchange has been included in the modeling.

## 6.4 CURRENT PHOSPHORUS BUDGET

The current conditions phosphorus budget was developed using the P8 model results (Section 6.2), the internal load evaluation (Section 6.3.3) and the BATHTUB model. Phosphorus budgets were developed for 2001 and 2003 and are presented in Table 6.5. Detailed model output is presented in Appendix A.

- The P8-predicted watershed load for 2001 and 2003 were averaged to establish an average watershed (external) load budget for each lake.
- The internal load was estimated at a release rate of 6 $mg/m^2/day$ for Cedar Island and Pike Lakes. However, for Cedar Island Lake that rate severely underpredicted water quality in 2003, so the 2003 Cedar Island budget assumes a rate of 12 $mg/m^2/day$.
- The average annual internal load budget assumes a release rate of 6 $mg/m^2/day$ for Cedar Island and Pike Lakes and as described in section 6.3.3 above, a 0 load for Eagle.
- Atmospheric load is as shown in Table 6.1
- The upstream load for Eagle Lake is calculated as the sum of the BATHTUB modeled phosphorus outflow load for Cedar Island and Pike Lakes.

**Table 6.5. Current total phosphorus budget for Cedar Island, Pike and Eagle Lakes in 2001 and 2003.**

| Lake | Source | Source | 2001 Annual Load (kg/yr) | 2003 Annual Load (kg/yr) | Average Annual TP Load (kg/yr) |
|---|---|---|---|---|---|
| Cedar Island Lake | Wasteload | Watershed Load | 130.4 | 91.7 | 111.0 |
| | Load | Internal Load | 113.1 | 226.2 | 113.1[1] |
| | | Atmospheric Load | 8.6 | 8.6 | 8.6 |
| | | **TOTAL LOAD** | **252.1** | **326.5** | **232.7** |
| Pike Lake | Wasteload | Watershed Load | 242.9 | 162.0 | 202.5 |
| | Load | Internal Load | 77.0 | 77.0 | 77.0 |
| | | Atmospheric Load | 6.5 | 6.5 | 6.5 |
| | | **TOTAL LOAD** | **326.4** | **245.5** | **286.0** |
| Eagle Lake | Wasteload | Watershed Load | 357.8 | 255.4 | 306.6 |
| | | Upstream Load | 254.6 | 187.6 | 209.5[2] |
| | Load | Internal Load | -- | -- | -- |
| | | Atmospheric Load | 31.1 | 31.1 | 31.1 |
| | | **TOTAL LOAD** | **643.5** | **474.1** | **547.2** |

[1]Assumes an internal load release rate of 6 mg/m$^2$/day rather than the average of 2001 and 2003 as the 2003 internal load was atypical.
[2]Sum of phosphorus outflow load from Cedar Island and Pike as calculated in the BATHTUB model (see Appendix A).

## 6.5 WATER QUALITY RESPONSE MODELING

The BATHTUB model was developed using the P8 loads and runoff volumes. Two 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. Since channels and pipes connect the lakes, diffusive exchange of nutrients is expected to be minimal. The model was set so that no diffusive exchange would occur. The chlorophyll-a response model used was model 1 from the BATHTUB package, which accounts for nitrogen, phosphorus, light, and flushing rate. Secchi depth was predicted using the “Secchi vs. Chl-a & Turbidity” equation.

For more information on these model equations, see the BATHTUB model documentation (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 initial calibration factors were applied to any of the lakes except for the export of phosphorus from upstream lakes if they exist in the watershed.  Model details are presented in Appendix A.

### 6.5.1 Fit of the Model

Model fit for each of the lakes is presented in Table 6.6, Table 6.7, and Table 6.8. Cedar Island Lake demonstrated a uniquely different pattern. In the wet year, the watershed loads were sufficient to account for in-lake concentrations. However, in the dry year, the total phosphorus concentration was considerably higher, suggesting that internal loading is a significant contributor to the total load to the lake during the dry year. In-lake conditions can vary considerably year to year in Cedar Island Lake, suggesting that internal loading is a driving force in Cedar Island Lake.

**Table 6.6. Model fit for Cedar Island Lake.**

| Year | Variable | Predicted Summer Mean | Observed Summer Mean |
|---|---|---|---|
| 2001 | Total phosphorus (µg/L) | 130 | 99 |
| | Chlorophyll-a (µg/L) | 84 | 61 |
| | Secchi depth (meters) | 0.5 | 0.6 |
| | | | |
| 2003 | Total phosphorus (µg/L) | 181 | 296 |
| | Chlorophyll-a (µg/L) | 103 | 126 |
| | Secchi depth (meters) | 0.4 | 0.4 |

The model over-predicted some of the Pike Lake parameters in the wet year (2001) and under-predicted some of them in the dry year (2003). It is likely that in dry years internal load is an important factor in the late-season algal blooms that result in a reduction in clarity.

**Table 6.7. Model fit for Pike Lake.**

| Year | Variable | Predicted Summer Mean | Observed Summer Mean |
|---|---|---|---|
| 2001 | Total phosphorus (µg/L) | 97 | 77 |
| | Chlorophyll-a (µg/L) | 47 | 36 |
| | Secchi depth (meters) | 0.8 | 1.3 |
| | | | |
| 2003 | Total phosphorus (µg/L) | 95 | 84 |
| | Chlorophyll-a (µg/L) | 47 | 74 |
| | Secchi depth (meters) | 0.8 | 0.9 |

Eagle Lake compared well in both years, however, an over-prediction of total phosphorus is noted in the wet year. Water quality was considerably better in Eagle Lake in the wet year, likely due to some attenuation of loads from upstream lakes such as Cedar Island Lake. However, the model predicted water quality better in the dry year, potentially due to the higher loads coming from Cedar Island Lake. It is likely that phosphorus loads were over-predicted for the wet year.

**Table 6.8. Model fit for Eagle Lake.**

| Year | Variable | Predicted Summer Mean | Observed Summer Mean |
|---|---|---|---|
| 2001 | Total phosphorus (µg/L) | 48 | 32 |
| | Chlorophyll-a (µg/L) | 26 | 19 |
| | Secchi depth (meters) | 1.3 | 2.5 |
| | | | |
| 2003 | Total phosphorus (µg/L) | 47 | 50 |
| | Chlorophyll-a (µg/L) | 25 | 38 |
| | Secchi depth (meters) | 1.4 | 1.8 |

In 2001, the model over-predicted total phosphorus concentrations in Eagle Lake. This may be due to an over-estimation of total phosphorus contributions from Cedar Island Lake. The

BATHTUB model assumes all of the inflow, minus evaporation, flows to the next body of water. However, the outlet to Cedar Island Lake is a lift station that is only operated during significant runoff events. Pumping records were obtained from the City of Maple Grove and are presented in Table 6.9. The model over-predicted outflow by approximately two-thirds. However, the pumping records were quite variable and were not collected specifically for this study. Consequently, these data are used to provide some perspective on the modeling results.

**Table 6.9. Annual estimated discharge from the outlet of Cedar Island Lake.**

| Year | Outflow (gallons) | Outflow ($hm^3$) |
|---|---|---|
| 2002 | 237,378,600 | 0.90 |
| 2003 | 55,323,000 | 0.21 |
| 2004 | 5,996,700 | 0.02 |
| 2005 | 61,665,300 | 0.23 |

Note: Based on pumping records provided by the City of Maple Grove.

## 6.6 CONCLUSIONS

### 6.6.1 Cedar Island Lake

Phosphorus in Cedar Island Lake comes from both external and internal sources, however the internal loading is a significant source, especially in dry years. Based on the internal loading estimate, the internal load, in lieu of external loading, has the capacity to cause Cedar Island Lake to exceed the State standard. Significant focus needs to be placed on controlling internal loads in Cedar Island Lake.

### 6.6.2 Pike Lake

Pike Lake also demonstrates a high potential for internal loading with periods of anoxia stretching well into the spring and fall. However, the watershed model estimated sufficient watershed loading to account for monitored lake concentrations. It is likely that both internal and external loads are critical in the phosphorus cycling of Pike Lake. Significant focus should be placed on both of these sources.

### 6.6.3 Eagle Lake

Eagle Lake is a deep lake that receives a considerable amount of water from two upstream, shallow lakes with poor water quality. Based on the modeling, 39 to 49% of the lake’s load can be attributed to the upstream lakes. Consequently, reducing the loads from these upstream water bodies has the potential to considerably improve water quality in Eagle Lake. The lake does demonstrate the potential for internal loading; however, the role of internal loading is likely small compared to the external load and the load from upstream lakes.

# 7.0 TMDL Allocation

## 7.1 TOTAL MAXIMUM DAILY LOAD CALCULATIONS

Nutrient loads in this TMDL are set for phosphorus since this is typically the limiting nutrient for nuisance aquatic plants. This TMDL is written to solve the TMDL equation for a numeric target of 60 µg/L of total phosphorus for Cedar Island and Pike Lakes and 40 µg/L of total phosphorus for Eagle Lake. This TMDL presents load and wasteload allocations for each of these lakes and estimated load reductions to achieve these end points.

### 7.1.1 Load Allocation

The Load Allocation (LA) includes all nonpermitted sources, including atmospheric deposition and internal loading. Atmospheric deposition was calculated as described in Section 6.3.2 and shown in Table 6.1. As atmospheric load is impossible to control on a local basis, no reduction in that source was assumed for this TMDL.

Internal Load was calculated in the following manner. For Eagle Lake the TMDL includes a nominal 5.0 kg/year internal load. For Cedar Island and Pike Lakes, a release rate of 1 $mg/m^2$/day was used based on the low end of the sediment phosphorus release rate scale for eutrophic lakes.

**Table 7.1. Internal load calculations for the TMDL.**

| Year | Release Rate ($mg/m^2$/day)[1] | Anoxic Factor (days) | Lake Surface Area (ha) | Gross Load ($mg/m^2$/summer) | Gross Load (kg/yr) |
|---|---|---|---|---|---|
| Cedar Island Lake | 1 | 59 | 31.95 | 59 | 18.9 |
| Pike Lake | 1 | 53 | 24.2 | 53 | 12.8 |
| Eagle Lake | - | 34 | 116.2 | - | 5.0 |

### 7.1.2 Wasteload Allocation

Stormwater discharges are regulated under the NPDES program and allocations of nutrient reductions are considered wasteloads. Because there is not enough information available to assign loads to individual permit holders, the Wasteload Allocations are combined in this TMDL as Categorical Wasteload Allocations (see Table 7.2) assigned to all permitted dischargers in the contributing watershed. There are no known industrial dischargers in the watershed. The pollutant load from construction stormwater is considered to be less than one percent of the TMDL and difficult to quantify. Consequently, the WLA includes pollutant loading from construction stormwater sources.

Each permittee ("MS4") has committed to implement Best Management Practices (BMPs) to reduce nutrient loading to each lake. The MS4s cooperated in developing the TMDL and

Implementation Plan and will continue to work together through the ongoing Commission Technical Advisory Committee (TAC) to identify and implement BMPs either individually or in collaboration. This collective approach allows for greater reductions for some permit holders with greater opportunity and less for those with greater constraints. The collective approach will be outlined in an Implementation Plan that will establish implementation policies and priorities. Construction stormwater activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install, and maintain all BMPs required under the permit or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

**Table 7.2. Wasteload allocation by NPDES permitted facility for each lake.**

| NPDES Permit Number | Cedar Island | Pike | Eagle |
|---|---|---|---|
| MS400102-Maple Grove | Categorical WLA | Categorical WLA | Categorical WLA |
| MS400112-Plymouth | N/A | Categorical WLA | Categorical WLA |
| MS400138-Hennepin | Categorical WLA | Categorical WLA | Categorical WLA |
| MS400170-MnDOT | Categorical WLA | Categorical WLA | Categorical WLA |

N/A = Not applicable – does not drain to lake.

### 7.1.3 Margin of Safety

A margin of safety has been incorporated into this TMDL by using conservative assumptions. These were utilized to account for an inherently imperfect understanding of the lake system and to ultimately ensure that the nutrient reduction strategy is protective of the water quality standard.

Conservative modeling assumptions included applying sedimentation rates from the Canfield-Bachmann model that likely under-predict the sedimentation rate for shallow lakes. The sedimentation rate refers to the loss of phosphorus from the water column as a result of settling. This can occur as algae die and settle, as organic material settles, or as algae are grazed by the zooplankton. Zooplankton grazing plays a large role in algal and subsequent phosphorus sedimentation in shallow lakes (Meijer et al. 1994). However, the Canfield-Bachmann equation does not account for the expected higher sedimentation rates expected in healthy shallow lake systems as a result of increased zooplankton grazing. Consequently, the model-predicted phosphorus concentrations will be higher than expected because they do not account for the additional loss of phosphorus from the water column from that grazing.

Secondly, the Canfield-Bachmann model was used to match data by only adjusting the loads and not applying calibration factors. It is likely that the sedimentation rates used in the model are conservatively low for most Minnesota lakes, because of the relatively shallow nature of those lakes. The third margin of safety factor is provided by developing load allocations for the summer season when lake water quality is worst and most sensitive to loads.  Finally, the Eagle Lake model assumed that the entire annual modeled outflow from Cedar Island Lake would be transported by storm sewer downstream to Eagle Lake, although the records from the outlet pumping indicate that in some years the actual pumped outflow is less than the modeled volume. The Eagle Lake model thus likely overpredicts the lake exchange load from Cedar Island Lake.

### 7.1.4 Summary of TMDL Allocations

The loading capacity is the total maximum daily load. The TMDL was developed using an inverted Canfield-Bachmann model to calculate the total predicted phosphorus load at the State total phosphorus standard. Hydrologic inputs were derived from P8 and XP-SWMM to determine residence time for each of the lakes. An average runoff year (1999) was selected to determine the loading capacity of the lake. Models and calculation details are provided in Appendix A. The watershed load was then calculated as the difference between the total load at goal and the sum of the atmospheric, internal, and upstream loads at goal.

For all the lakes, the wasteload, internal load, and atmospheric load allocations were divided by 365.25 days per year (to account for leap year) to convert the annual load to a daily load. The load and wasteload allocations are shown in Table 7.3. Allocations by source are provided in Table 7.4. These allocations will guide the development of an implementation plan and necessary reductions.

**Table 7.3. TMDL allocations for Cedar Island, Pike, and Eagle Lakes.**

| Lake | TP Wasteload Allocation (kg/day) | TP Load Allocation (kg/day) | Margin of Safety | Total Phosphorus TMDL (kg/day) |
|---|---|---|---|---|
| Cedar Island Lake | 0.133 | 0.075 | Implicit | 0.208 |
| Pike Lake | 0.350 | 0.052 | Implicit | 0.402 |
| Eagle Lake | 0.810 | 0.099 | Implicit | 0.909 |

**Table 7.4. TMDL total phosphorus loads partitioned among the major sources.**

| | Allocation | Source | Existing TP Load | | Total Phosphorus TMDL | | Load Reduction |
|---|---|---|---|---|---|---|---|
| | | | (kg/day) | (kg/year) | (kg/day) | (kg/year) | (kg/year) |
| Cedar Island Lake | Wasteload | Watershed | 0.304 | 111.0 | 0.133 | 48.5 | 62.5 |
| | Load | Atmospheric | 0.024 | 8.6 | 0.024 | 8.6 | -- |
| | | Internal | 0.310 | 113.1 | 0.051 | 18.9 | 94.2 |
| | | | **0.638** | **232.7** | **0.208** | **76.0** | **156.7** |
| Pike Lake | Wasteload | Watershed | 0.554 | 202.5 | 0.350 | 127.7 | 74.8 |
| | Load | Atmospheric | 0.017 | 6.5 | 0.017 | 6.5 | -- |
| | | Internal | 0.211 | 77.0 | 0.035 | 12.8 | 64.2 |
| | | | **0.782** | **286.0** | **0.402** | **147.0** | **139.0** |
| Eagle Lake | Wasteload | Watershed | 0.839 | 306.6 | 0.511 | 186.8 | 119.8 |
| | | Upstream Load | 0.574 | 209.5 | 0.299 | 109.1 | 100.4 |
| | Load | Atmospheric | 0.085 | 31.1 | 0.085 | 31.1 | -- |
| | | Internal | -- | -- | 0.014 | 5.0 | -- |
| | | | **1.498** | **547.2** | **0.909** | **332.0** | **220.2** |

## 7.2 PREDICTED LAKE RESPONSE

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

### 7.2.1 Modeled Historic Loads

Using the Canfield-Bachmann equation, historic loads and load reductions were calculated for each of the basins. These calculations provide some insight into the assimilative capacity of the lake under historical hydrologic conditions as well as over time. Additionally, these results provide a sense for the level of effort necessary to achieve the TMDL and whether that TMDL will be protective of the water quality standard.

For the three years with monitoring data, Cedar Island Lake required a 48 to 90% reduction in total phosphorus loads (Figure 7.1). Much of this load is likely internal loading and requires evaluating the plant community and fisheries to establish healthy shallow lake conditions. Establishment of biological goals for the lake will be critical in reestablishing a healthy shallow lake plant community.

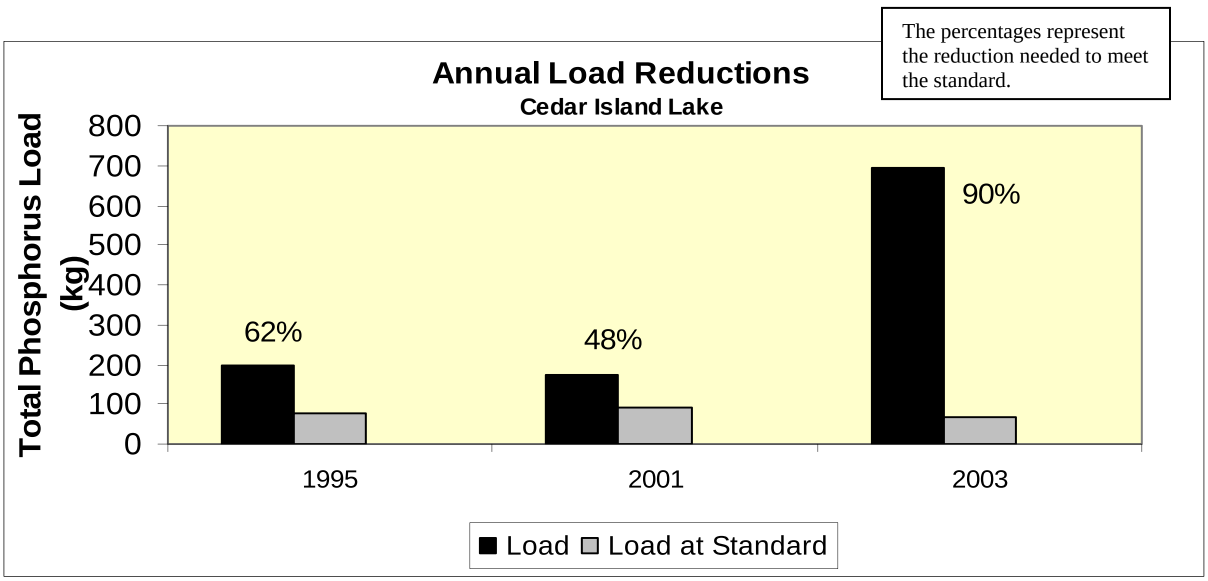



**Figure 7.1. Modeled annual load and load at the standard for Cedar Island Lake.**

Pike Lake required a 0 to 49% reduction in total phosphorus loads to the lake to meet the State water quality standard for shallow lakes (Figure 7.2). Loading is likely a result of both internal and external loads. Establishment of biological goals for the lake will be critical in reestablishing a healthy shallow lake plant community.

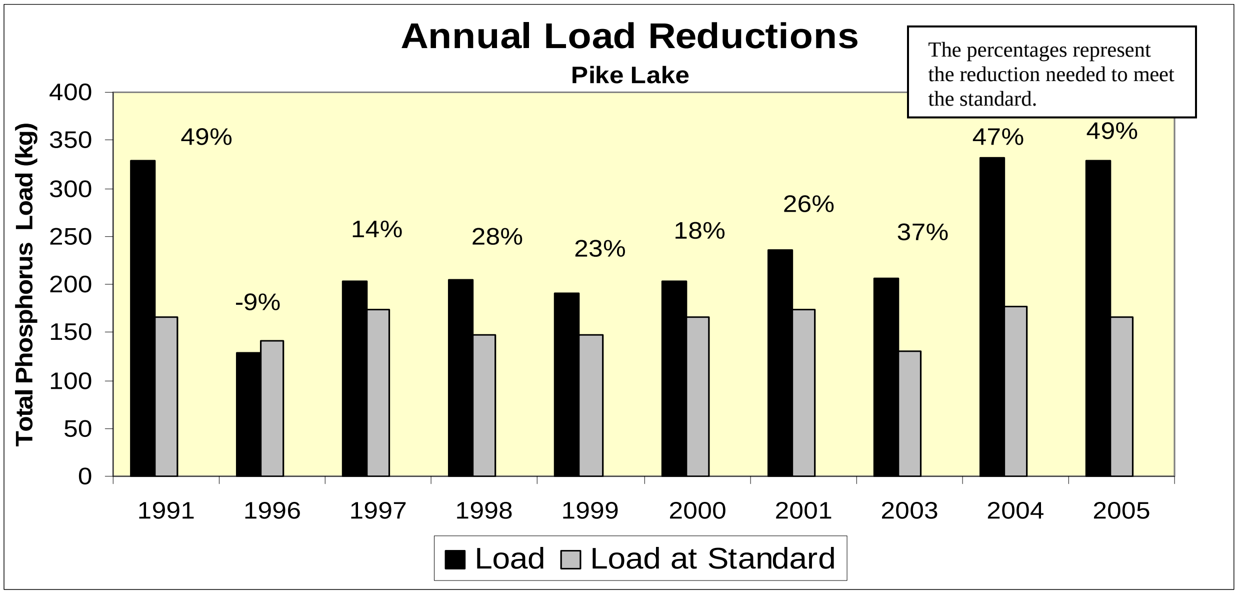



**Figure 7.2. Modeled annual load and load at the standard for Pike Lake.**

Eagle Lake required a 0 to 34% reduction in total phosphorus loads to meet the State standard for deep lakes (Figure 7.3). It is likely that much of this could be accomplished through treatment of both Cedar Island and Pike Lakes.

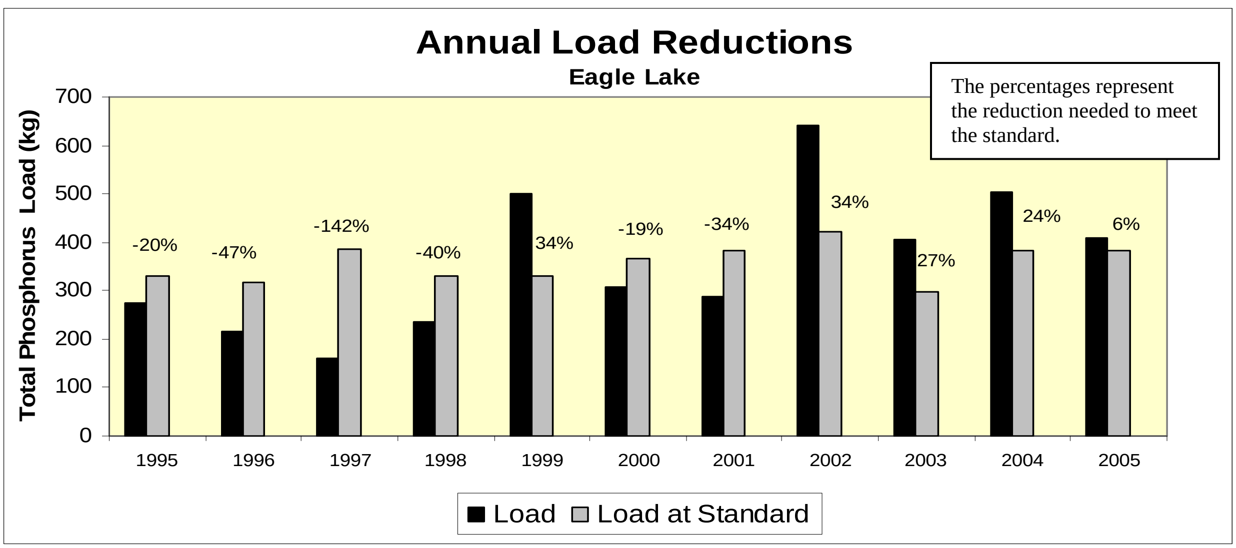



**Figure 7.3. Modeled annual load and load at the standard for Eagle Lake.**

### 7.2.2 Water Quality Response to Load Reductions

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

### 7.2.2.1 Phosphorus

The modeled response to phosphorus load reductions in all basins is presented in Figures 7.4 and 7.5. All three lakes have a predicted positive response to reductions in phosphorus loads.

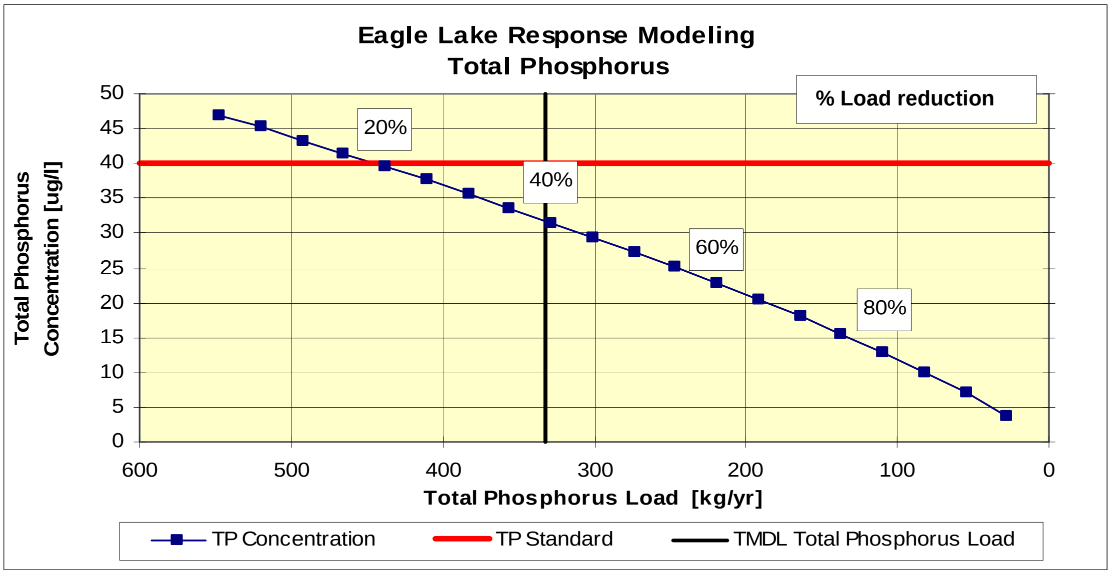



**Figure 7.4. Eagle Lake total phosphorus concentration predicted for total phosphorus load reductions applied to all sources.**

However, both Cedar Island and Pike Lakes are shallow basins with a significant potential to internally load phosphorus. Consequently, the measured response will likely be much less pronounced until internal loading is controlled or biological feedback mechanisms are reestablished in the lake.

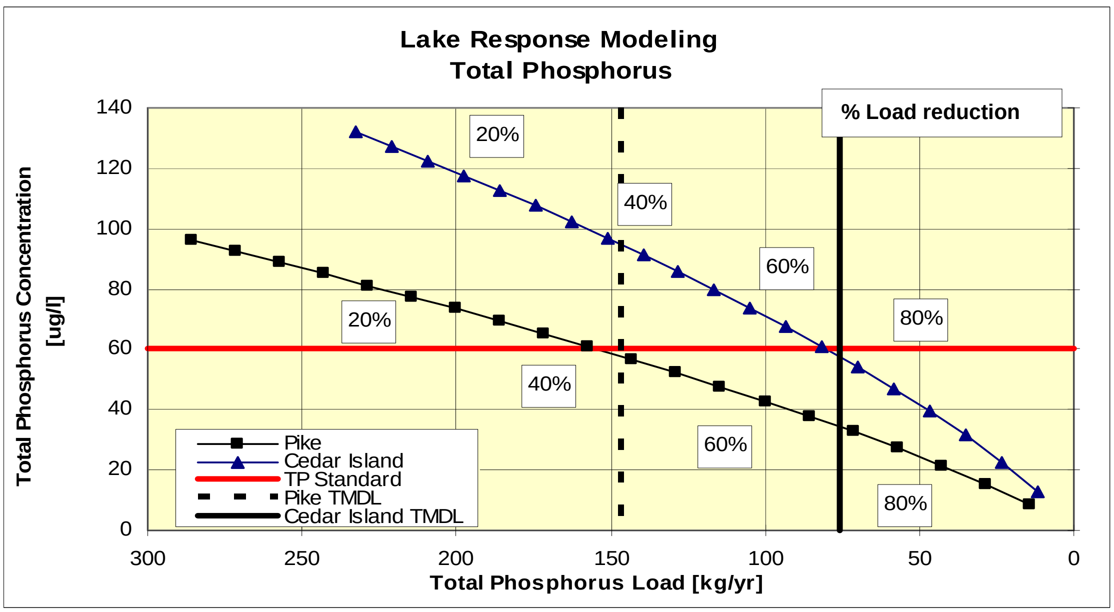



**Figure 7.5. Total phosphorus concentration predicted for total phosphorus load reductions applied to all sources.**

### 7.2.2.2 Chlorophyll-a

The modeled response to chlorophyll-a is presented in Figures 7.6 and 7.7. Although a positive response is predicted in all three lakes, there is a need to reestablish plant and fish communities in Cedar Island and Pike Lakes to provide biological controls on phytoplankton such as shading by aquatic vegetation and grazing by zooplankton.

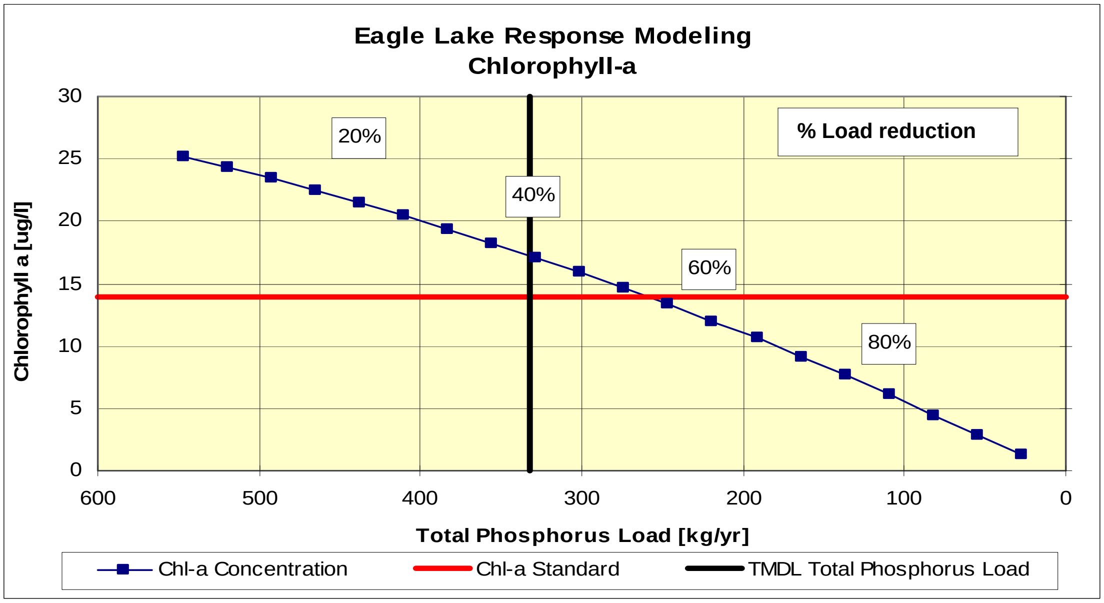



**Figure 7.6. Eagle Lake chlorophyll-a concentration predicted for total phosphorus load reductions applied to all sources.**

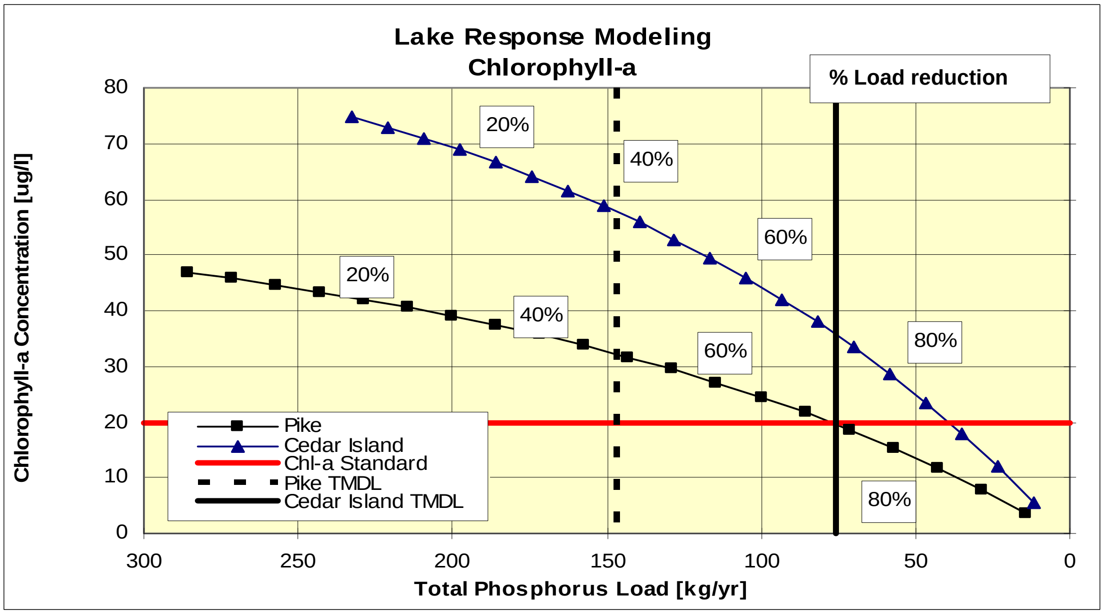



**Figure 7.7. Chlorophyll-a concentration predicted for total phosphorus load reductions applied to all sources.**

### 7.2.2.3 Secchi Depth

Secchi depth response to total phosphorus reductions is presented in Figures 7.8 and 7.9. Both Pike and Eagle Lakes demonstrate a positive response to reductions in total phosphorus loading. It is likely that Cedar Island would meet the State standard of greater than 1 meter in Secchi depth transparency only with extreme reductions in phosphorus loading and if the biological health in Cedar Island Lake is restored.

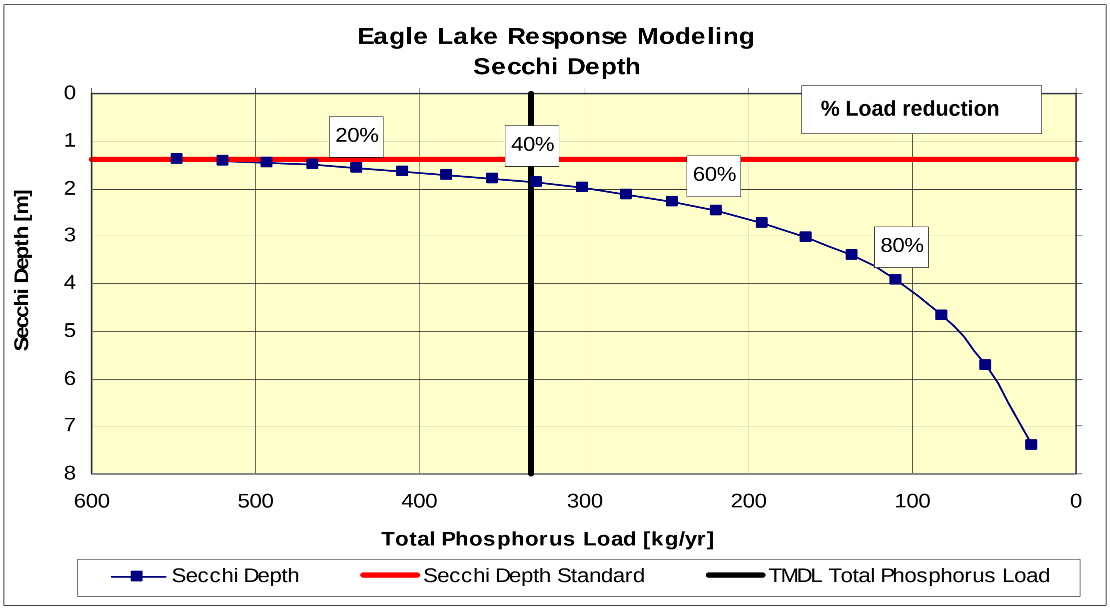



**Figure 7.8. Eagle Lake Secchi depth predicted for total phosphorus load reductions applied to all sources.**

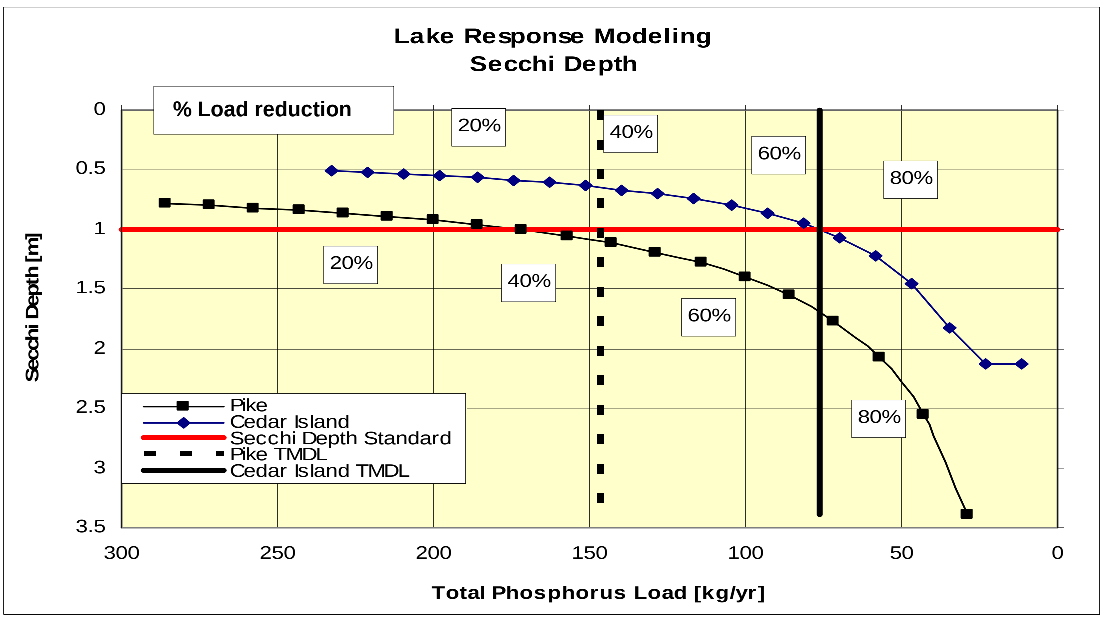



**Figure 7.9. Secchi depth predicted for total phosphorus load reductions applied to all sources.**

## 7.3 SEASONAL AND ANNUAL VARIATION

The daily load reduction targets in this TMDL are calculated from the current phosphorus budget for each of the lakes. The budget is an average of two years of monitoring data, a wet and a dry year. BMPs designed to address excess loads to the lakes will be designed for 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 modeled years addresses annual variability in lake loading.

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

### 7.3.1 Critical Condition

The critical condition for these lakes is the summer growing season. Minnesota lakes typically demonstrate impacts from excessive nutrients during the summer recreation season (June 1 - September 30) including excessive algal blooms and fish kills. Lake goals have focused on summer-mean total phosphorus, Secchi transparency and chlorophyll-a concentrations, which have been linked to user perception (Heiskary and Wilson 2005). Consequently, the lake response models have focused on the summer growing season as the critical condition. Additionally, these lakes tend to have relatively short residence times and, therefore, respond to summer growing season loads.

## 7.4 RESERVE CAPACITY/FUTURE GROWTH

The watersheds for these lakes are all fully covered by MS4 communities and are included in the Wasteload Allocation. The watershed is almost entirely developed and most of the development projects that occur are redevelopment or small infill projects. No new NPDES sources are anticipated in these watersheds, therefore, no portion of the Wasteload Allocation is being held in reserve.

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

# 8.0 Public Participation

## 8.1 INTRODUCTION

As a part of the strategy to achieve implementation of the necessary allocations, the Shingle Creek Watershed Management Commission (SCWMC) seeks stakeholder and public engagement and participation regarding their concerns, interests, and questions regarding the development of the TMDL. Specifically, meetings were held for a Technical Advisory Committee representing key stakeholders. Additionally, the SCWMC reviewed the TMDL with City Councils and citizens advisory committees at meetings to which lake association members were invited.

## 8.2 TECHNICAL ADVISORY COMMITTEE

A technical advisory committee was established so that interested stakeholders could be involved in key decisions involved in developing the TMDL. Stakeholders represented on the Technical Advisory Committee include local cities, Minnesota DNR, the Metropolitan Council, Hennepin County, the U.S. Geological Survey (USGS), Three Rivers Park District, and the Minnesota Pollution Control Agency. All meetings were open to interested individuals and organizations. Technical Advisory Committee meetings to review this and other lake TMDLs in the watershed were held on December 8, 2005, February 9, 2006, March 9, 2006, and June 27, 2007.

## 8.3 STAKEHOLDER MEETINGS

The preliminary results of the TMDL were presented to the City of Plymouth Environmental Quality Board on March 8, 2006. This citizen commission invited lake association members and other interested parties to attend this meeting. In addition, the draft findings of the TMDL and the preliminary Implementation Plan were presented to the City of Maple Grove Lake Quality Commission on May 21, 2008 and on October 15, 2008.

## 8.4 PUBLIC MEETINGS

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

# 9.0 Implementation

## 9.1 IMPLEMENTATION FRAMEWORK

### 9.1.1 The Shingle Creek Watershed Management Commission

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

The Shingle Creek Water Quality Plan (WQP):

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

The Water Quality Plan is composed of four parts:

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

This WQP charts the course the Commission will take to meet its Second Generation Watershed Management Plan goals to protect and improve water quality and meet Commission and State water quality standards. While the Plan lays out a series of activities and projects, implementation will occur as the Commission's and cities' budgets permit. The Commission as part of the Major Plan Amendment process also revised its cost share formula to provide for Commission participation in the cost of TMDL implementation projects.

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

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

### 9.1.2 Member Cities

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

## 9.2 REDUCTION STRATEGIES

### 9.2.1 Annual Load Reductions

The focus in implementation will be on reducing the annual phosphorus loads to the lakes through structural and nonstructural Best Management Practices. The Total Maximum Daily Loads, Table 7.4 above, which establish the daily and annual TMDL loads, are replicated as Table 9.1 below.

**Table 9.1. TMDL total phosphorus loads partitioned among the major sources.**

| | Allocation | Source | Existing TP Load | | Total Phosphorus TMDL | | Load Reduction |
|---|---|---|---|---|---|---|---|
| | | | (kg/day) | (kg/year) | (kg/day) | (kg/year) | (kg/year) |
| Cedar Island Lake | Wasteload | Watershed | 0.304 | 111.0 | 0.133 | 48.5 | 62.5 |
| | Load | Atmospheric | 0.024 | 8.6 | 0.024 | 8.6 | -- |
| | | Internal | 0.310 | 113.1 | 0.051 | 18.9 | 94.2 |
| | | | **0.638** | **232.7** | **0.208** | **76.0** | **156.7** |
| | ***67% Load Reduction Required*** | | | | | | |
| Pike Lake | Wasteload | Watershed | 0.554 | 202.5 | 0.350 | 127.7 | 74.8 |
| | Load | Atmospheric | 0.017 | 6.5 | 0.017 | 6.5 | -- |
| | | Internal | 0.211 | 77.0 | 0.035 | 12.8 | 64.2 |
| | | | **0.782** | **286.0** | **0.402** | **147.0** | **139.0** |
| | ***49% Load Reduction Required*** | | | | | | |
| Eagle Lake | Wasteload | Watershed | 0.839 | 306.6 | 0.511 | 186.8 | 119.8 |
| | | Upstream Load | 0.574 | 209.5 | 0.299 | 109.1 | 100.4 |
| | Load | Atmospheric | 0.085 | 31.1 | 0.085 | 31.1 | -- |
| | | Internal | -- | -- | 0.014 | 5.0 | -- |
| | | | **1.498** | **547.2** | **0.909** | **332.0** | **220.2** |
| | ***40% Load Reduction Required*** | | | | | | |

### 9.2.2 Actions

Restoration options for lakes are numerous with varying rates of success. Consequently, each technology must be evaluated in light of our current understanding of physical and biological processes in that lake. Most of the watershed draining to these lakes is fully developed, and options for reducing external nutrient loads are limited and will likely be costly to implement. Following is a description of potential actions for controlling nutrients in these lakes that will be further developed in the Cedar Island-Pike-Eagle Lakes Implementation Plan. The estimated total cost of implementing these and other potential BMPs ranges from $500,000 to $3,000,000.

#### 9.2.2.1 External Load Reductions

The Eagle Lake watershed is mostly developed with some infill development opportunities. New development and redevelopment that meets certain thresholds will be required to provide pretreatment of stormwater prior to discharge into the other water resources in the watershed. Small, incremental reductions are also possible through retrofit as redevelopment occurs and through the implementation of Best Management Practices (BMPs) throughout the subwatershed.

*Retrofit BMPs where possible.* Much, but not all, of the watershed was developed with treatment controls, generally in the form of stormwater detention ponds. As opportunities arise, retrofit water quality treatment through a variety of Best Management Practices including detention ponds, native plantings, sump manholes, swirl separators, and trash collectors. These small practices are effective in removing debris, leaf litter, and other potential pollutants. Depending on the type of BMP, location, easement requirements, and other factors, costs can range from $5,000 for a sump manhole to $250,000 or more for a detention pond. The number of BMPs necessary to achieve the required phosphorus load reduction is unknown and is dependent on the types of opportunities that arise. Recent highway projects have added significant treatment to the watershed draining to the lakes. MnDOT included an extensive stormwater treatment system with the recent I-94 third lane project, and Hennepin County included detention ponds in the recent CSAH (County State Aid Highway) 61 (Hemlock Lane) improvements.

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

*Target street sweeping.* Identify key areas and target those areas for more frequent street sweeping and consider replacing mechanical street sweepers with more efficient regenerative air sweepers. Dustless sweepers cost $150,000-200,000, about twice the cost of traditional broom sweepers. As the drainage area to these lakes encompasses both Maple Grove and Plymouth, each city should consider how to accomplish this within the context of their street sweeping programs.

*Encourage shoreline restoration.* Most property owners maintain a turfed edge to the shoreline. While no shoreline surveys are available, property owners typically maintain either a mowed edge that experiences some mass wasting, or a hard edge of riprap or retaining wall. Encourage property owners to restore their shoreline with native plants to reduce erosion and capture direct runoff. Maple Grove should consider demonstration projects in city parks and open spaces. Approximately 21,000 linear feet of residential shoreline is present on Cedar Island and Eagle Lakes, with the balance of the shoreline and all of Pike Lake's shoreline being riparian wetlands. Planting 75 percent of the developed shoreline with native buffers would cost an estimated $472,500 to 787,500.

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

*Improve upstream lakes.* Eagle Lake is influenced by the water quality in Pike and Cedar Island Lakes. Reduction in in-lake phosphorus concentrations in those lakes would reduce the phosphorus load exported to Eagle Lake.

#### 9.2.2.2 Internal Loads

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

*Chemical treatment.* Following implementation of BMPs to reduce external nutrient load sources, it may be feasible to chemically treat Eagle Lake with alum to remove phosphorus from the water column and bind it to sediments. Because they are shallow, neither Pike Lake nor Cedar Island Lake is a good candidate for this type of treatment. The estimated cost of chemically treating Eagle Lake is $400,000.

*Vegetation management.* Curly-leaf pondweed is a nuisance in Cedar Island Lake and contributes to significant mid-season algal blooms. Some chemical treatment has been applied by the lake association. Chemical treatments applied for at least three to five years in a row may be necessary to limit growth of this phosphorus source. The estimated cost of this treatment is $35,000 per treatment.

*Fishery management.* In partnership with the DNR, Pike and Cedar Island Lakes should be considered for rough fish removal. The estimated cost of this option is $50,000. Because Cedar Island Lake is hydraulically connected to several ponds and wetlands, fish barriers may be necessary to prevent future migration into the lake, or fish removal may need to be performed periodically when the population reestablishes. Pike Lake is connected to Eagle Lake by a channel cut through a large wetland that connects the two lakes. It may not be possible to create an effective fish barrier between the two lakes.

*Drawdown.* Cedar Island Lake may be a good candidate for a water level drawdown. The existing lift station supplemented by additional pumps could be used to pump down water levels, exposing the lake sediments and providing an opportunity for the native seed bank to reestablish a more beneficial aquatic vegetation community. Some additional chemical treatment may be necessary if the entire lake cannot be entirely drained. In addition, the pumped outlet is discharged by storm sewer to Eagle Lake, so some type of chemical injection may be necessary to treat the Cedar Island outflow before it discharges into Eagle Lake. The estimated cost of this option is $500,000.

#### 9.2.2.3 Other Strategies

*Conduct aquatic plant surveys and prepare vegetation management plans.* Aquatic plants should periodically be surveyed on the three lakes to track changes in the plant community and monitor growth and extent of nuisance species such as Eurasian water milfoil and curly-leaf pondweed. The cost of a survey and management plan is about $10,000 per lake.

*Manage fish populations.* Partner with the DNR to monitor and manage the fish population to maintain a beneficial community.

## 9.3 IMPLEMENTATION STRATEGY

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

Based on this understanding of the appropriate standards for lakes, this TMDL has been established with the intent to implement all the appropriate activities that are not considered greater than extraordinary efforts. It is expected that it may take 10-20 years to implement BMPs and load-reduction activities. If all of the appropriate BMPs and activities have been implemented and the lakes still do not meet the current water quality standards, the TMDL will be reevaluated and the Shingle Creek Watershed Management Commission will begin a process with the MPCA to develop more appropriate site-specific standards for the lakes. The process will be based on the MPCA’s methodology for determining site-specific standards.

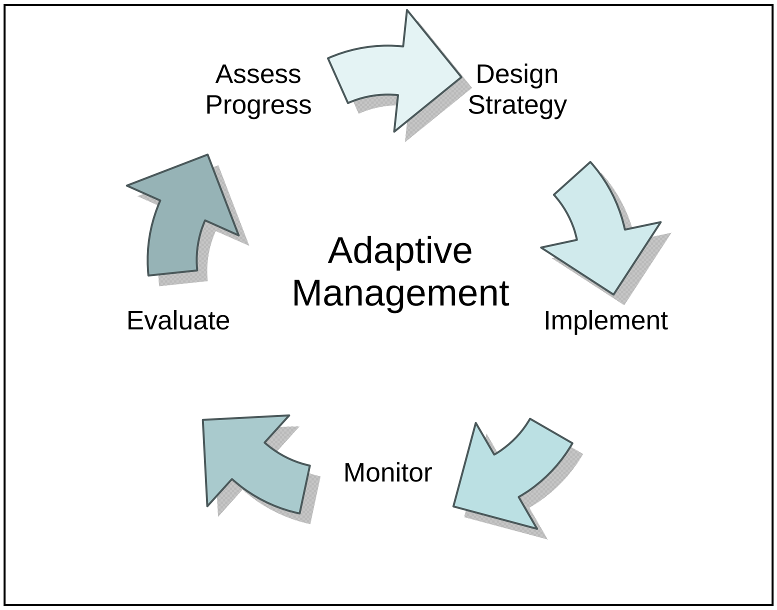



**Figure 9.1. Adaptive management.**

# 10.0 Reasonable Assurance

## 10.1 INTRODUCTION

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

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

## 10.2 THE SHINGLE CREEK WATERSHED MANAGEMENT COMMISSION

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

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

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

The Commission has received significant grant funding from the Minnesota Pollution Control Agency, the Board of Water and Soil Resources, the Metropolitan Council, and the Department of Natural Resources to undertake planning and demonstration projects. The Commission intends to continue to solicit funds and partnerships from these and other sources to supplement the funds provided by the nine cities having land in the watershed. It is expected that the Commission will continuously update the annual Capital Improvement Programs (CIPs) as a part of its annual budget process.

## 10.3 NPDES MS4 STORMWATER PERMITS

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

Within the Eagle Lake chain of lakes watershed, two cities, Hennepin County and MnDOT Metro District are covered under the Phase II General NPDES Stormwater Permit – MNR040000. The unique permit numbers assigned to the MS4s that drain to the chain of lakes are as follows:

- Maple Grove – MS400102
- Plymouth – MS400112
- Hennepin County – MS400138
- MnDOT Metro District – MS400170

Stormwater discharges are regulated under NPDES and allocations of nutrient reductions are considered wasteloads. Because there is not enough information available to assign loads to individual permit holders, the Wasteload Allocations are combined in this TMDL as Categorical Wasteload Allocations (see Table 7.2). There are no known industrial dischargers in the watershed. The pollutant load from construction stormwater is considered to be less than one percent of the TMDL and difficult to quantify. Consequently, the WLA also includes pollutant loading from construction stormwater sources.

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

> "If a USEPA-approved **TMDL(s)** has been developed, you must review the adequacy of your Storm Water Pollution Prevention Program to meet the **TMDL's Waste Load Allocation** set for storm water sources. If the **Storm Water Pollution Prevention Program** is not meeting the

> applicable requirements, schedules and objectives of the **TMDL**, you must modify your **Storm Water Pollution Prevention Program**, as appropriate, within 18 months after the TMDL is approved."

MS4s contributing stormwater to the lakes will comply with this requirement during the implementation period of the TMDL. The Implementation Plan identifies specific BMP opportunities sufficient to achieve the load reduction. Construction stormwater activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install, and maintain all BMPs required under the permit, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

In this TMDL the Load Allocation is also allocated in the same manner as the WLA. Each permittee has committed to implement BMPs to reduce nutrient loading to the lakes. The MS4s cooperated in developing the TMDL and Implementation Plan and will continue to work together through the ongoing Commission Technical Advisory Committee (TAC) to identify and implement BMPs either individually or in collaboration. This collective approach allows for greater reductions for some permit holders with greater opportunity and less for those with greater constraints. The collective approach is to be outlined in an Implementation Plan developed by the Shingle Creek Watershed Management Commission.

## 10.4 MONITORING

### 10.4.1 Monitoring Implementation of Policies and BMPs

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

### 10.4.2 Follow-up Monitoring

The SCWMC monitors water quality in local lakes through the funding of special studies and citizen volunteer efforts. Additional monitoring is proposed in the Commission's Water Quality Plan in an effort to ensure the quality of data. Schedules of monitoring activities are identified in the Shingle Creek Water Quality Plan (SCWMC 2007). Results of all monitoring will be included in their annual water quality monitoring report.

These three lakes will be periodically monitored by the CAMP program through the Shingle Creek Watershed Management Commission (SCWMC). The CAMP program is operated by

Metropolitan Council Environmental Services and is a volunteer monitoring program. Citizen volunteers collect data and samples biweekly.

# 11.0 Literature Cited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# Appendix A

## Lake Response Modeling Summary

## MODELING AND CALCULATION DETAIL

The attached tables and model runs provide detail of modeling performed for this TMDL.

**TMDL Table 6.5, Current Total Phosphorus Budget**
P8 modeling was performed for each lake. For each lake in this Appendix A, there is a Table 1 that shows P8 Results for the period 1992 - 2003. This table shows the P8 runoff flow and load in acre-feet and pounds, cubic hectometers and kilograms. This table also shows acre-feet of runoff calculated using the Shingle Creek Watershed Commission's calibrated SWMM model.

TMDL Table 6.5 presents annual phosphorus budgets for 2001 and 2003. Those years were used to calibrate the water quality response model. The P8 values were used in the existing conditions models and in establishing the TMDLs as described below.

TMDL Table 6.1 shows the calculation of atmospheric deposition load for the lakes. Section 6.3.3 of the TMDL describes the estimation of internal loads for the lakes. For each lake in this Appendix A there is a Table 2 that summarizes Lake Morphometry characteristics that were used in the estimation of atmospheric and internal loads.

Spreadsheet models using the Canfield Bachmann natural lakes equation and other equations from the BATHTUB model as described in Section 6.5 were used to estimate phosphorus sedimentation and phosphorus outflow. The models for 2001 and 2003 and for the average TP budget are included in this appendix. The modeling assumed that the entire outflow load from Cedar Island and Pike Lakes would be transported downstream to Eagle Lake. This likely overpredicts the outflow load from Cedar Island Lake as in some years the pumped outlet is operated very infrequently. This assumption provides an additional margin of safety for calculating reductions necessary for Eagle Lake.

**TMDL Tables 6.6, 6.7, and 6.8, Model Fit**
Model fit for the years 2001 and 2003 was calculated using the spreadsheet models, the details of which are presented in the "Lake Response Modeling" spreadsheet for each year modeled as well as for the average TP budget.

**TMDL Tables 7.3 and 7.4, TMDL Total Phosphorus Allocations**
Inverted Canfield Bachmann equations were used to calculate the TMDL. For each lake there is in this appendix a (Lake Name) Table 3, Inverted Canfield Bachmann Calculation. This reverse-calculates the load under existing conditions and at the appropriate TP standard. The TMDL was established using the 1999 flow conditions, representative of an average precipitation year.

The total TP TMDL for each of the lakes was partitioned by difference. Atmospheric load was held constant and internal load was calculated as shown in Table 7.1. The atmospheric load, internal load, and for Eagle Lake the upstream load were subtracted from the TMDL to obtain the watershed load. The final spreadsheet model in this appendix for each lake shows the modeled load and lake response at the water quality standard.

## Cedar Island Lake Table 1
## P8 Results

| Precip (in) | Year | P8 Flow (ac-ft) | P8 Load (lbs) |
|---|---|---|---|
| 35 | 1992 | 581.65 | 252.98 |
| 37 | 1993 | 573.87 | 255.85 |
| 30 | 1994 | 436.44 | 193.37 |
| 33 | 1995 | 480.5 | 215.73 |
| 29 | 1996 | 453.63 | 196.53 |
| 34 | 1997 | 639.67 | 414.96 |
| 31 | 1998 | 486.12 | 207.69 |
| 31 | 1999 | 492.38 | 218.47 |
| 35 | 2000 | 586.17 | 299.49 |
| 35 | 2001 | 636.75 | 287.55 |
| 43 | 2002 | 732.68 | 355.13 |
| 25 | 2003 | 409.83 | 202.16 |

| Year | Precip (in) | SWMM (ac-ft) | P8 Flow (ac-ft) | % diff | TP-P8 (lbs) | TP-ICB (lbs) | % diff | |
|---|---|---|---|---|---|---|---|---|
| 1992 | 35 | 603 | 582 | -4% | | | | |
| 1993 | 37 | 562 | 574 | 2% | | | | |
| 1994 | 30 | 442 | 436 | -1% | | | | |
| 1995 | 33 | 496 | 481 | -3% | | | | |
| 1996 | 29 | 416 | 454 | 9% | 197 | 434 | -121% | |
| 1997 | 34 | 568 | 640 | 13% | | | | |
| 1998 | 31 | 432 | 486 | 13% | | | | |
| 1999 | 31 | 447 | 492 | 10% | 218 | 385 | -76% | Average |
| 2000 | 35 | 551 | 586 | 6% | | | | |
| 2001 | 35 | 564 | 637 | 13% | | | | |
| 2002 | 43 | 737 | 733 | -1% | | | | Wet |
| 2003 | 25 | 423 | 410 | -3% | | | | Dry |

ICB = Inverted Canfield Bachmann
SWMM = Shingle Creek SWMM model calibrated in the Shingle Creek Chloride TMDL

| Precip (in) | Year | P8 Flow (hm3) | P8 Load (kg) | TP (ug/L) |
|---|---|---|---|---|
| 35 | 1992 | 0.72 | 114.75 | 160 |
| 37 | 1993 | 0.71 | 116.05 | 164 |
| 30 | 1994 | 0.54 | 87.71 | 163 |
| 33 | 1995 | 0.59 | 97.86 | 165 |
| 29 | 1996 | 0.56 | 89.15 | 159 |
| 34 | 1997 | 0.79 | 188.23 | 238 |
| 31 | 1998 | 0.60 | 94.21 | 157 |
| 31 | 1999 | 0.61 | 99.10 | 163 |
| 35 | 2000 | 0.72 | 135.85 | 188 |
| 35 | 2001 | 0.79 | 130.43 | 166 |
| 43 | 2002 | 0.90 | 161.09 | 178 |
| 25 | 2003 | 0.51 | 91.70 | 181 |

**Cedar Island Lake Table 2**
**Lake Morphometry**

| Depth | Depth Segment | Acres | Volume (ac-ft) | Bottom Area | % Lake Area | m3 | Liters | m2 | Km2 | z |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 78.95 | | | 100.00 | | | 319,511 | 0.32 | 1.10 |
| 5 | 0-5 | 37.55 | 284.91315 | 41.40 | 52.44 | 351,474.3 | 351,474,327.9 | | | |
| 10 | | | | 37.55 | 47.56 | - | - | | | |
| 15 | | | | | | | | | | |
| 20 | | | | | | | | | | |
| 25 | | | | | | | | | | |
| TOTAL | | | 284.91315 | | | 351,474.3 | 351,474,327.9 | | | |

**Cedar Island Lake Table 3**
**Inverted Canfield Bachmann Calculation**

## EXISTING

Total Watershed Loads

| | | ICB Load (kg) | Modeled TP Average | Measured TP Average | L Average | z (m) | p (1/yr) | o Average | Volume (ac-ft) | Water Load (ac-ft) | Residence Time (yr) | Inflow Concen-tration (ug/L) | Lake Surface Area (km2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1995 | 197 | 121 | 121 | 615.5 | 1.1 | 1.68656 | 2.93782 | 285 | 481 | 0.6 | 332 | 0.32 |
| | 2001 | 175 | 99 | 99 | 546.3 | 1.1 | 2.23499 | 2.78167 | 285 | 637 | 0.4 | 222 | 0.32 |
| | 2003 | 695 | 296 | 296 | 2172.9 | 1.1 | 1.43850 | 5.23508 | 285 | 410 | 0.7 | 1,375 | 0.32 |
| | | **P8 Load (kg)** | | | | | | | | | | | |
| Average | 1999 | 99 | 73 | | 309.7 | 1.1 | 1.72765 | 2.14485 | 285 | 492 | 0.6 | 163 | 0.32 |
| Wet | 2002 | 161 | 87 | | 503.4 | 1.1 | 2.57081 | 2.67937 | 285 | 733 | 0.4 | 178 | 0.32 |
| Dry | 2003 | 92 | 74 | | 286.6 | 1.1 | 1.43800 | 2.06997 | 285 | 410 | 0.7 | 181 | 0.32 |

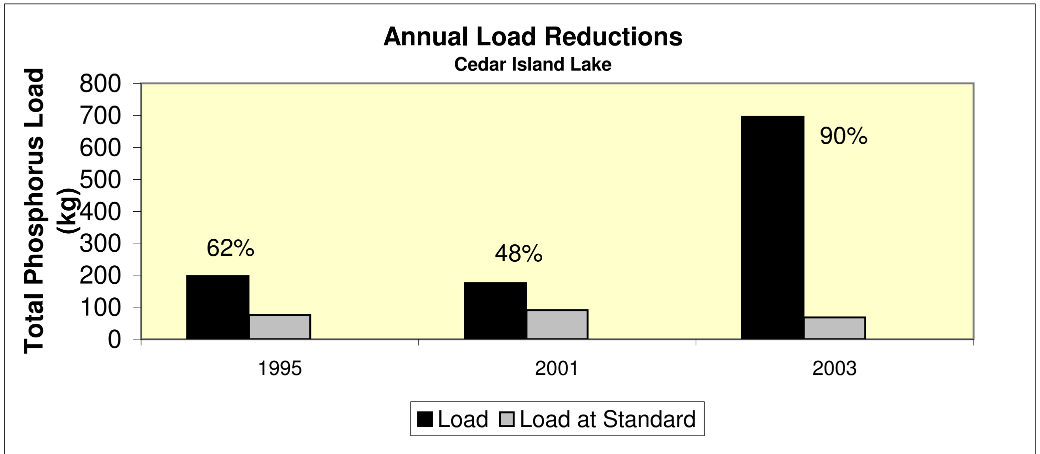
## AT STANDARD

Total Watershed Loads

| | | ICB Load (kg) | Modeled TP Average | Measured TP Average | L Average | z (m) | p (1/yr) | o Average | Volume (ac-ft) | Water Load (ac-ft) | Residence Time (yr) | Inflow Concen-tration (ug/L) | Lake Surface Area (km2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1995 | 76 | 60 | | 236.4 | 1.1 | 1.68596 | 1.89516 | 285 | 481 | 0.6 | 128 | 0.32 |
| | 2001 | 91 | 60 | | 283.4 | 1.1 | 2.23421 | 2.05940 | 285 | 637 | 0.4 | 115 | 0.32 |
| | 2003 | 68 | 60 | | 212.5 | 1.1 | 1.43800 | 1.80504 | 285 | 410 | 0.7 | 134 | 0.32 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | 1999 | 76 | 60 | | 237.5 | 1.1 | 1.72632 | 1.89938 | 285 | 492 | 0.6 | 125 | 0.32 |
| Wet | 2002 | 99 | 60 | | 309.4 | 1.1 | 2.57193 | 2.14387 | 285 | 733 | 0.4 | 109 | 0.32 |
| Dry | 2003 | 68 | 60 | | 212.5 | 1.1 | 1.43509 | 1.80504 | 285 | 409 | 0.7 | 135 | 0.32 |

| Year | Load | Load at Standard | % Reduction |
|---|---|---|---|
| 1995 | 197 | 76 | 62% |
| 2001 | 175 | 91 | 48% |
| 2003 | 695 | 68 | 90% |



**Pike Lake Table 1**
**P8 Results**

| Precip (in) | Year | P8 Flow (ac-ft) | P8 Load (lbs) |
|---|---|---|---|
| 35 | 1992 | 1161.7 | 465.3 |
| 37 | 1993 | 1162.2 | 501.98 |
| 30 | 1994 | 898.15 | 395.56 |
| 33 | 1995 | 978.15 | 438.51 |
| 29 | 1996 | 924.02 | 397.63 |
| 34 | 1997 | 1301.3 | 773.23 |
| 31 | 1998 | 991.49 | 420.34 |
| 31 | 1999 | 989.58 | 424.18 |
| 35 | 2000 | 1195.2 | 571.98 |
| 35 | 2001 | 1274.8 | 535.67 |
| 43 | 2002 | 1463.9 | 650.09 |
| 25 | 2003 | 820.62 | 357.34 |

| Year | Precip (in) | SWMM (ac-ft) | P8 Flow (ac-ft) | % diff | TP-P8 (lbs) | TP-ICB (lbs) | % diff | |
|---|---|---|---|---|---|---|---|---|
| 1992 | 35 | 1264 | 1162 | -8% | 465 | | | |
| 1993 | 37 | 1179 | 1162 | -1% | 502 | | | |
| 1994 | 30 | 929 | 898 | -3% | 396 | | | |
| 1995 | 33 | 1041 | 978 | -6% | 439 | | | |
| 1996 | 29 | 873 | 924 | 6% | 398 | 283 | 29% | |
| 1997 | 34 | 1190 | 1301 | 9% | 773 | 447 | 42% | |
| 1998 | 31 | 906 | 991 | 9% | 420 | 450 | -7% | |
| 1999 | 31 | 938 | 990 | 5% | 424 | 419 | 1% | Average |
| 2000 | 35 | 1155 | 1195 | 3% | 572 | 447 | 22% | |
| 2001 | 35 | 1182 | 1275 | 8% | 536 | 519 | 3% | |
| 2002 | 43 | 1547 | 1464 | -5% | 650 | | | Wet |
| 2003 | 25 | 887 | 821 | -7% | 357 | 453 | -27% | Dry |

| Precip (in) | Year | P8 Flow (hm3) | P8 Load (kg) | TP (ug/L) |
|---|---|---|---|---|
| 35 | 1992 | 1.43 | 211.06 | 147 |
| 37 | 1993 | 1.43 | 227.70 | 159 |
| 30 | 1994 | 1.11 | 179.43 | 162 |
| 33 | 1995 | 1.21 | 198.91 | 165 |
| 29 | 1996 | 1.14 | 180.36 | 158 |
| 34 | 1997 | 1.61 | 350.74 | 218 |
| 31 | 1998 | 1.22 | 190.67 | 156 |
| 31 | 1999 | 1.22 | 192.41 | 158 |
| 35 | 2000 | 1.47 | 259.45 | 176 |
| 35 | 2001 | 1.57 | 242.98 | 154 |
| 43 | 2002 | 1.81 | 294.88 | 163 |
| 25 | 2003 | 1.01 | 162.09 | 160 |

ICB = Inverted Canfield Bachmann
SWMM = Shingle Creek SWMM model calibrated in the Shingle Creek Chloride TMDL

# Pike Lake Table 2
## Lake Morphometry

| Depth | Depth Segment | Acres | Volume (ac-ft) | Bottom Area | % Lake Area | m3 | Liters | m2 | Km2 | z |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 59.81 | | | 100.00 | | | 242,051 | 0.24 | 2.62 |
| 5 | 0-5 | 44.42 | 259.62295 | 15.39 | 25.73 | 320,275.9 | 320,275,855.4 | | | |
| 10 | 10-May | 28.16 | 179.91267 | 16.26 | 27.19 | 221,943.7 | 221,943,722.0 | | | |
| 15 | 15-Oct | 2.89 | 66.78537 | 25.27 | 42.25 | 82,387.7 | 82,387,709.4 | | | |
| 20 | 15-20 | 0.47 | 7.54244 | 2.42 | 4.05 | 9,304.5 | 9,304,493.2 | | | |
| | 20+ | | | 0.47 | 0.79 | | | | | |
| **TOTAL** | | | 513.86342 | | | 633,911.8 | 633,911,780.0 | | | |

**Pike Lake Table 3**
**Inverted Canfield Bachmann Calculation**

## EXISTING

Total Watershed Loads

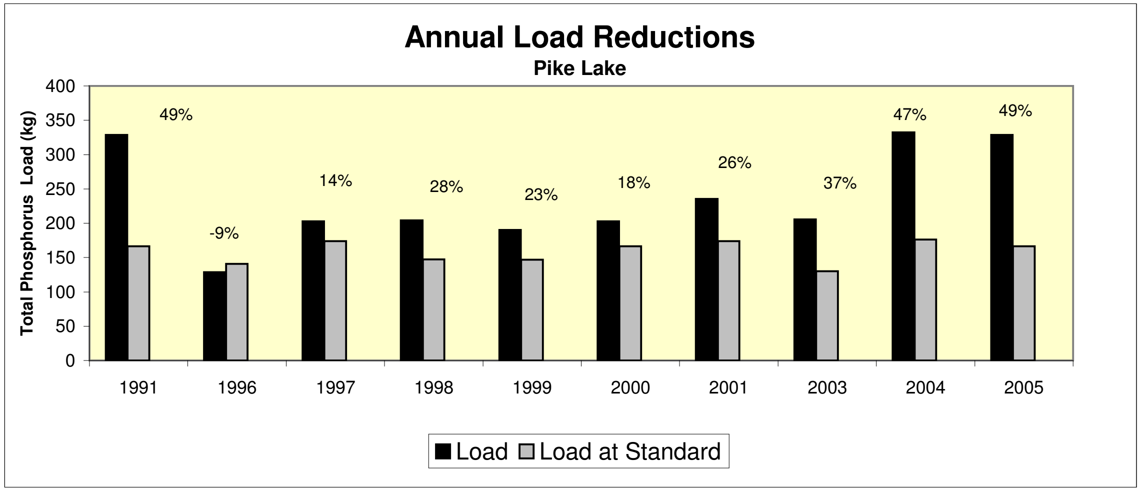
| | ICB Load (kg) | Modeled TP Average | Measured TP Average | L Average | z (m) | p (1/yr) | o Average | Volume (ac-ft) | Water Load (ac-ft) | Residence Time (yr) | Inflow Concen-tration (ug/L) | Lake Surface Area (km2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1991 | 329 | 101 | 101 | 1368.8 | 2.62 | 2.325744 | 2.846921 | 514 | 1,195 | 0.4 | 223 | 0.24 |
| 1996 | 129 | 56 | 56 | 535.6 | 2.62 | 1.798054 | 1.852427 | 514 | 924 | 0.6 | 113 | 0.24 |
| 1997 | 203 | 67 | 67 | 845.2 | 2.62 | 2.532205 | 2.282926 | 514 | 1,301 | 0.4 | 126 | 0.24 |
| 1998 | 204 | 77 | 77 | 851.3 | 2.62 | 1.929344 | 2.290382 | 514 | 991 | 0.5 | 167 | 0.24 |
| 1999 | 190 | 73 | 73 | 792.1 | 2.62 | 1.925628 | 2.216077 | 514 | 990 | 0.5 | 156 | 0.24 |
| 2000 | 203 | 70 | 70 | 845.2 | 2.62 | 2.325744 | 2.282897 | 514 | 1,195 | 0.4 | 138 | 0.24 |
| 2001 | 235 | 76 | 76 | 980.5 | 2.62 | 2.480638 | 2.443518 | 514 | 1,275 | 0.4 | 150 | 0.24 |
| 2003 | 206 | 84 | 84 | 857.1 | 2.62 | 1.596848 | 2.297489 | 514 | 821 | 0.6 | 203 | 0.24 |
| 2004 | 332 | 98 | 98 | 1385.1 | 2.62 | 2.532205 | 2.862433 | 514 | 1,301 | 0.4 | 207 | 0.24 |
| 2005 | 329 | 101 | 101 | 1368.8 | 2.62 | 2.325744 | 2.846921 | 514 | 1,195 | 0.4 | 223 | 0.24 |

## AT STANDARD

Total Watershed Loads

| | | ICB Load (kg) | Modeled TP Average | Measured TP Average | L Average | z (m) | p (1/yr) | o Average | Volume (ac-ft) | Water Load (ac-ft) | Residence Time (yr) | Inflow Concen-tration (ug/L) | Lake Surface Area (km2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1991 | 166 | 60 | | 693.4 | 2.62 | 2.325744 | 2.084931 | 514 | 1,195 | 0.4 | 113 | 0.24 |
| | 1996 | 141 | 60 | | 586.1 | 2.62 | 1.798054 | 1.930516 | 514 | 924 | 0.6 | 123 | 0.24 |
| | 1997 | 176 | 60 | | 734.6 | 2.62 | 2.532205 | 2.140845 | 514 | 1,301 | 0.4 | 110 | 0.24 |
| | 1998 | 147 | 60 | | 613.1 | 2.62 | 1.929344 | 1.970676 | 514 | 991 | 0.5 | 120 | 0.24 |
| Average | 1999 | 147 | 60 | | 612.3 | 2.62 | 1.925628 | 1.969556 | 514 | 990 | 0.5 | 120 | 0.24 |
| | 2000 | 166 | 60 | | 693.4 | 2.62 | 2.325744 | 2.084931 | 514 | 1,195 | 0.4 | 113 | 0.24 |
| | 2001 | 174 | 60 | | 724.3 | 2.62 | 2.480638 | 2.127086 | 514 | 1,275 | 0.4 | 111 | 0.24 |
| Wet | 2002 | 193 | 60 | | 804.2 | 2.62 | 2.848803 | 2.231421 | 514 | 1,464 | 0.4 | 107 | 0.24 |
| Dry | 2003 | 130 | 60 | | 541.7 | 2.62 | 1.596848 | 1.862011 | 514 | 821 | 0.6 | 128 | 0.24 |
| | 2004 | 176 | 60 | | 734.6 | 2.62 | 2.532205 | 2.140845 | 514 | 1,301 | 0.4 | 110 | 0.24 |
| | 2005 | 166 | 60 | | 693.4 | 2.62 | 2.325744 | 2.084931 | 514 | 1,195 | 0.4 | 113 | 0.24 |

| Year | Load | Load at Standard | % Reduction |
|---|---|---|---|
| 1991 | 329 | 166 | 49% |
| 1996 | 129 | 141 | -9% |
| 1997 | 203 | 174 | 14% |
| 1998 | 204 | 147 | 28% |
| 1999 | 190 | 147 | 23% |
| 2000 | 203 | 166 | 18% |
| 2001 | 235 | 174 | 26% |
| 2003 | 206 | 130 | 37% |
| 2004 | 332 | 176 | 47% |
| 2005 | 329 | 166 | 49% |



## Eagle Lake Table 1
## P8 Results

| Precip (in) | Year | P8 Flow (ac-ft) | P8 Load (lbs) | Direct Eagle (lbs) |
|---|---|---|---|---|
| 35 | 1992 | 3445.45 | 1429.35 | 711.07 |
| 37 | 1993 | 3439.07 | 1507.76 | 749.93 |
| 30 | 1994 | 2660.09 | 1178.10 | 589.17 |
| 33 | 1995 | 2915.15 | 1305.48 | 651.24 |
| 29 | 1996 | 2730.35 | 1183.96 | 589.80 |
| 34 | 1997 | 3751.47 | 2240.89 | 1052.70 |
| 31 | 1998 | 2923.31 | 1248.79 | 620.76 |
| 31 | 1999 | 2934.26 | 1279.25 | 636.60 |
| 35 | 2000 | 3484.37 | 1689.65 | 818.18 |
| 35 | 2001 | 3733.25 | 1612.10 | 788.88 |
| 43 | 2002 | 4326.08 | 1978.54 | 973.32 |
| 25 | 2003 | 2436.35 | 1122.51 | 563.01 |

| Year | Precip (in) | SWMM (ac-ft) | P8 Flow (ac-ft) | % diff | TP-P8 (lbs) | TP-ICB (lbs) | % diff | |
|---|---|---|---|---|---|---|---|---|
| 1992 | 35 | 3500 | 3445 | -2% | | | | |
| 1993 | 37 | 3274 | 3439 | 5% | | | | |
| 1994 | 30 | 2578 | 2660 | 3% | | | | |
| 1995 | 33 | 2891 | 2915 | 1% | 1305 | 609 | 53% | |
| 1996 | 29 | 2423 | 2730 | 13% | 1184 | 477 | 60% | |
| 1997 | 34 | 3293 | 3751 | 14% | 2241 | 351 | 84% | |
| 1998 | 31 | 2514 | 2923 | 16% | 1249 | 519 | 58% | |
| 1999 | 31 | 2605 | 2934 | 13% | 1279 | 1102 | 14% | Average |
| 2000 | 35 | 3204 | 3484 | 9% | 1690 | 680 | 60% | |
| 2001 | 35 | 3283 | 3733 | 14% | 1612 | 633 | 61% | |
| 2002 | 43 | 4298 | 4326 | 1% | 1979 | 1412 | 29% | Wet |
| 2003 | 25 | 2443 | 2436 | 0% | 1123 | 897 | 20% | Dry |

| Precip (in) | Year | P8 Flow (hm3) | P8 Load (kg) | Direct Eagle (kg) | TP (ug/L) |
|---|---|---|---|---|---|
| 35 | 1992 | 4.25 | 648.35 | 322.54 | 152 |
| 37 | 1993 | 4.24 | 683.92 | 340.17 | 161 |
| 30 | 1994 | 3.28 | 534.39 | 267.25 | 163 |
| 33 | 1995 | 3.60 | 592.17 | 295.40 | 165 |
| 29 | 1996 | 3.37 | 537.04 | 267.53 | 159 |
| 34 | 1997 | 4.63 | 1,016.47 | 477.50 | 220 |
| 31 | 1998 | 3.61 | 566.45 | 281.58 | 157 |
| 31 | 1999 | 3.62 | 580.27 | 288.76 | 160 |
| 35 | 2000 | 4.30 | 766.43 | 371.13 | 178 |
| 35 | 2001 | 4.61 | 731.25 | 357.84 | 159 |
| 43 | 2002 | 5.34 | 897.47 | 441.50 | 168 |
| 25 | 2003 | 3.01 | 509.17 | 255.38 | 169 |

ICB = Inverted Canfield Bachmann
SWMM = Shingle Creek SWMM model calibrated in the Shingle Creek Chloride TMDL

## Eagle Lake Table 2
## Lake Morphometry

| Depth | Depth Segment | Acres | Volume (ac-ft) | Bottom Area | % Lake Area | m3 | Liters | m2 | Km2 | z |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 287.23 | | | 100 | | | 1,162,420 | 1.16 | 3.17 |
| 5 | 0-5 | 174.97 | 1143.96652 | 112.26 | 39.08 | 1,411,219.1 | 1,411,219,063.9 | | | |
| 10 | 5-10 | 139.50 | 784.50268 | 35.47 | 12.35 | 967,777.6 | 967,777,566.3 | | | |
| 15 | 10-15 | 91.46 | 573.19047 | 48.04 | 16.73 | 707,098.8 | 707,098,770.7 | | | |
| 20 | 15-20 | 46.04 | 337.31803 | 45.42 | 15.81 | 416,122.0 | 416,122,000.5 | | | |
| 25 | 20-25 | 17.25 | 152.45229 | 28.79 | 10.02 | 188,068.1 | 188,068,077.8 | | | |
| 30 | 25+ | 3.93 | 49.02270 | 13.32 | 4.64 | 60,475.3 | 60,475,344.2 | | | |
| **TOTAL** | | | 2991.43000 | 3.93 | 1.37 | 3,690,285.5 | 3,690,285,479.3 | | | |

**Eagle Lake Table 3**
**Inverted Canfield Bachmann Calculation**

## EXISTING

Total Watershed Loads

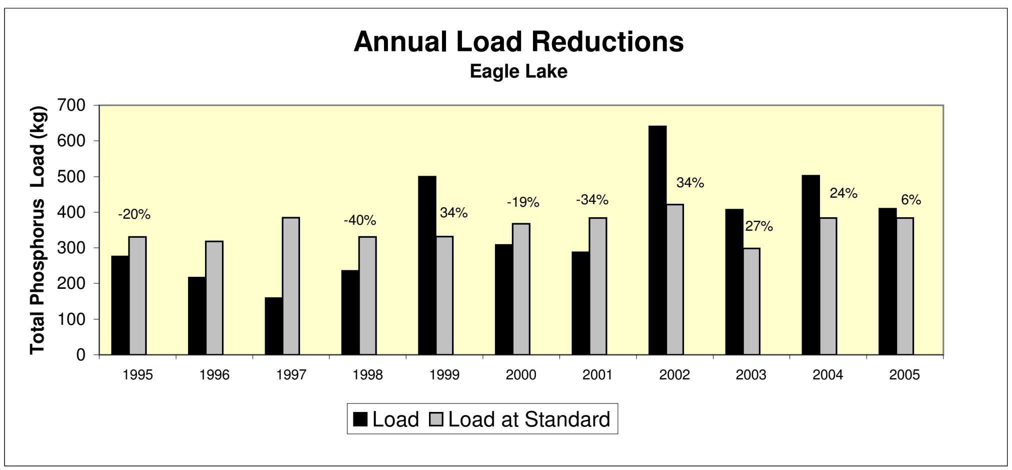
| Year | ICB Load (kg) | Modeled TP Average | Measured TP Average | L Average | z (m) | p (1/yr) | o Average | Volume (ac-ft) | Water Load (ac-ft) | Residence Time (yr) | Inflow Concen-tration (ug/L) | Lake Surface Area (km2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1995 | 276 | 35 | 35 | 238.0 | 3.17 | 0.97451 | 1.170932 | 2,991 | 2,915 | 1.0 | 77 | 1.16 |
| 1996 | 216 | 30 | 30 | 186.3 | 3.17 | 0.912733 | 1.046732 | 2,991 | 2,730 | 1.1 | 64 | 1.16 |
| 1997 | 159 | 20 | 20 | 137.2 | 3.17 | 1.254085 | 0.909738 | 2,991 | 3,751 | 0.8 | 34 | 1.16 |
| 1998 | 235 | 31 | 31 | 203.0 | 3.17 | 0.977238 | 1.088614 | 2,991 | 2,923 | 1.0 | 65 | 1.16 |
| 1999 | 500 | 54 | 54 | 431.0 | 3.17 | 0.980899 | 1.536767 | 2,991 | 2,934 | 1.0 | 138 | 1.16 |
| 2000 | 308 | 35 | 35 | 265.9 | 3.17 | 1.164796 | 1.231836 | 2,991 | 3,484 | 0.9 | 72 | 1.16 |
| 2001 | 287 | 32 | 32 | 247.5 | 3.17 | 1.247994 | 1.192072 | 2,991 | 3,733 | 0.8 | 62 | 1.16 |
| 2002 | 641 | 55 | 55 | 552.3 | 3.17 | 1.446172 | 1.721675 | 2,991 | 4,326 | 0.7 | 120 | 1.16 |
| 2003 | 407 | 50 | 50 | 350.7 | 3.17 | 0.814451 | 1.3984 | 2,991 | 2,436 | 1.2 | 135 | 1.16 |
| 2004 | 502 | 49 | 49 | 433.1 | 3.17 | 1.247994 | 1.540225 | 2,991 | 3,733 | 0.8 | 109 | 1.16 |
| 2005 | 409 | 42 | 42 | 352.9 | 3.17 | 1.247994 | 1.402261 | 2,991 | 3,733 | 0.8 | 89 | 1.16 |

## AT STANDARD

Total Watershed Loads

| | Year | ICB Load (kg) | Modeled TP Average | Measured TP Average | L Average | z (m) | p (1/yr) | o Average | Volume (ac-ft) | Water Load (ac-ft) | Residence Time (yr) | Inflow Concen-tration (ug/L) | Lake Surface Area (km2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1995 | 330 | 40 | 40 | 284.7 | 3.17 | 0.97451 | 1.27106 | 2,991 | 2,915 | 1.0 | 92 | 1.16 |
| | 1996 | 318 | 40 | 40 | 274.1 | 3.17 | 0.912733 | 1.249119 | 2,991 | 2,730 | 1.1 | 94 | 1.16 |
| | 1997 | 385 | 40 | 40 | 331.9 | 3.17 | 1.254085 | 1.363508 | 2,991 | 3,751 | 0.8 | 83 | 1.16 |
| | 1998 | 331 | 40 | 40 | 285.2 | 3.17 | 0.977238 | 1.272014 | 2,991 | 2,923 | 1.0 | 92 | 1.16 |
| Average | 1999 | 332 | 40 | 40 | 285.8 | 3.17 | 0.980899 | 1.273293 | 2,991 | 2,934 | 1.0 | 92 | 1.16 |
| | 2000 | 368 | 40 | 40 | 317.0 | 3.17 | 1.164796 | 1.335071 | 2,991 | 3,484 | 0.9 | 86 | 1.16 |
| | 2001 | 384 | 40 | 40 | 330.9 | 3.17 | 1.247994 | 1.361597 | 2,991 | 3,733 | 0.8 | 83 | 1.16 |
| Wet | 2002 | 422 | 40 | 40 | 363.7 | 3.17 | 1.446172 | 1.421755 | 2,991 | 4,326 | 0.7 | 79 | 1.16 |
| Dry | 2003 | 298 | 40 | 40 | 257.1 | 3.17 | 0.814451 | 1.212914 | 2,991 | 2,436 | 1.2 | 99 | 1.16 |
| | 2004 | 384 | 40 | 40 | 330.9 | 3.17 | 1.247994 | 1.361597 | 2,991 | 3,733 | 0.8 | 83 | 1.16 |
| | 2005 | 384 | 40 | 40 | 330.9 | 3.17 | 1.247994 | 1.361597 | 2,991 | 3,733 | 0.8 | 83 | 1.16 |

| Year | Load | Load at Standard | % Reduction |
|---|---|---|---|
| 1995 | 276 | 330 | -20% |
| 1996 | 216 | 318 | -47% |
| 1997 | 159 | 385 | -142% |
| 1998 | 235 | 331 | -40% |
| 1999 | 500 | 332 | 34% |
| 2000 | 308 | 368 | -19% |
| 2001 | 287 | 384 | -34% |
| 2002 | 641 | 422 | 34% |
| 2003 | 407 | 298 | 27% |
| 2004 | 502 | 384 | 24% |
| 2005 | 409 | 384 | 6% |



# 2001 Loading Summary for: Cedar Island Lake

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

## Inflow from Drainage Areas

| Name | Drainage Area [$km^2$] | Runoff Depth [m/yr] | Discharge [$10^6$ $m^3$/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 1 Watershed | | | 0.786 | 165.9 | 1.0 | 130.4 |
| 2 | | | | | 1.0 | |
| 3 | | | | | 1.0 | |
| 4 | | | | | 1.0 | |
| 5 | | | | | 1.0 | |
| 6 | | | | | 1.0 | |
| 7 | | | | | 1.0 | |
| 8 | | | | | 1.0 | |
| 9 | | | | | 1.0 | |
| 10 | | | | | 1.0 | |
| 11 | | | | | 1.0 | |
| 12 | | | | | 1.0 | |
| 13 | | | | | 1.0 | |
| *Summation* | *0.00* | *0.00* | *0.79* | *165.9* | | *130.4* |

## Inflow from Upstream Lakes

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

## Atmosphere

| Lake Area [$km^2$] | Precipitation [m/yr] | Evaporation [m/yr] | Net Inflow [$10^6$ $m^3$/yr] | Aerial Loading Rate [$kg/km^2$-yr] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 0.3195 | 1.01 | 1.01 | 0.00 | 26.80 | 1.0 | 8.6 |

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

## Groundwater

| Lake Area [$km^2$] | Groundwater Flux [m/yr] | Net Inflow [$10^6$ $m^3$/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|
| 0.3195 | 0.0 | 0.00 | 0 | 1.0 | - |

## Internal

| Lake Area [$km^2$] | Anoxic Factor [days] | Release Rate [$mg/m^2$-day] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|
| 0.3195 | 59.0 | 6.0 | 1.0 | 113.1 |

**Net Discharge [$10^6$ $m^3$/yr] = 0.79** **Net Load [kg/yr] = 252.1**

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.

# 2001 Lake Response Modeling for: Cedar Island Lake

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 252 | [kg/yr] |
| | | Q (lake outflow) = | 0.8 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 0.3510 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.45 | [yr] |
| | | $P_i$ = W/Q = | 321 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **129.8** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **99.0** | **[ug/l]** |
| **CHLOROPHYLL-A CONCENTRATION** | | | | |
| | $[\text{Chl}a] = CB \times 0.28 \times [TP]$ | as f(TP), Walker 1999, Model 4 | | |
| | | CB (Calibration factor) = | 1.00 | [--] |
| **Model Predicted In-Lake [Chl-a]** | | | **36.3** | **[ug/l]** |
| | $[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$ | as f(TP, N, Flushing), Walker 1999, Model 1 | | |
| | | CB (Calibration factor) = | 1.00 | |
| | $B_x = \dfrac{X_{pn}^{1.33}}{4.31}$ | P (Total Phosphorus) = | 130 | [ug/l] |
| | | N (Total Nitrogen) = | 3,361 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 130.4 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 116.8 | [ug/l] |
| | | G (Kinematic factor) = | 0.16 | [--] |
| | | $F_s$ (Flushing Rate) = | 2.24 | [year$^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 1.10 | [m] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$ | a (Non algal turbidity) = | 0.10 | [m$^{-1}$] |
| | | S (Secchi Depth) = | 0.46 | [m] |
| | | Maximum lake depth = | 2.13 | [m] |
| **Model Predicted In-Lake [Chl-a]** | | | **83.6** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **61.0** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.10 | [m$^{-1}$] |
| **Model Predicted In-Lake SD** | | | **0.46** | **[m]** |
| **Observed In-Lake SD** | | | **0.60** | **[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) =** | **150** | **[kg/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **102** | **[kg/yr]** |

# 2003 Loading Summary for: Cedar Island Lake

| Water Budgets | | | | Phosphorus Loading | | |
|---|---|---|---|---|---|---|
| **Inflow from Drainage Areas** | | | | | | |
| Name | Drainage Area [km$^2$] | Runoff Depth [m/yr] | Discharge [$10^6$ $m^3$/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [kg/yr] |
| 1 Watershed | | | 0.506 | 181.2 | 1.0 | 91.7 |
| 2 | | | | | 1.0 | |
| 3 | | | | | 1.0 | |
| 4 | | | | | 1.0 | |
| 5 | | | | | 1.0 | |
| 6 | | | | | 1.0 | |
| 7 | | | | | 1.0 | |
| 8 | | | | | 1.0 | |
| 9 | | | | | 1.0 | |
| 10 | | | | | 1.0 | |
| 11 | | | | | 1.0 | |
| 12 | | | | | 1.0 | |
| 13 | | | | | 1.0 | |
| *Summation* | *0.00* | *0.00* | *0.51* | *181.2* | | *91.7* |

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

| **Atmosphere** | | | | | | |
|---|---|---|---|---|---|---|
| Lake Area [km$^2$] | Precipitation [m/yr] | Evaporation [m/yr] | Net Inflow [$10^6$ $m^3$/yr] | Aerial Loading Rate [kg/km$^2$-yr] | Calibration Factor [--] | Load [kg/yr] |
| 0.3195 | 0.69 | 0.69 | 0.00 | 26.80 | 1.0 | 8.6 |
| | | | Dry-year total P deposition = | 24.9 | | |
| | | | Average-year total P deposition = | 26.8 | | |
| | | | Wet-year total P deposition = | 29.0 | | |
| | | | (Barr Engineering 2004) | | | |

| **Groundwater** | | | | | |
|---|---|---|---|---|---|
| Lake Area [km$^2$] | Groundwater Flux [m/yr] | Net Inflow [$10^6$ $m^3$/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
| 0.3195 | 0.0 | 0.00 | 0 | 1.0 | - |

| **Internal** | | | | |
|---|---|---|---|---|
| Lake Area [km$^2$] | Anoxic Factor [days] | Release Rate [mg/m$^2$-day] | Calibration Factor [--] | Load [kg/yr] |
| 0.3195 | 59.0 | 12.0 | 1.0 | 226.2 |

| | | | |
|---|---|---|---|
| **Net Discharge [$10^6$ $m^3$/yr] =** | **0.51** | **Net Load [kg/yr] =** | **326.5** |

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

# 2003 Lake Response Modeling for: Cedar Island Lake

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 326 | [kg/yr] |
| | | Q (lake outflow) = | 0.5 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 0.3510 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.69 | [yr] |
| | | $P_i$ = W/Q = | 645 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **180.6** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **296.0** | **[ug/l]** |
| **CHLOROPHYLL-A CONCENTRATION** | | | | |
| | $[\text{Chl}a] = CB \times 0.28 \times [TP]$ | as f(TP), Walker 1999, Model 4 | | |
| | | CB (Calibration factor) = | 1.00 | [--] |
| **Model Predicted In-Lake [Chl-a]** | | | **50.6** | **[ug/l]** |
| | $[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$ | as f(TP, N, Flushing), Walker 1999, Model 1 | | |
| | | CB (Calibration factor) = | 1.00 | |
| | $B_x = \dfrac{X_{pn}^{1.33}}{4.31}$ | P (Total Phosphorus) = | 181 | [ug/l] |
| | | N (Total Nitrogen) = | 3,361 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 181.4 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 149.7 | [ug/l] |
| | | G (Kinematic factor) = | 0.16 | [--] |
| | | $F_s$ (Flushing Rate) = | 1.44 | [$\text{year}^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 1.10 | [m] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$ | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| | | S (Secchi Depth) = | 0.37 | [m] |
| | | Maximum lake depth = | 2.13 | [m] |
| **Model Predicted In-Lake [Chl-a]** | | | **103.4** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **126.0** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| **Model Predicted In-Lake SD** | | | **0.37** | **[m]** |
| **Observed In-Lake SD** | | | **0.40** | **[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) =** | **235** | **[kg/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **91** | **[kg/yr]** |

# Total Phosphorus Budget for: Cedar Island Lake

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

## Inflow from Drainage Areas

| Name | Drainage Area [km²] | Runoff Depth [m/yr] | Discharge [$10^6$ $m^3$/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 1 Watershed | | | 0.646 | 171.9 | 1.0 | 111.1 |
| 2 | | | | | 1.0 | |
| 3 | | | | | 1.0 | |
| 4 | | | | | 1.0 | |
| 5 | | | | | 1.0 | |
| 6 | | | | | 1.0 | |
| 7 | | | | | 1.0 | |
| 8 | | | | | 1.0 | |
| 9 | | | | | 1.0 | |
| 10 | | | | | 1.0 | |
| 11 | | | | | 1.0 | |
| 12 | | | | | 1.0 | |
| 13 | | | | | 1.0 | |
| *Summation* | *0.00* | *0.00* | *0.65* | *171.9* | | *111.05* |

## Inflow from Upstream Lakes

| Name | Discharge [$10^6$ $m^3$/yr] | Estimated P Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|
| 1 | | - | 1.0 | |
| 2 | | - | 1.0 | |
| 3 | | - | 1.0 | |
| *Summation* | *0.00* | - | | *0* |

## Atmosphere

| Lake Area [km²] | Precipitation [m/yr] | Evaporation [m/yr] | Net Inflow [$10^6$ $m^3$/yr] | Aerial Loading Rate [kg/km²-yr] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 0.3195 | 0.69 | 0.69 | 0.00 | 26.80 | 1.0 | 8.6 |
| | | Dry-year total P deposition = | | 24.9 | | |
| | | Average-year total P deposition = | | 26.8 | | |
| | | Wet-year total P deposition = | | 29.0 | | |
| | | (Barr Engineering 2004) | | | | |

## Groundwater

| Lake Area [km²] | Groundwater Flux [m/yr] | Net Inflow [$10^6$ $m^3$/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|
| 0.3195 | 0.0 | 0.00 | 0 | 1.0 | 0 |

## Internal

| Lake Area [km²] | Anoxic Factor [days] | Release Rate [mg/m²-day] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|
| 0.3195 | 59.0 | 6.0 | 1.0 | 113.10 |

| | | | |
|---|---|---|---|
| **Net Discharge [$10^6$ $m^3$/yr] =** | **0.65** | **Net Load [kg/yr] =** | **232.7** |

NOTES

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

# Lake Response Modeling at TP Budget for: Cedar Island Lake

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 233 | [kg/yr] |
| | | Q (lake outflow) = | 0.6 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 0.3510 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.54 | [yr] |
| | | $P_i$ = W/Q = | 360 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **132.2** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **-** | **[ug/l]** |
| **CHLOROPHYLL-A CONCENTRATION** | | | | |
| | $[\text{Chl}a] = CB \times 0.28 \times [TP]$ | as f(TP), Walker 1999, Model 4 | | |
| | | CB (Calibration factor) = | 1.00 | [--] |
| **Model Predicted In-Lake [Chl-a]** | | | **37.0** | **[ug/l]** |
| | $[\text{Chl}a] = \dfrac{CB \times B_x}{\left[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})\right]}$ | 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) = | 132 | [ug/l] |
| | | N (Total Nitrogen) = | 3,361 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 132.9 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 118.5 | [ug/l] |
| | | G (Kinematic factor) = | 0.16 | [--] |
| | | $F_s$ (Flushing Rate) = | 1.84 | [$year^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 1.10 | [m] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$ | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| | | S (Secchi Depth) = | 0.45 | [m] |
| | | Maximum lake depth = | 2.13 | [m] |
| **Model Predicted In-Lake [Chl-a]** | | | **85.0** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **-** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| **Model Predicted In-Lake SD** | | | **0.45** | **[m]** |
| **Observed In-Lake SD** | | | **-** | **[m]** |
| **PHOSPHORUS SEDIMENTATION RATE** | | | | |
| | $P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$ | | | |
| | | **$P_{sed}$ (phosphorus sedimentation) =** | **147** | **[kg/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **85** | **[kg/yr]** |

## TMDL Loading Summary for: Cedar Island Lake

| Water Budgets | | | | Phosphorus Loading | | |
|---|---|---|---|---|---|---|
| ***Inflow from Drainage Areas*** | | | | | | |
| Name | Drainage Area [km$^2$] | Runoff Depth [m/yr] | Discharge [$10^6$ m$^3$/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [kg/yr] |
| 1 Watershed | | | 0.610 | 79.7 | 1.0 | 48.6 |
| 2 | | | | | 1.0 | |
| 3 | | | | | 1.0 | |
| 4 | | | | | 1.0 | |
| 5 | | | | | 1.0 | |
| 6 | | | | | 1.0 | |
| 7 | | | | | 1.0 | |
| 8 | | | | | 1.0 | |
| 9 | | | | | 1.0 | |
| 10 | | | | | 1.0 | |
| 11 | | | | | 1.0 | |
| 12 | | | | | 1.0 | |
| 13 | | | | | 1.0 | |
| *Summation* | *0.00* | *0.00* | *0.61* | *79.7* | | *48.6* |
| ***Inflow from Upstream Lakes*** | | | | | | |
| Name | | | Discharge [$10^6$ m$^3$/yr] | Estimated P Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
| 1 | | | | - | 1.0 | |
| 2 | | | | - | 1.0 | |
| 3 | | | | - | 1.0 | |
| *Summation* | | | *0.00* | - | | *0* |
| ***Atmosphere*** | | | | | | |
| Lake Area [km$^2$] | Precipitation [m/yr] | Evaporation [m/yr] | Net Inflow [$10^6$ m$^3$/yr] | Aerial Loading Rate [kg/km$^2$-yr] | Calibration Factor [--] | Load [kg/yr] |
| 0.3195 | 0.69 | 0.69 | 0.00 | 26.80 | 1.0 | 8.6 |
| | | | Dry-year total P deposition = | 24.9 | | |
| | | | Average-year total P deposition = | 26.8 | | |
| | | | Wet-year total P deposition = | 29.0 | | |
| | | | (Barr Engineering 2004) | | | |
| ***Groundwater*** | | | | | | |
| Lake Area [km$^2$] | Groundwater Flux [m/yr] | | Net Inflow [$10^6$ m$^3$/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
| 0.3195 | 0.0 | | 0.00 | 0 | 1.0 | 0 |
| ***Internal*** | | | | | | |
| Lake Area [km$^2$] | Anoxic Factor [days] | | | Release Rate [mg/m$^2$-day] | Calibration Factor [--] | Load [kg/yr] |
| 0.3195 | 59.0 | | | 1.0 | 1.0 | 18.9 |
| | | | **Net Discharge [$10^6$ m$^3$/yr] = 0.61** | | | **Net Load [kg/yr] = 76.0** |

NOTES

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

## Lake Response Modeling at TMDL for: Cedar Island Lake

| Modeled Parameter | Equation | Parameters | Value [Units] | |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 76 | [kg/yr] |
| | | Q (lake outflow) = | 0.6 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 0.3510 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.58 | [yr] |
| | | $P_i$ = W/Q = | 125 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **59.5** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **-** | **[ug/l]** |
| **CHLOROPHYLL-A CONCENTRATION** | | | | |
| | $[\text{Chl}a] = CB \times 0.28 \times [TP]$ | as f(TP), Walker 1999, Model 4 | | |
| | | CB (Calibration factor) = | 1.00 | [--] |
| **Model Predicted In-Lake [Chl-a]** | | | **16.7** | **[ug/l]** |
| | $[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$ | as f(TP, N, Flushing), Walker 1999, Model 1 | | |
| | | CB (Calibration factor) = | 1.00 | |
| | $B_x = \dfrac{X_{pn}^{1.33}}{4.31}$ | P (Total Phosphorus) = | 59 | [ug/l] |
| | | N (Total Nitrogen) = | 3,361 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 51.5 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\dfrac{N-150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 58.1 | [ug/l] |
| | | G (Kinematic factor) = | 0.16 | [--] |
| | | $F_s$ (Flushing Rate) = | 1.74 | [year$^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 1.10 | [m] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$ | a (Non algal turbidity) = | 0.10 | [m$^{-1}$] |
| | | S (Secchi Depth) = | 0.87 | [m] |
| | | Maximum lake depth = | 2.13 | [m] |
| **Model Predicted In-Lake [Chl-a]** | | | **41.9** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **-** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.10 | [m$^{-1}$] |
| **Model Predicted In-Lake SD** | | | **0.87** | **[m]** |
| **Observed In-Lake SD** | | | **-** | **[m]** |
| **PHOSPHORUS SEDIMENTATION RATE** | | | | |
| | $P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$ | | | |
| | | **$P_{sed}$ (phosphorus sedimentation) =** | **40** | **[kg/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **36** | **[kg/yr]** |

# 2001 Loading Summary for: Pike Lake

| Water Budgets | | | | Phosphorus Loading | | |
|---|---|---|---|---|---|---|
| ***Inflow from Drainage Areas*** | | | | | | |
| Name | Drainage Area [km$^2$] | Runoff Depth [m/yr] | Discharge [$10^6$ m$^3$/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [kg/yr] |
| 1 Watershed | | | 1.573 | 154.5 | 1.0 | 243.0 |
| 2 | | | | | 1.0 | |
| 3 | | | | | 1.0 | |
| 4 | | | | | 1.0 | |
| 5 | | | | | 1.0 | |
| 6 | | | | | 1.0 | |
| 7 | | | | | 1.0 | |
| 8 | | | | | 1.0 | |
| 9 | | | | | 1.0 | |
| 10 | | | | | 1.0 | |
| 11 | | | | | 1.0 | |
| 12 | | | | | 1.0 | |
| 13 | | | | | 1.0 | |
| *Summation* | *0.00* | *0.00* | *1.57* | *154.5* | | *243.0* |
| ***Inflow from Upstream Lakes*** | | | | | | |
| Name | | | Discharge [$10^6$ m$^3$/yr] | Estimated P Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
| 1 | | | | - | 1.0 | |
| 2 | | | | - | 1.0 | |
| 3 | | | | - | 1.0 | |
| *Summation* | | | *0.00* | - | | - |
| ***Atmosphere*** | | | | | | |
| Lake Area [km$^2$] | Precipitation [m/yr] | Evaporation [m/yr] | Net Inflow [$10^6$ m$^3$/yr] | Aerial Loading Rate [kg/km$^2$-yr] | Calibration Factor [--] | Load [kg/yr] |
| 0.2420 | 1.01 | 1.01 | 0.00 | 26.80 | 1.0 | 6.5 |
| | | | Dry-year total P deposition = | 24.9 | | |
| | | | Average-year total P deposition = | 26.8 | | |
| | | | Wet-year total P deposition = | 29.0 | | |
| | | | (Barr Engineering 2004) | | | |
| ***Groundwater*** | | | | | | |
| Lake Area [km$^2$] | Groundwater Flux [m/yr] | | Net Inflow [$10^6$ m$^3$/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
| 0.242 | 0.0 | | 0.00 | 0 | 1.0 | - |
| ***Internal*** | | | | | | |
| Lake Area [km$^2$] | Anoxic Factor [days] | | | Release Rate [mg/m$^2$-day] | Calibration Factor [--] | Load [kg/yr] |
| 0.242 | 53.0 | | | 6.0 | 1.0 | 77.0 |
| | | | **Net Discharge [$10^6$ m$^3$/yr] = 1.57** | | **Net Load [kg/yr] =** | **326.4** |

NOTES

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

# 2001 Lake Response Modeling for: Pike Lake

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 326 | [kg/yr] |
| | | Q (lake outflow) = | 1.6 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 0.6339 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.40 | [yr] |
| | | $P_i$ = W/Q = | 208 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **97.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **77.0** | **[ug/l]** |
| **CHLOROPHYLL-A CONCENTRATION** | | | | |
| | $[\text{Chl}a] = CB \times 0.28 \times [TP]$ | as f(TP), Walker 1999, Model 4 | | |
| | | CB (Calibration factor) = | 1.00 | [--] |
| **Model Predicted In-Lake [Chl-a]** | | | **27.2** | **[ug/l]** |
| | $[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$ | as f(TP, N, Flushing), Walker 1999, Model 1 | | |
| | | CB (Calibration factor) = | 1.00 | |
| | $B_x = \dfrac{X_{pn}^{1.33}}{4.31}$ | P (Total Phosphorus) = | 97 | [ug/l] |
| | | N (Total Nitrogen) = | 3,361 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 93.8 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 91.2 | [ug/l] |
| | | G (Kinematic factor) = | 0.39 | [--] |
| | | $F_s$ (Flushing Rate) = | 2.48 | [year$^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039F_s)$ | $Z_{mix}$ (Mixing Depth) = | 2.62 | [m] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$ | a (Non algal turbidity) = | 0.10 | [m$^{-1}$] |
| | | S (Secchi Depth) = | 0.78 | [m] |
| | | Maximum lake depth = | 6.71 | [m] |
| **Model Predicted In-Lake [Chl-a]** | | | **47.0** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **36.0** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.10 | [m$^{-1}$] |
| **Model Predicted In-Lake SD** | | | **0.78** | **[m]** |
| **Observed In-Lake SD** | | | **1.30** | **[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) =** | **174** | **[kg/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **153** | **[kg/yr]** |

# 2003 Loading Summary for: Pike Lake

| Water Budgets | | | | Phosphorus Loading | | |
|---|---|---|---|---|---|---|
| **Inflow from Drainage Areas** | | | | | | |
| Name | Drainage Area [km$^2$] | Runoff Depth [m/yr] | Discharge [$10^6$ m$^3$/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [kg/yr] |
| 1 Watershed | | | 1.013 | 160.0 | 1.0 | 162.1 |
| 2 | | | | | 1.0 | |
| 3 | | | | | 1.0 | |
| 4 | | | | | 1.0 | |
| 5 | | | | | 1.0 | |
| 6 | | | | | 1.0 | |
| 7 | | | | | 1.0 | |
| 8 | | | | | 1.0 | |
| 9 | | | | | 1.0 | |
| 10 | | | | | 1.0 | |
| 11 | | | | | 1.0 | |
| 12 | | | | | 1.0 | |
| 13 | | | | | 1.0 | |
| *Summation* | *0.00* | *0.00* | *1.01* | *160.0* | | *162.1* |

**Inflow from Upstream Lakes**

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

**Atmosphere**

| Lake Area [km$^2$] | Precipitation [m/yr] | Evaporation [m/yr] | Net Inflow [$10^6$ m$^3$/yr] | Aerial Loading Rate [kg/km$^2$-yr] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 0.242 | 0.69 | 0.69 | 0.00 | 26.80 | 1.0 | 6.5 |
| | | | Dry-year total P deposition = | 24.9 | | |
| | | | Average-year total P deposition = | 26.8 | | |
| | | | Wet-year total P deposition = | 29.0 | | |
| | | | (Barr Engineering 2004) | | | |

**Groundwater**

| Lake Area [km$^2$] | Groundwater Flux [m/yr] | Net Inflow [$10^6$ m$^3$/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|
| 0.242 | 0.0 | 0.00 | 0 | 1.0 | - |

**Internal**

| Lake Area [km$^2$] | Anoxic Factor [days] | Release Rate [mg/m$^2$-day] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|
| 0.242 | 53.0 | 6.0 | 1.0 | 77.0 |

| | | | |
|---|---|---|---|
| **Net Discharge [$10^6$ m$^3$/yr] =** | **1.01** | **Net Load [kg/yr] =** | **245.5** |

NOTES

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

# 2003 Lake Response Modeling for: Pike Lake

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 246 | [kg/yr] |
| | | Q (lake outflow) = | 1.0 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 0.6339 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.63 | [yr] |
| | | $P_i$ = W/Q = | 242 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **94.9** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **84.0** | **[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]** | | | **26.6** | **[ug/l]** |
| | $$[\mathrm{Chl}a] = \frac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times a)]}$$ | as f(TP, N, Flushing), Walker 1999, Model 1 | | |
| | | CB (Calibration factor) = | 1.00 | |
| | $$B_x = \frac{X_{pn}^{1.33}}{4.31}$$ | P (Total Phosphorus) = | 95 | [ug/l] |
| | | N (Total Nitrogen) = | 3,361 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 91.5 | [ug/l] |
| | $$X_{pn} = \left[P^{-2} + \left(\frac{N - 150}{12}\right)^{-2}\right]^{-0.5}$$ | $X_{pn}$ (Composite nutrient conc.)= | 89.5 | [ug/l] |
| | | G (Kinematic factor) = | 0.38 | [--] |
| | | $F_s$ (Flushing Rate) = | 1.60 | [$year^{-1}$] |
| | $$G = Z_{mix}(0.14 + 0.0039 F_s)$$ | $Z_{mix}$ (Mixing Depth) = | 2.62 | [m] |
| | $$F_s = \frac{Q}{V}$$ $$a = \frac{1}{SD} - 0.025 \times [\mathrm{Chl}a]$$ | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| | | S (Secchi Depth) = | 0.78 | [m] |
| | | Maximum lake depth = | 6.71 | [m] |
| **Model Predicted In-Lake [Chl-a]** | | | **46.9** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **74.0** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $$SD = \frac{CS}{(a + 0.025 \times [\mathrm{Chl}a])}$$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| **Model Predicted In-Lake SD** | | | **0.78** | **[m]** |
| **Observed In-Lake SD** | | | **0.90** | **[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) =** | **149** | **[kg/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **96** | **[kg/yr]** |

# *Total Phosphorus Budget for: Pike Lake*

| Water Budgets | | | | Phosphorus Loading | | |
|---|---|---|---|---|---|---|
| ***Inflow from Drainage Areas*** | | | | | | |
| Name | Drainage Area [km$^2$] | Runoff Depth [m/yr] | Discharge [$10^6$ m$^3$/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [kg/yr] |
| 1 Watershed | 0.42 | 3.09 | 1.293 | 156.7 | 1.0 | 202.6 |
| 2 | | | | | 1.0 | |
| 3 | | | | | 1.0 | |
| 4 | | | | | 1.0 | |
| 5 | | | | | 1.0 | |
| 6 | | | | | 1.0 | |
| 7 | | | | | 1.0 | |
| 8 | | | | | 1.0 | |
| 9 | | | | | 1.0 | |
| 10 | | | | | 1.0 | |
| 11 | | | | | 1.0 | |
| 12 | | | | | 1.0 | |
| 13 | | | | | 1.0 | |
| *Summation* | *0.42* | *3.09* | *1.29* | *156.7* | | *202.55* |

***Inflow from Upstream Lakes***

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

***Atmosphere***

| Lake Area [km$^2$] | Precipitation [m/yr] | Evaporation [m/yr] | Net Inflow [$10^6$ m$^3$/yr] | Aerial Loading Rate [kg/km$^2$-yr] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 0.242 | 0.89 | 0.89 | 0.00 | 26.80 | 1.0 | 6.5 |
| | | | Dry-year total P deposition = | 24.9 | | |
| | | | Average-year total P deposition = | 26.8 | | |
| | | | Wet-year total P deposition = | 29.0 | | |
| | | | (Barr Engineering 2004) | | | |

***Groundwater***

| Lake Area [km$^2$] | Groundwater Flux [m/yr] | | Net Inflow [$10^6$ m$^3$/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 0.242 | 0.0 | | 0.00 | 0 | 1.0 | - |

***Internal***

| Lake Area [km$^2$] | Anoxic Factor [days] | | | Release Rate [mg/m$^2$-day] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 0.242 | 53.0 | | | 6.0 | 1.0 | 77.0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | **Net Discharge [$10^6$ m$^3$/yr] =** | **1.29** | | **Net Load [kg/yr] =** | **286.0** |

NOTES

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

# *Lake Response Modeling at TP Budget for: Pike Lake*

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 286 | [kg/yr] |
| | | Q (lake outflow) = | 1.3 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 0.6339 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.49 | [yr] |
| | | $P_i$ = W/Q = | 221 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **96.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **-** | **[ug/l]** |
| **CHLOROPHYLL-A CONCENTRATION** | | | | |
| | $[\text{Chl}a] = CB \times 0.28 \times [TP]$ | as f(TP), Walker 1999, Model 4 | | |
| | | CB (Calibration factor) = | 1.00 | [--] |
| **Model Predicted In-Lake [Chl-a]** | | | **26.9** | **[ug/l]** |
| | $[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$ | as f(TP, N, Flushing), Walker 1999, Model 1 | | |
| | | CB (Calibration factor) = | 1.00 | |
| | $B_x = \dfrac{X_{pn}^{1.33}}{4.31}$ | P (Total Phosphorus) = | 96 | [ug/l] |
| | | N (Total Nitrogen) = | 3,361 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 92.6 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 90.3 | [ug/l] |
| | | G (Kinematic factor) = | 0.39 | [--] |
| | | $F_s$ (Flushing Rate) = | 2.04 | [$year^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 2.62 | [m] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$ | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| | | S (Secchi Depth) = | 0.78 | [m] |
| | | Maximum lake depth = | 6.71 | [m] |
| **Model Predicted In-Lake [Chl-a]** | | | **46.9** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **-** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| **Model Predicted In-Lake SD** | | | **0.78** | **[m]** |
| **Observed In-Lake SD** | | | **-** | **[m]** |
| **PHOSPHORUS SEDIMENTATION RATE** | | | | |
| | $P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$ | | | |
| | | **$P_{sed}$ (phosphorus sedimentation) =** | **162** | **[kg/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **124** | **[kg/yr]** |

# *TMDL Loading Summary for: Pike Lake*

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

## *Inflow from Drainage Areas*

| | Name | Drainage Area [$km^2$] | Runoff Depth [m/yr] | Discharge [$10^6$ $m^3$/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|---|
| 1 | Watershed | | | 1.220 | 104.7 | 1.0 | 127.7 |
| 2 | | | | | | 1.0 | |
| 3 | | | | | | 1.0 | |
| 4 | | | | | | 1.0 | |
| 5 | | | | | | 1.0 | |
| 6 | | | | | | 1.0 | |
| 7 | | | | | | 1.0 | |
| 8 | | | | | | 1.0 | |
| 9 | | | | | | 1.0 | |
| 10 | | | | | | 1.0 | |
| 11 | | | | | | 1.0 | |
| 12 | | | | | | 1.0 | |
| 13 | | | | | | 1.0 | |
| | *Summation* | *0.00* | *0.00* | *1.22* | *104.7* | | *127.7* |

## *Inflow from Upstream Lakes*

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

## *Atmosphere*

| Lake Area [$km^2$] | Precipitation [m/yr] | Evaporation [m/yr] | Net Inflow [$10^6$ $m^3$/yr] | Aerial Loading Rate [$kg/km^2$-yr] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 0.242 | 0.89 | 0.89 | 0.00 | 26.80 | 1.0 | 6.5 |

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

## *Groundwater*

| Lake Area [$km^2$] | Groundwater Flux [m/yr] | Net Inflow [$10^6$ $m^3$/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|
| 0.242 | 0.0 | 0.00 | 0 | 1.0 | - |

## *Internal*

| Lake Area [$km^2$] | Anoxic Factor [days] | Release Rate [$mg/m^2$-day] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|
| 0.242 | 53.0 | 1.0 | 1.0 | 12.8 |

| | | | |
|---|---|---|---|
| **Net Discharge [$10^6$ $m^3$/yr] =** | **1.22** | **Net Load [kg/yr] =** | **147.0** |

NOTES

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

## *Lake Response Modeling at TMDL for: Pike Lake*

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 147 | [kg/yr] |
| | | Q (lake outflow) = | 1.2 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 0.6339 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.52 | [yr] |
| | | $P_i$ = W/Q = | 120 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **59.7** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **-** | **[ug/l]** |
| **CHLOROPHYLL-A CONCENTRATION** | | | | |
| | $[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$ | as f(TP), Walker 1999, Model 4 | | |
| | | CB (Calibration factor) = | 1.00 | [--] |
| **Model Predicted In-Lake [Chl-a]** | | | **16.7** | **[ug/l]** |
| | $$[\mathrm{Chl}a] = \frac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \mathrm{a})]}$$ | as f(TP, N, Flushing), Walker 1999, Model 1 | | |
| | | CB (Calibration factor) = | 1.00 | |
| | $$B_x = \frac{X_{pn}^{\ 1.33}}{4.31}$$ | P (Total Phosphorus) = | 60 | [ug/l] |
| | | N (Total Nitrogen) = | 3,361 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 51.7 | [ug/l] |
| | $$X_{pn} = \left[P^{-2} + \left(\frac{N - 150}{12}\right)^{-2}\right]^{-0.5}$$ | $X_{pn}$ (Composite nutrient conc.)= | 58.2 | [ug/l] |
| | | G (Kinematic factor) = | 0.39 | [--] |
| | | $F_s$ (Flushing Rate) = | 1.92 | [$year^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 2.62 | [m] |
| | $$F_s = \frac{Q}{V} \quad a = \frac{1}{SD} - 0.025 \times [\mathrm{Chl}a]$$ | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| | | S (Secchi Depth) = | 1.07 | [m] |
| | | Maximum lake depth = | 6.71 | [m] |
| **Model Predicted In-Lake [Chl-a]** | | | **33.1** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **-** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $$SD = \frac{CS}{(\mathrm{a} + 0.025 \times [\mathrm{Chl}a])}$$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| **Model Predicted In-Lake SD** | | | **1.07** | **[m]** |
| **Observed In-Lake SD** | | | **-** | **[m]** |
| **PHOSPHORUS SEDIMENTATION RATE** | | | | |
| | $$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$$ | | | |
| | | **$P_{sed}$ (phosphorus sedimentation) =** | **74** | **[kg/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | $W-P_{sed}$ = | | **73** | **[kg/yr]** |

## 2001 Loading Summary for: Eagle Lake

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

### Inflow from Drainage Areas

| Name | Drainage Area [$km^2$] | Runoff Depth [m/yr] | Discharge [$10^6$ $m^3$/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 1 Watershed | | | 4.607 | 77.7 | 1.0 | 357.8 |
| 2 | | | | | 1.0 | |
| 3 | | | | | 1.0 | |
| 4 | | | | | 1.0 | |
| 5 | | | | | 1.0 | |
| 6 | | | | | 1.0 | |
| 7 | | | | | 1.0 | |
| 8 | | | | | 1.0 | |
| 9 | | | | | 1.0 | |
| 10 | | | | | 1.0 | |
| 11 | | | | | 1.0 | |
| 12 | | | | | 1.0 | |
| 13 | | | | | 1.0 | |
| *Summation* | *0.00* | *0.00* | *4.61* | *77.7* | | *357.8* |

### Inflow from Upstream Lakes

| Name | Discharge [$10^6$ $m^3$/yr] | Estimated P Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|
| 1 Cedar Island | 0.79 | 129.8 | 1.0 | 102.0 |
| 2 Pike | 1.57 | 97.0 | 1.0 | 152.6 |
| 3 | | - | 1.0 | |
| *Summation* | *2.36* | *113.4* | | *254.6* |

### Atmosphere

| Lake Area [$km^2$] | Precipitation [m/yr] | Evaporation [m/yr] | Net Inflow [$10^6$ $m^3$/yr] | Aerial Loading Rate [$kg/km^2$-yr] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 1.162 | 1.01 | 1.01 | 0.00 | 26.80 | 1.0 | 31.1 |
| | | | Dry-year total P deposition = | 24.9 | | |
| | | | Average-year total P deposition = | 26.8 | | |
| | | | Wet-year total P deposition = | 29.0 | | |
| | | | (Barr Engineering 2004) | | | |

### Groundwater

| Lake Area [$km^2$] | Groundwater Flux [m/yr] | Net Inflow [$10^6$ $m^3$/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|
| 1.162 | 0.0 | 0.00 | 0 | 1.0 | 0 |

### Internal

| Lake Area [$km^2$] | Anoxic Factor [days] | Release Rate [$mg/m^2$-day] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|
| 1.162 | 0.0 | 0.0 | 1.0 | 0.0 |

**Net Discharge [$10^6$ $m^3$/yr] = 6.97** | **Net Load [kg/yr] = 643.5**

NOTES

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

# 2001 Lake Response Modeling for: Eagle Lake

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 644 | [kg/yr] |
| | | Q (lake outflow) = | 7.0 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 3.6900 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.53 | [yr] |
| | | $P_i$ = W/Q = | 92 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **48.3** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **32.0** | **[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]** | | | **13.5** | **[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) = | 48 | [ug/l] |
| | | N (Total Nitrogen) = | 3,361 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 39.4 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 47.5 | [ug/l] |
| | | G (Kinematic factor) = | 0.47 | [--] |
| | | $F_s$ (Flushing Rate) = | 1.89 | [$year^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 3.17 | [m] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - 0.025 \times [\mathrm{Chl}a]$ | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| | | S (Secchi Depth) = | 1.34 | [m] |
| | | Maximum lake depth = | 10.36 | [m] |
| **Model Predicted In-Lake [Chl-a]** | | | **25.8** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **19.0** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\mathrm{a} + 0.025 \times [\mathrm{Chl}a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| **Model Predicted In-Lake SD** | | | **1.34** | **[m]** |
| **Observed In-Lake SD** | | | **2.50** | **[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) =** | **307** | **[kg/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **337** | **[kg/yr]** |

# 2003 Loading Summary for: Eagle Lake

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

## Inflow from Drainage Areas

| Name | Drainage Area [km$^2$] | Runoff Depth [m/yr] | Discharge [$10^6$ m$^3$/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 1 Watershed | | | 3.006 | 85.0 | 1.0 | 255.4 |
| 2 | | | | | 1.0 | |
| 3 | | | | | 1.0 | |
| 4 | | | | | 1.0 | |
| 5 | | | | | 1.0 | |
| 6 | | | | | 1.0 | |
| 7 | | | | | 1.0 | |
| 8 | | | | | 1.0 | |
| 9 | | | | | 1.0 | |
| 10 | | | | | 1.0 | |
| 11 | | | | | 1.0 | |
| 12 | | | | | 1.0 | |
| 13 | | | | | 1.0 | |
| *Summation* | *0.00* | *0.00* | *3.01* | *85.0* | | *255.4* |

## Inflow from Upstream Lakes

| Name | Discharge [$10^6$ m$^3$/yr] | Estimated P Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|
| 1 Cedar Island | 0.51 | 180.6 | 1.0 | 91.4 |
| 2 Pike | 1.01 | 94.9 | 1.0 | 96.2 |
| 3 | | - | 1.0 | |
| *Summation* | *1.52* | *137.8* | | *187.6* |

## Atmosphere

| Lake Area [km$^2$] | Precipitation [m/yr] | Evaporation [m/yr] | Net Inflow [$10^6$ m$^3$/yr] | Aerial Loading Rate [kg/km$^2$-yr] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 1.162 | 0.69 | 0.69 | 0.00 | 26.80 | 1.0 | 31.1 |
| | | | Dry-year total P deposition = | 24.9 | | |
| | | | Average-year total P deposition = | 26.8 | | |
| | | | Wet-year total P deposition = | 29.0 | | |
| | | | (Barr Engineering 2004) | | | |

## Groundwater

| Lake Area [km$^2$] | Groundwater Flux [m/yr] | Net Inflow [$10^6$ m$^3$/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|
| 1.162 | 0.0 | 0.00 | 0 | 1.0 | - |

## Internal

| Lake Area [km$^2$] | Anoxic Factor [days] | Release Rate [mg/m$^2$-day] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|
| 1.162 | 0.0 | 0.0 | 1.0 | - |

| | | | |
|---|---|---|---|
| **Net Discharge [$10^6$ m$^3$/yr] =** | **4.53** | **Net Load [kg/yr] =** | **474.1** |

NOTES

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

# 2003 Lake Response Modeling for: Eagle Lake

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 474 | [kg/yr] |
| | | Q (lake outflow) = | 4.5 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 3.6900 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.82 | [yr] |
| | | $P_i$ = W/Q = | 105 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **47.2** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **50.0** | **[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]** | | | **13.2** | **[ug/l]** |
| | $[\mathrm{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \mathrm{a})]}$ | as f(TP, N, Flushing), Walker 1999, Model 1 | | |
| | | CB (Calibration factor) = | 1.00 | |
| | $B_x = \dfrac{X_{pn}^{1.33}}{4.31}$ | P (Total Phosphorus) = | 47 | [ug/l] |
| | | N (Total Nitrogen) = | 3,361 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 38.3 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 46.5 | [ug/l] |
| | | G (Kinematic factor) = | 0.46 | [--] |
| | | $F_s$ (Flushing Rate) = | 1.23 | [$year^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 3.17 | [m] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - 0.025 \times [\mathrm{Chl}a]$ | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| | | S (Secchi Depth) = | 1.36 | [m] |
| | | Maximum lake depth = | 10.36 | [m] |
| **Model Predicted In-Lake [Chl-a]** | | | **25.4** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | **38.0** | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\mathrm{a} + 0.025 \times [\mathrm{Chl}a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| **Model Predicted In-Lake SD** | | | **1.36** | **[m]** |
| **Observed In-Lake SD** | | | **1.80** | **[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) =** | **261** | **[kg/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **213** | **[kg/yr]** |

# *Total Phosphorus Budget for: Eagle Lake*

| Water Budgets | | | | Phosphorus Loading | | |
|---|---|---|---|---|---|---|
| ***Inflow from Drainage Areas*** | | | | | | |
| Name | Drainage Area [km$^2$] | Runoff Depth [m/yr] | Discharge [$10^6$ m$^3$/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [kg/yr] |
| 1 Watershed | | | 3.807 | 80.5 | 1.0 | 306.6 |
| 2 | | | | | 1.0 | |
| 3 | | | | | 1.0 | |
| 4 | | | | | 1.0 | |
| 5 | | | | | 1.0 | |
| 6 | | | | | 1.0 | |
| 7 | | | | | 1.0 | |
| 8 | | | | | 1.0 | |
| 9 | | | | | 1.0 | |
| 10 | | | | | 1.0 | |
| 11 | | | | | 1.0 | |
| 12 | | | | | 1.0 | |
| 13 | | | | | 1.0 | |
| *Summation* | *0.00* | *0.00* | *3.81* | *80.5* | | *306.6* |

| ***Inflow from Upstream Lakes*** | | | | |
|---|---|---|---|---|
| Name | Discharge [$10^6$ m$^3$/yr] | Estimated P Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
| 1 Cedar Island | 0.65 | 132.2 | 1.0 | 85.4 |
| 2 Pike | 1.29 | 96.0 | 1.0 | 124.1 |
| 3 | | - | 1.0 | |
| *Summation* | *1.94* | *114.1* | | *209.5* |

| ***Atmosphere*** | | | | | | |
|---|---|---|---|---|---|---|
| Lake Area [km$^2$] | Precipitation [m/yr] | Evaporation [m/yr] | Net Inflow [$10^6$ m$^3$/yr] | Aerial Loading Rate [kg/km$^2$-yr] | Calibration Factor [--] | Load [kg/yr] |
| 1.162 | 0.99 | 0.99 | 0.00 | 26.80 | 1.0 | 31.1 |
| | | | Dry-year total P deposition = | 24.9 | | |
| | | | Average-year total P deposition = | 26.8 | | |
| | | | Wet-year total P deposition = | 29.0 | | |
| | | | (Barr Engineering 2004) | | | |

| ***Groundwater*** | | | | | |
|---|---|---|---|---|---|
| Lake Area [km$^2$] | Groundwater Flux [m/yr] | Net Inflow [$10^6$ m$^3$/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
| 1.162 | 0.0 | 0.00 | 0 | 1.0 | - |

| ***Internal*** | | | | |
|---|---|---|---|---|
| Lake Area [km$^2$] | Anoxic Factor [days] | Release Rate [mg/m$^2$-day] | Calibration Factor [--] | Load [kg/yr] |
| 1.162 | 0.0 | 0.0 | 1.0 | - |

| | | | |
|---|---|---|---|
| **Net Discharge [$10^6$ m$^3$/yr] =** | **5.75** | **Net Load [kg/yr] =** | **547.2** |

NOTES

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

## Lake Response Modeling at TP Budget for: Eagle Lake

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 547 | [kg/yr] |
| | | Q (lake outflow) = | 5.7 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 3.6900 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.64 | [yr] |
| | | $P_i$ = W/Q = | 95 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **47.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | | **[ug/l]** |
| **CHLOROPHYLL-A CONCENTRATION** | | | | |
| | $[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$ | as f(TP), Walker 1999, Model 4 | | |
| | | CB (Calibration factor) = | 1.00 | [--] |
| **Model Predicted In-Lake [Chl-a]** | | | **13.2** | **[ug/l]** |
| | $[\mathrm{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \mathrm{a})]}$ | as f(TP, N, Flushing), Walker 1999, Model 1 | | |
| | | CB (Calibration factor) = | 1.00 | |
| | $B_x = \dfrac{X_{pn}^{1.33}}{4.31}$ | P (Total Phosphorus) = | 47 | [ug/l] |
| | | N (Total Nitrogen) = | 3,233 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 38.0 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 46.2 | [ug/l] |
| | | G (Kinematic factor) = | 0.46 | [--] |
| | | $F_s$ (Flushing Rate) = | 1.56 | [$\mathrm{year}^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 3.17 | [m] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - 0.025 \times [\mathrm{Chl}a]$ | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| | | S (Secchi Depth) = | 1.36 | [m] |
| | | Maximum lake depth = | 10.36 | [m] |
| **Model Predicted In-Lake [Chl-a]** | | | **25.2** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\mathrm{a} + 0.025 \times [\mathrm{Chl}a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.10 | [$m^{-1}$] |
| **Model Predicted In-Lake SD** | | | **1.36** | **[m]** |
| **Observed In-Lake SD** | | | | **[m]** |
| **PHOSPHORUS SEDIMENTATION RATE** | | | | |
| | $P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$ | | | |
| | | **$P_{sed}$ (phosphorus sedimentation) =** | **277** | **[kg/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **270** | **[kg/yr]** |

# TMDL Loading Summary for: Eagle Lake

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

## Inflow from Drainage Areas

| Name | Drainage Area [km²] | Runoff Depth [m/yr] | Discharge [$10^6$ m³/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 1 Watershed | | | 3.620 | 51.6 | 1.0 | 186.8 |
| 2 | | | | | 1.0 | |
| 3 | | | | | 1.0 | |
| 4 | | | | | 1.0 | |
| 5 | | | | | 1.0 | |
| 6 | | | | | 1.0 | |
| 7 | | | | | 1.0 | |
| 8 | | | | | 1.0 | |
| 9 | | | | | 1.0 | |
| 10 | | | | | 1.0 | |
| 11 | | | | | 1.0 | |
| 12 | | | | | 1.0 | |
| 13 | | | | | 1.0 | |
| *Summation* | *0.00* | *0.00* | *3.62* | *51.6* | | *186.8* |

## Inflow from Upstream Lakes

| Name | Discharge [$10^6$ m³/yr] | Estimated P Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|
| 1 Cedar Island | 0.61 | 59.5 | 1.0 | 36.3 |
| 2 Pike | 1.22 | 59.7 | 1.0 | 72.8 |
| 3 | | - | 1.0 | |
| *Summation* | *1.83* | *59.6* | | *109.1* |

## Atmosphere

| Lake Area [km²] | Precipitation [m/yr] | Evaporation [m/yr] | Net Inflow [$10^6$ m³/yr] | Aerial Loading Rate [kg/km²-yr] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|---|
| 1.162 | 0.99 | 0.99 | 0.00 | 26.80 | 1.0 | 31.1 |
| | | | Dry-year total P deposition = | 24.9 | | |
| | | | Average-year total P deposition = | 26.8 | | |
| | | | Wet-year total P deposition = | 29.0 | | |
| | | | (Barr Engineering 2004) | | | |

## Groundwater

| Lake Area [km²] | Groundwater Flux [m/yr] | Net Inflow [$10^6$ m³/yr] | Phosphorus Concentration [ug/L] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|---|
| 1.162 | 0.0 | 0.00 | 0 | 1.0 | - |

## Internal

| Lake Area [km²] | Anoxic Factor [days] | Release Rate [mg/m²-day] | Calibration Factor [--] | Load [kg/yr] |
|---|---|---|---|---|
| 1.162 | 0.0 | 0.0 | 1.0 | 5.0 |

| | | | |
|---|---|---|---|
| **Net Discharge [$10^6$ m³/yr] =** | **5.45** | **Net Load [kg/yr] =** | **332.0** |

NOTES

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

# *Lake Response Modeling at TMDL for: Eagle Lake*

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 332 | [kg/yr] |
| | | Q (lake outflow) = | 5.5 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 3.6900 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.68 | [yr] |
| | | $P_i$ = W/Q = | 61 | [ug/l] |
| **Model Predicted In-Lake [TP]** | | | **32.7** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | | **[ug/l]** |
| **CHLOROPHYLL-A CONCENTRATION** | | | | |
| | $[\text{Chl}a] = CB \times 0.28 \times [TP]$ | as f(TP), Walker 1999, Model 4 | | |
| | | CB (Calibration factor) = | 1.00 | [--] |
| **Model Predicted In-Lake [Chl-a]** | | | **9.2** | **[ug/l]** |
| | $[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$ | as f(TP, N, Flushing), Walker 1999, Model 1 | | |
| | | CB (Calibration factor) = | 1.00 | |
| | $B_x = \dfrac{X_{pn}^{1.33}}{4.31}$ | P (Total Phosphorus) = | 33 | [ug/l] |
| | | N (Total Nitrogen) = | 3,233 | [ug/l] |
| | | $B_x$ (Nutrient-Potential Chl-a conc.) = | 23.8 | [ug/l] |
| | $X_{pn} = \left[P^{-2} + \left(\dfrac{N-150}{12}\right)^{-2}\right]^{-0.5}$ | $X_{pn}$ (Composite nutrient conc.)= | 32.5 | [ug/l] |
| | | G (Kinematic factor) = | 0.46 | [--] |
| | | $F_s$ (Flushing Rate) = | 1.48 | [year$^{-1}$] |
| | $G = Z_{mix}(0.14 + 0.0039 F_s)$ | $Z_{mix}$ (Mixing Depth) = | 3.17 | [m] |
| | $F_s = \dfrac{Q}{V}$ ; $a = \dfrac{1}{SD} - 0.025 \times [\text{Chl}a]$ | a (Non algal turbidity) = | 0.10 | [m$^{-1}$] |
| | | S (Secchi Depth) = | 1.83 | [m] |
| | | Maximum lake depth = | 10.36 | [m] |
| **Model Predicted In-Lake [Chl-a]** | | | **17.8** | **[ug/l]** |
| **Observed In-Lake [Chl-a]** | | | | **[ug/l]** |
| **SECCHI DEPTH** | | | | |
| | $SD = \dfrac{CS}{(\text{a} + 0.025 \times [\text{Chl}a])}$ | as f(Chla), Walker (1999) | | |
| | | CS (Calibration factor) = | 1.00 | [--] |
| | | a (Non algal turbidity) = | 0.10 | [m$^{-1}$] |
| **Model Predicted In-Lake SD** | | | **1.83** | **[m]** |
| **Observed In-Lake SD** | | | | **[m]** |
| **PHOSPHORUS SEDIMENTATION RATE** | | | | |
| | $P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$ | | | |
| | | **$P_{sed}$ (phosphorus sedimentation) =** | **154** | **[kg/yr]** |
| **PHOSPHORUS OUTFLOW LOAD** | | | | |
| | W-$P_{sed}$ = | | **178** | **[kg/yr]** |