Duck Lake Use Attainability Analysis

Prepared for
Riley-Purgatory-Bluff Creek Watershed District

May 2005

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Executive Summary

Overview

This report contains the results of a Use Attainability Analysis (UAA) of Duck Lake. The UAA is a structured scientific assessment of the chemical, physical, and biological conditions in a water body. The analysis includes diagnosis of the causes of observed problems and prescription of alternative remedial measures (such as a diagnostic-feasibility study) that will result in the attainment of the intended beneficial uses of Duck Lake. The analysis is based upon historical water quality data, results of an intensive lake monitoring program in 2002, sediment sampling in 2003, evaluations of the application of best management practices for the watershed, and computer simulations of watershed runoff. Computer simulations were used to estimate watershed runoff (phosphorus and flow) under existing and proposed future land use and under varying climatic conditions.

Riley-Purgatory-Bluff Creek Watershed District Water Quality Goals

The approved *Riley-Purgatory-Bluff Creek Watershed District Water Management Plan,* 1996, articulated five specific goals for Duck Lake. These goals address recreation, water quality, aquatic communities, water quantity, and wildlife. Wherever possible, Riley-Purgatory-Bluff Creek Watershed District (RPBCWD) goals for Duck Lake have been quantified using a standardized lake rating system termed Carlson's Trophic State Index (Carlson 1977). This rating system considers the lake's total phosphorus, chlorophyll *a*, and Secchi disc transparency measurements to assign it a water quality index number that reflects its general level of fertility. The resulting index values generally range between 0 and 100, with increasing values indicating more fertile conditions.

Total phosphorus, chlorophyll *a*, and Secchi disc transparency are key water quality parameters upon which Carlson's Trophic State Index (TSI) statistics are computed, for the following reasons:

- Phosphorus generally controls the growth of algae in lake systems. Of all the substances needed for biological growth, phosphorus is typically the limiting nutrient.
- Chlorophyll *a* is the main pigment in algae. Therefore, the amount of chlorophyll *a* in the water indicates the abundance of algae present in the lake.
- Secchi disc transparency is a measure of water clarity and is inversely related to the abundance of algae.

Although any one or all three parameters can be used to compute TSI, water transparency is most often used, since people's perceptions of water clarity are most directly related to recreational use impairment. The TSI rating system is scaled to place a mesotrophic (medium fertility level) lake on the scale between 40 and 50, and high and low fertility lakes (eutrophic and oligotrophic) toward the high and low ends of the TSI range, respectively. Characteristics of lakes in different trophic status categories are listed below with their respective TSI ranges:

1. **Oligotrophic**—[$20 \leq$ TSI ≤ 38] clear, low productivity lakes, with total phosphorus concentrations less than or equal to 10 µg/L, chlorophyll *a* concentrations less than or equal to 2 µg/L, and Secchi disc transparencies greater than or equal to 4.6 meters (15 feet).
2. **Mesotrophic—**[$38 \leq$ TSI ≤ 50] intermediate productivity lakes, with 10 to 25 µg/L total phosphorus, 2 to 8 µg/L chlorophyll *a* concentrations, and Secchi disc measurements of 2 to 4.6 meters (6 to 15 feet).
3. **Eutrophic—**[$50 \leq$ TSI ≤ 62] high productivity lakes, with 25 to 57 µg/L total phosphorus, 8 to 26 µg/L chlorophyll *a* concentrations, and Secchi disc measurements of 0.85 to 2 meters (2.7 to 6 feet).
4. **Hypereutrophic—**[$62 \leq$ TSI] extremely productive lakes, with total phosphorus concentrations greater than 57 µg/L, chlorophyll *a* concentrations greater than 26 µg/L, and Secchi disc measurements less than 0.85 meters (less than 2.7 feet).

The RPBCWD goals for Duck Lake include the following:

1. The **Recreation Goal** is to provide water quality that: fully supports the lake's MDNR ecological class 40 rating (i.e., a Trophic State Index (TSI_{SD}) of 54.5 or lower). With the implementation of lake and watershed management practices as described in this UAA, a TSI_{SD} of 55.7 to 57.1 can be achieved. The recreation goal has not been attained and is not attainable.
2. The **Water Quality Goal** is a trophic state index score that meets or exceeds the necessary level to attain and maintain full support of fishing: A Trophic State Index (TSI_{SD}) of 54.5 or lower fully supports the lake's fishery. With the implementation of lake and watershed management practices as described in this UAA, a TSI_{SD} of 55.7 to 57.1 can be achieved. The water quality goal has not been attained and is not attainable.
3. The **Aquatic Communities Goal** is a water quality that fully supports fishing, according to the Minnesota Department of Natural Resources (MDNR) "Ecological Use Classification." With the implementation of lake and watershed management practices as described in this UAA, a TSI_{SD} of 55.7 to 57.1 can be achieved. The aquatic communities goal has not been attained and is not attainable.
4. The **Water Quantity Goal** for Duck Lake is to manage surface water runoff from a regional flood, the critical 100-year frequency storm event. This goal has been achieved.
5. The **Wildlife Goal** for Duck Lake is to protect existing, beneficial wildlife uses. The wildlife goal has been achieved.

Minnesota Pollution Control Agency Standard

A Minnesota Pollution Control Agency standard for shallow lakes has been proposed and is expected to be finalized in 2005. The total phosphorus standard for shallow lakes in the Twin Cities Metropolitan Area (North Central Hardwood Forest Ecoregion) is 60 μg/L (i.e., less than or equal to 60 μg/L) and the Secchi disc standard is 1.2 meters (i.e., greater than or equal to 1.2 meters). This standard has been set with the intention to permit the "propagation and maintenance of a healthy community of cold water sport or commercial fish and associated aquatic life.....these waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be useable." The standard is found in proposed changes to Minnesota Rules Chapter 7050.0222, Subp. 4. Class 2B Waters. This standard can be met with the implementation of lake and watershed management practices as described in this UAA.

Water Quality Problem Assessment

An evaluation of water quality data for Duck Lake from 1971 to 2002 was completed to determine the current status of the lake's water quality. Results of this evaluation indicate that the lake's water quality is poor and has basically remained in this condition over time. The poor water quality has its origins in historical and current inputs of phosphorus and the accumulation of phosphorus in lake sediments. The poor water quality of Duck Lake is perpetuated by the presence of invasive submersed aquatic vegetation (*Potamogeton crispus*, i.e. curlyleaf pondweed), phosphorus release from sediments, and inputs of storm water runoff that is high in phosphorus.

Historical Water Quality Trends

Trend analyses from 1971 through 2002 indicate that there has been no significant change in Duck Lake's water quality. The results of the regression analyses indicate that Secchi disc transparency has increased at a rate of 0.01 m per year; chlorophyll *a* concentration in the surface waters (upper 6 feet) has declined at the rate of 0.7 μg/L per year; total phosphorus concentration in the surface waters has been increasing at a rate of 0.2 μg/L per year. The changes in Secchi disc, chlorophyll *a,* and total phosphorus are not significantly different from zero. Hence, the data indicate the lake's current water quality problems are unlikely to change unless management practices are implemented to improve the lake's water quality.

A comparison between baseline (i.e., 1971 to 1987) and current (1988 to 2002) trophic state index (TSI) values indicates that Duck Lake has been unable to fully support fishable use during the baseline and current periods. For the entire 1971 to 2002 period, Duck Lake was never able to meet the MDNR criteria (TSI $\leq$ 54.5) for fully supported fishable use.

Current Water Quality

The current water quality of Duck Lake is poor and recreational activities are impaired by invasive aquatic vegetation growth, curlyleaf pondweed (*Potamogeton crispus*), and summer algal blooms that are very severe. In 2002 Duck Lake's average summer concentration of total phosphorus, concentration of chlorophyll *a*, and Secchi disc transparency were 123 µg/L, 43 µg/L, and 0.8 m, respectively. This current water quality condition of Duck Lake is largely the result of storm water inputs with high levels of phosphorus, historical inputs of sediment and phosphorus, and the current influence of invasive aquatic plants on the mobilization of phosphorus from lake sediments. As a result, the 2002 total phosphorus, chlorophyll *a*, and Secchi disc data indicate that Duck Lake ranges from eutrophic to hypereutrophic in the summer and hypereutrophic in the early-fall.

Phosphorus Budget

There are four major sources of phosphorus loading to Duck Lake: watershed runoff, release of phosphorus from lake sediments, the release of phosphorus from decaying aquatic plant material, and atmospheric deposition. Watershed modeling and in-lake modeling under different climatic conditions and for existing watershed land uses indicates that annual total phosphorus loads to the lake range from 139 pounds for a dry year to 182 pounds for a wet year (Figure EX-1). The average rate of watershed loading to the 38-acre lake is 3.9 pounds of phosphorus per acre of lake per year under existing watershed land use conditions and 4.2 pounds of phosphorus per acre of lake per year under future land use conditions. This rate of phosphorus loading is excessive and causes water quality problems ($L = 0.442\ g/m^2/yr$ under existing watershed land uses; $L = 0.472\ g/m^2/yr$ under future land uses).

Watershed modeling for the 212-acre contributing Duck Lake watershed shows that from 35 (dry year) to 78 (wet year) pounds of phosphorus loading to the lake originates from the surrounding watershed. During an average year watershed loading provides approximately 30.7 percent of the total phosphorus load to the lake, while internal loading (phosphorus loading during the summer from lake sediments and decaying plant material) provides approximately 62.7 percent of the total phosphorus load to the lake (Figure EX-2). The remaining phosphorus load comes from atmospheric deposition (6.6 percent).

During an average year, the high concentration of phosphorus that is observed in Duck Lake is significantly affected by internal lake processes that mobilize phosphorus from lake sediments by direct release of phosphorus from the sediments and by uptake and subsequent release of phosphorus by submerged aquatic plants. For an average year it is estimated that the direct release of phosphorus from Duck Lake bottom sediments is responsible for approximately 51 percent of the total phosphorus load to Duck Lake while aquatic plants are responsible for 12 percent of the total phosphorus load to Duck Lake. Because it is expected that future watershed land use changes will be minimal, total phosphorus loading in the future will be essentially unchanged. The proportion of phosphorus loading from internal sources is expected to be largely constant over time.

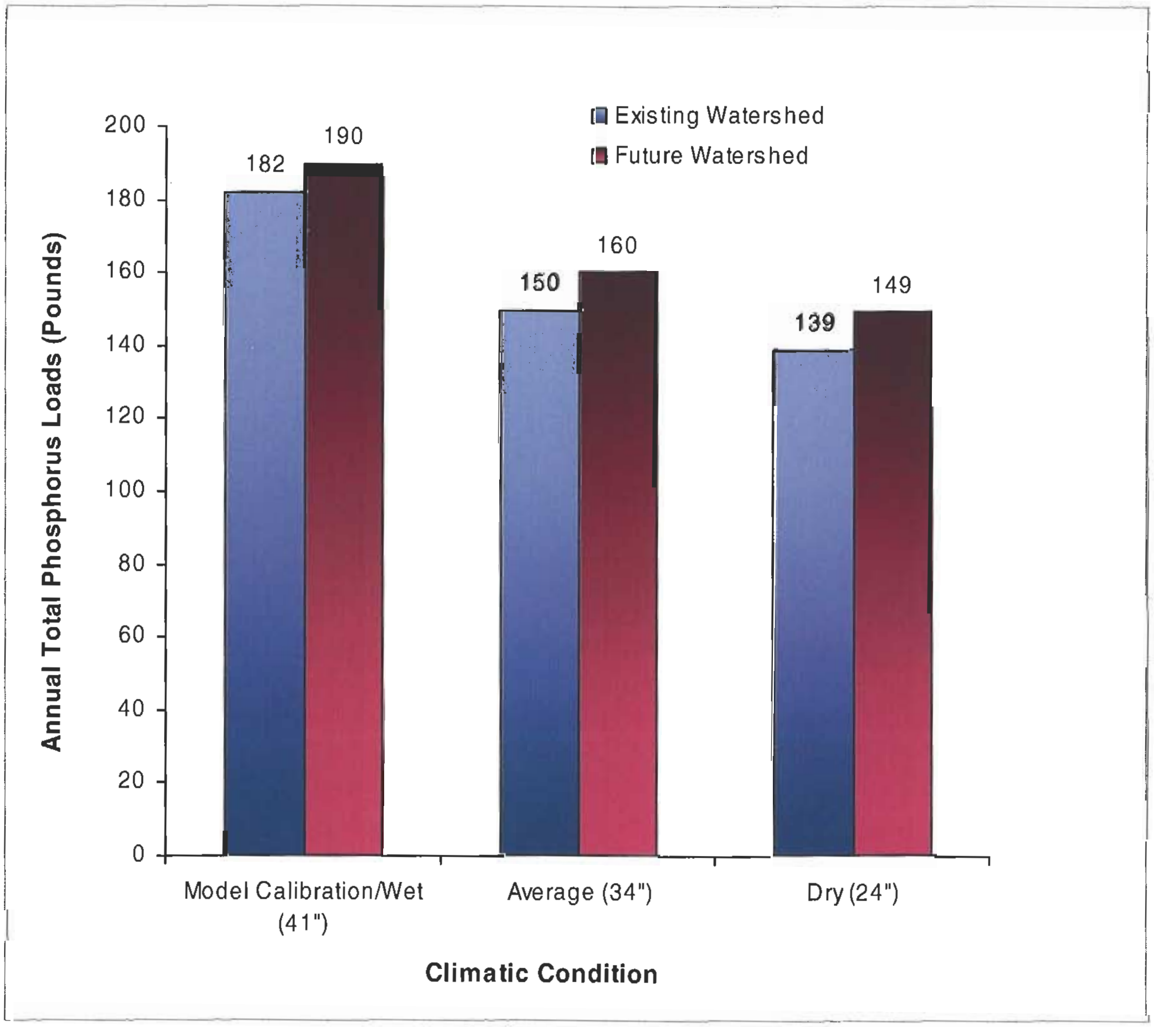

Figure EX-1 Total Phosphorus Loading to Duck Lake with Varying Climatic Conditions and with Existing and Future Watershed Land Uses

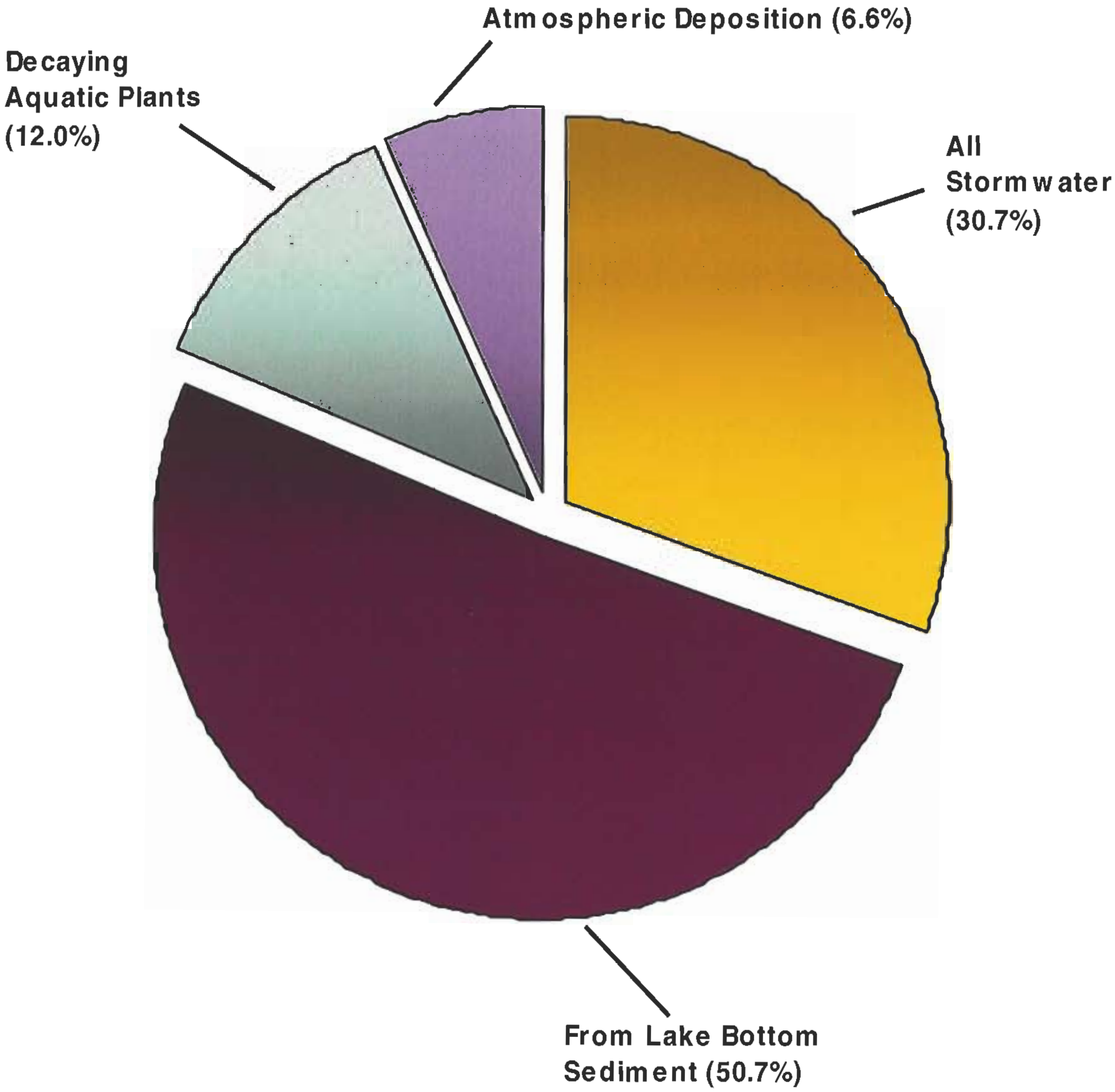

Figure EX-2 Proportion of Phosphorus Loading by Source (Average Climatic Condition, Existing Land Use)

Aquatic Plants

Macrophyte surveys were completed in Duck Lake on June 7 and August 21, 2002. The exotic (nonnative) species, curlyleaf pondweed (*Potamogeton crispus*), was found throughout the lake during June. The annual die-off of this plant in June released phosphorus to the lake, causing increased algal growth for the remainder of the summer. Shading from increased algal growth severely limited macrophyte growth in Duck Lake in the late summer. The maximum depth of plant growth was just over 8 feet in June and approximately 2 feet in August. In late summer, algal shading led to a reduction in native aquatic plant species such as elodea (*Elodea canadenis*), flat-stem pondweed (*Potamogeton zosteriformis*), and coontail (*Ceratophyllum demersum*). They were present throughout the lake in June, but their presence was greatly reduced in August. Late summer algal shading led to the disappearance of two native plant species, leafy pondweed (*Potamogeton foliosus*) and sago pondweed (*Potamogeton pectinatus*). They were present in June and absent in August. Management of curlyleaf pondweed is recommended to protect the lake's water quality, protect the native plant community, to improve the lake's fishery, and to insure that curlyleaf pondweed does not dominate the aquatic plant community when the clarity of Duck Lake improves.

Recommended Goal Achievement Alternatives

Two lake improvement alternatives will approach but not achieve the current District goal for Duck Lake, which is the water quality recommended by MDNR to fully support a Class 40 fishery. The second alternative below will achieve the proposed District goal for Duck Lake which is based upon the Minnesota Pollution Control Agency proposed standards for shallow lakes (proposed changes to Minnesota Rules Chapter 7050.0222, Subp. 4. Class 2B Waters). The proposed District goal would result in the attainment of the proposed MPCA phosphorus and Secchi disc transparency standards for Duck Lake.

The alternatives are:

- **Alternative 1**: Manage the aquatic plant curlyleaf pondweed by herbicide (Endothall) treatment for 4 years and treat the lake sediment with alum.
- **Alternative 2**: Manage the aquatic plant curlyleaf pondweed by herbicide (Endothall) treatment for 4 years, treat the lake sediment with alum, construct rainwater gardens (approximately 50) throughout the Duck Lake watershed.

The expected cost and benefit of each action is presented in Table EX-1 and Figure EX-3. For each alternative to be successful, the prescribed management activities must follow a particular sequence. For **Alternatives 1 and 2**, herbicide treatment should be performed at a minimum of two years before the alum treatment is completed.

Evaluation of the results of the herbicide treatment and alum treatment are recommended before construction of rainwater gardens. The evaluation will (1) determine benefits of the herbicide and alum treatments, (2) determine whether rainwater garden construction is needed, and (3) if rainwater garden construction is needed, determine whether any warranted changes in the number of rainwater gardens are required to attain the proposed District goal.

Table EX-1 Benefits and Costs of Two Management Alternatives

	Trophic State Index (TSI_{SD}) Value					
Management Alternative	**Current District Goal**	**Proposed District Goal Based Upon MPCA Standard**	**Dry Year–2000 (24 inches of precipitation)**	**Average Year–1999 (34 inches of precipitation)**	**Wet Year–2002 (41 inches of precipitation)**	**Cost**
Existing Watershed Land Uses						
Herbicide Treatment (4 years) and Alum Treatment (2 years)	≤54.5	≤57.7	58.1	58.2	59.3	$400,000
Herbicide Treatment (4 years) and Alum Treatment (2 years) and 50 Rainwater Gardens	≤54.5	≤57.7	55.7	56.0	57.1	$700,000
Future Watershed Land Uses						
Herbicide Treatment (4 years) and Alum Treatment (2 years)	≤54.5	≤57.7	59.9	58.7	59.6	$400,000
Herbicide Treatment (4 years) and Alum Treatment (2 years) and 50 Rainwater Gardens	≤54.5	≤57.7	56.4	57.1	57.0	$700,000

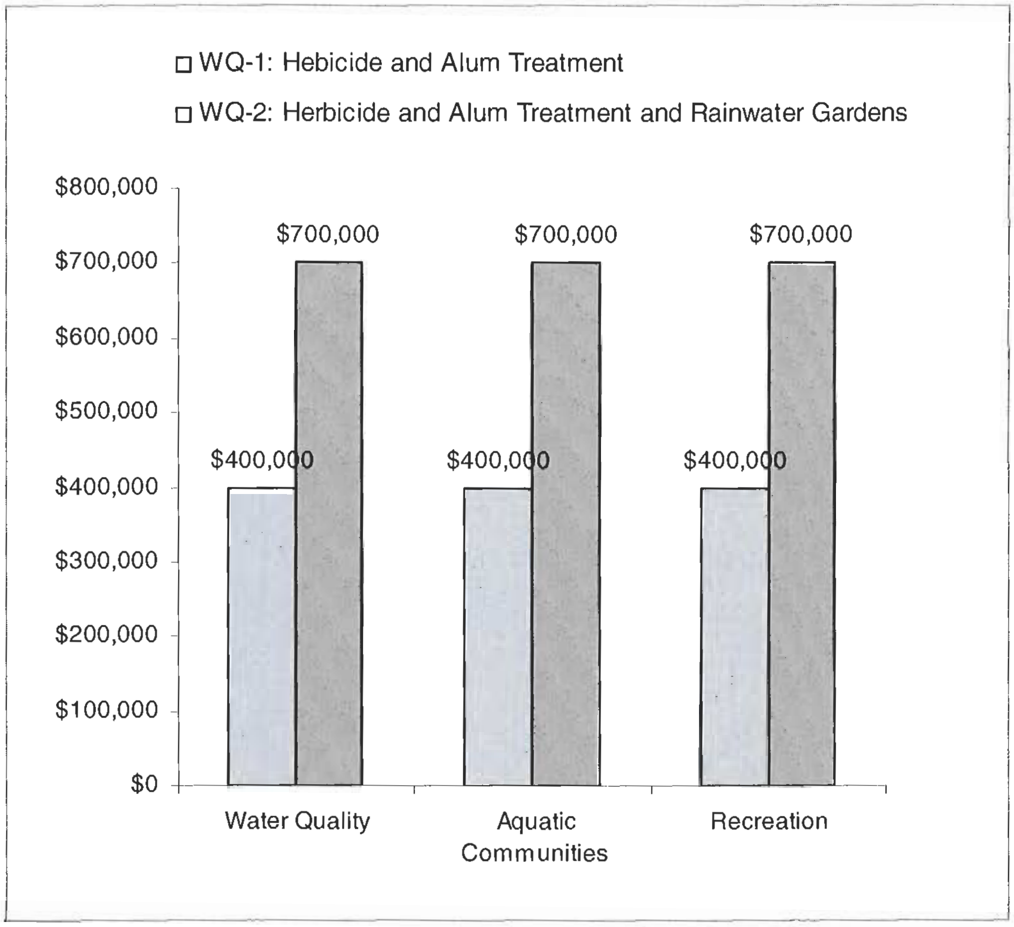

Figure EX-3 Cost to Implement Two Management Alternatives.

Selected Implementation Plan

The selected implementation plan is Alternative 2: herbicide (Endothall) treatment, alum treatment, and rain water garden construction. This implementation plan has been selected because it is important to control the constant release of phosphorus from the lake sediment and to control the periodic spike in phosphorus inputs during storm events. This plan will reduce the overall productivity of Duck Lake, control the spread of the invasive aquatic plant curlyleaf pondweed, and restore the lake to a more ecologically balanced condition.

This plan will require monitoring during the various stages of the restoration effort to evaluate effectiveness and determine whether the prescribed components and sequence of management efforts remains appropriate.

Recommended Goal Changes

An evaluation of the lake's water quality goal indicates the goal is unattainable and a goal change is warranted. The lake's recreation, aquatic communities, and water quality goals are based upon the lake's MDNR ecological class 40 rating and the water quality required to attain and maintain full support of the average fishery found in a Class 40 lake, a Trophic State Index (TSI_{SD}) of 54.5. The average fishery in a Class 40 lake includes northern pike, carp, black bullhead, white sucker, brown bullhead, yellow bullhead, pumpkinseed, yellow perch, and walleye. Duck Lake's fishery differs markedly from the average fishery found in a Class 40 lake. Periodic winterkills severely limit the lake's fishery to rough fish (black bullhead) and a few panfish (black crappie and bluegill). Because the lake's fishery does not include several species found in an average Class 40 lake (i.e., northern pike, walleye, yellow perch), its water quality requirements differ from an average Class 40 Lake. For this reason, a goal change is recommended.

The recommended water quality goal for Duck Lake is a TSI_{SD} of 57.7. This goal is based upon the Minnesota Pollution Control Agency (MPCA) phosphorus standard for shallow lakes in the North Central Hardwood Forest Ecoregion, which includes the Twin Cities Metropolitan Area. The standard is found in proposed changes to Minnesota Rules Chapter 7050.0222—Specific Water Quality Standards for Class 2 Waters of the State; Aquatic Life and Recreation, Subp. 4. Class 2B Waters. The standard requires the lake's phosphorus concentration to be less than or equal to 60 μg/L. The MPCA shallow lakes' standard further requires that the lake's Secchi disc transparency be at least 1 meter. The Secchi disc expected to occur in Duck Lake with a phosphorus concentration of 60 μg/L is 1.1 meters (TSI_{SD} of 57.7). Attainment of the proposed goal would meet the MPCA standards for phosphorus and Secchi disc transparency. The goal is attainable with the implementation of the selected implementation plan.

Duck Lake
Use Attainability Analyses

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1.0 Surface Water Resources Data

The approved Riley-Purgatory-Bluff Creek Watershed District, *Riley-Purgatory-Bluff Creek Watershed District Water Management Plan*, 1996, (Water Management Plan) inventoried and assessed Duck Lake. The plan articulated five specific goals for Duck Lake. These goals address recreation, aquatic communities, water quality, water quantity, and wildlife. This report (1) evaluates the existing and potential beneficial uses intended in these goals, (2) contains an analysis of the factors that potentially impair or limit those beneficial uses, particularly problems identified in the inventory and assessment, and (3) expands upon specific aspects of the inventory and assessment of Duck Lake contained in the approved Water Management Plan.

A use attainability analysis of Duck Lake was completed to provide the scientific foundation for a lake-specific best management plan that will maintain or attain the existing and potential beneficial uses of Duck Lake. A use attainability analysis evaluates existing and potential beneficial uses of a water resource. "Use attainment" refers to the designated beneficial uses, such as swimming and fishing. Factors that potentially impair or limit existing beneficial uses, including problems identified in the inventory and assessment, are investigated in the use attainability analysis. Lake analyses rely on previously collected field data and continue with watershed evaluations using water quality modeling.

The main tools used for the technical analysis are an advanced water quality model that predicts the amount of pollutants that reach a lake via stormwater runoff and an in-lake model that is used to better understand in-lake processes. Calibrating a lake model requires an accurate measurement of land use and stormwater inputs. Impacts of upland detention and treatment of stormwater are included in the model.

1.1 Land Use

All land use practices, historical, current, as well as future practices within a lake's watershed, impact the lake and its water quality. Impacts result from the export of sediment and nutrients, primarily phosphorus, to a lake from its watershed. Each land use contributes a different quantity of phosphorus to the lake, thereby affecting the lake's water quality differently. Historic, current, and proposed future land uses in the Duck Lake watershed are discussed in the following paragraphs.

The total Duck Lake watershed is 177 acres. The area of the Duck Lake watershed that contributes runoff to the lake is 158 acres. An additional 16 acres of land (i.e., noncontributing watershed area shown in Figure 1) lies within the Duck Lake watershed but does not contribute runoff to the lake because it is captured by a pond that does not have an outlet (all the water is infiltrated or evaporated). The entire 158-acre watershed that contributes runoff to Duck Lake is directly tributary to the lake, meaning there are no creeks or other inflows other than runoff from the area surrounding the lake or runoff from storm sewer inputs. Storm water runoff primarily comes from low density residential neighborhoods, but also includes runoff from a school and a park.

The historical land use of a lake can have a significant bearing on the current and future water quality of a lake. Figure 1 shows a recent aerial photograph of the watershed and Figure 2 shows an aerial photograph of the lake taken in 1947. A comparison of these figures shows that the land use has changed from primarily agricultural to suburban over the second half of the 20th century. Although historical agricultural inputs of high phosphorus sediment has likely had an effect on internal phosphorus loading in the present day, it appears that there was a relatively good buffer area of pasture land around the lake. This may have somewhat limited the input of high phosphorus sediment to the lake.

Land use data used in the Duck Lake UAA modeling efforts were derived from the Metropolitan Council Generalized Land Use Maps for the year 2000 (current land use) and 2020 (projected future land use). A detailed description of the current and future land uses of the Duck Lake watershed are presented in Table 1. Maps of the current and future land uses of the Duck Lake watershed are presented in Figures 3 and 4.

Table 1 Duck Lake Land Use for Existing and Proposed Future Land Use Conditions

Land Use Type	Existing Conditions	Future Conditions
Low Density Residential	144	153
Medium Density Residential	0	0
High Density Residential	0	0
Developed Parkland	5	6
Natural/Park/Open	16	0
Institutional	13	15
Commercial	0	0
Highway	0	4
Open Water	50	50

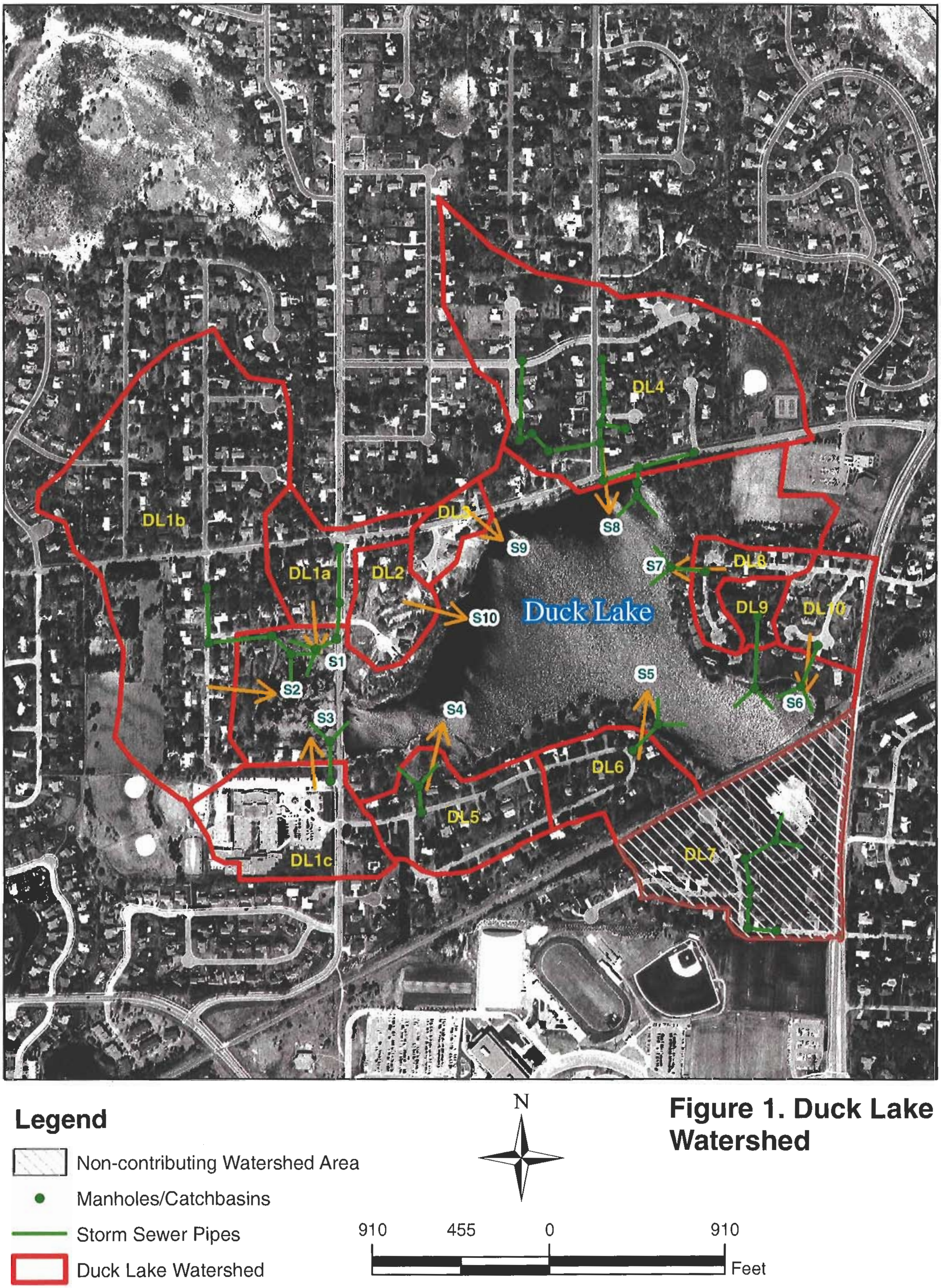
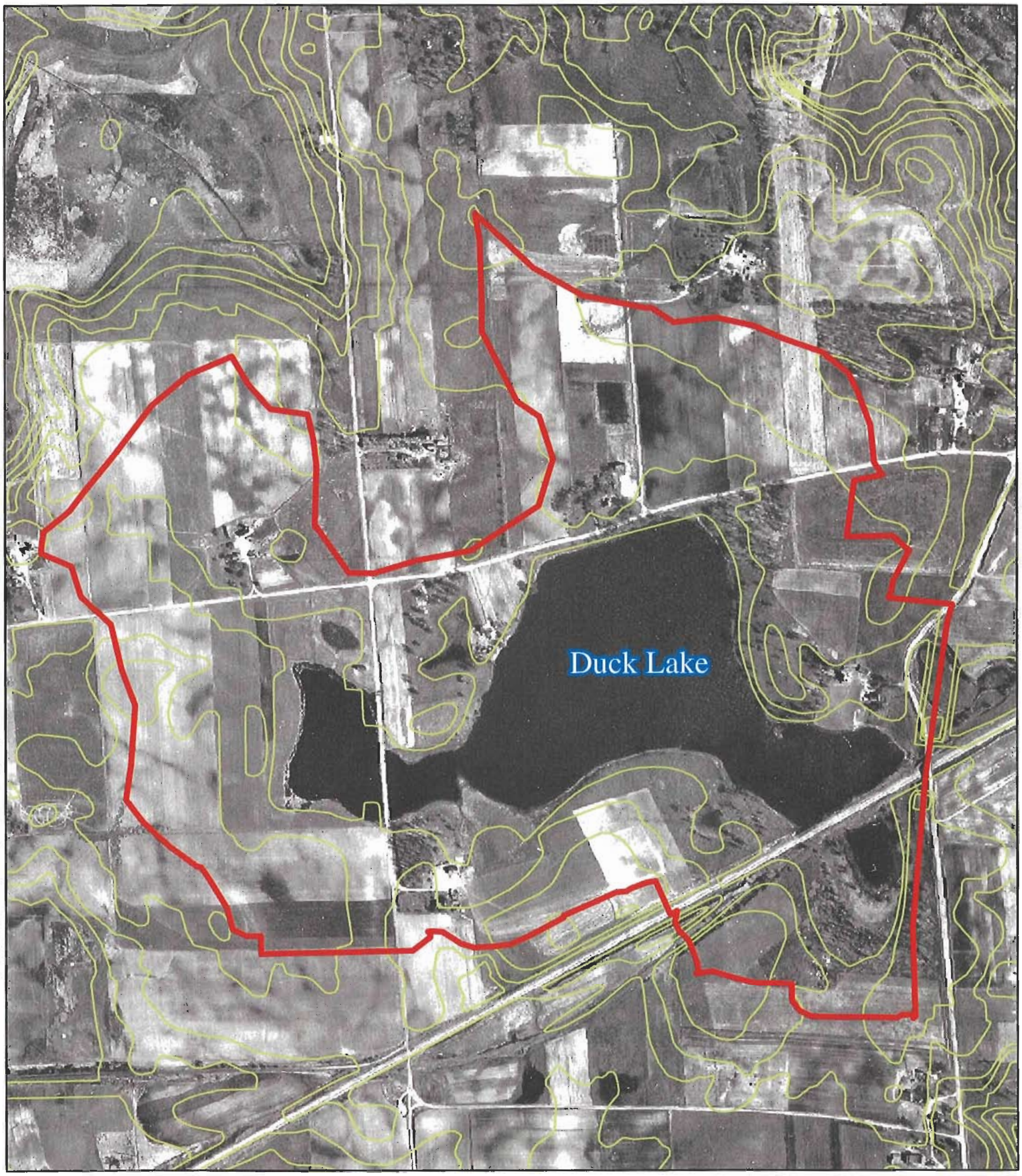


Figure 1. Duck Lake Watershed



Legend

Duck Lake Watershed

10 ft contours

N

750 375 0 750 Feet

Figure 2. Historical Land Use for the Duck Lake Watershed

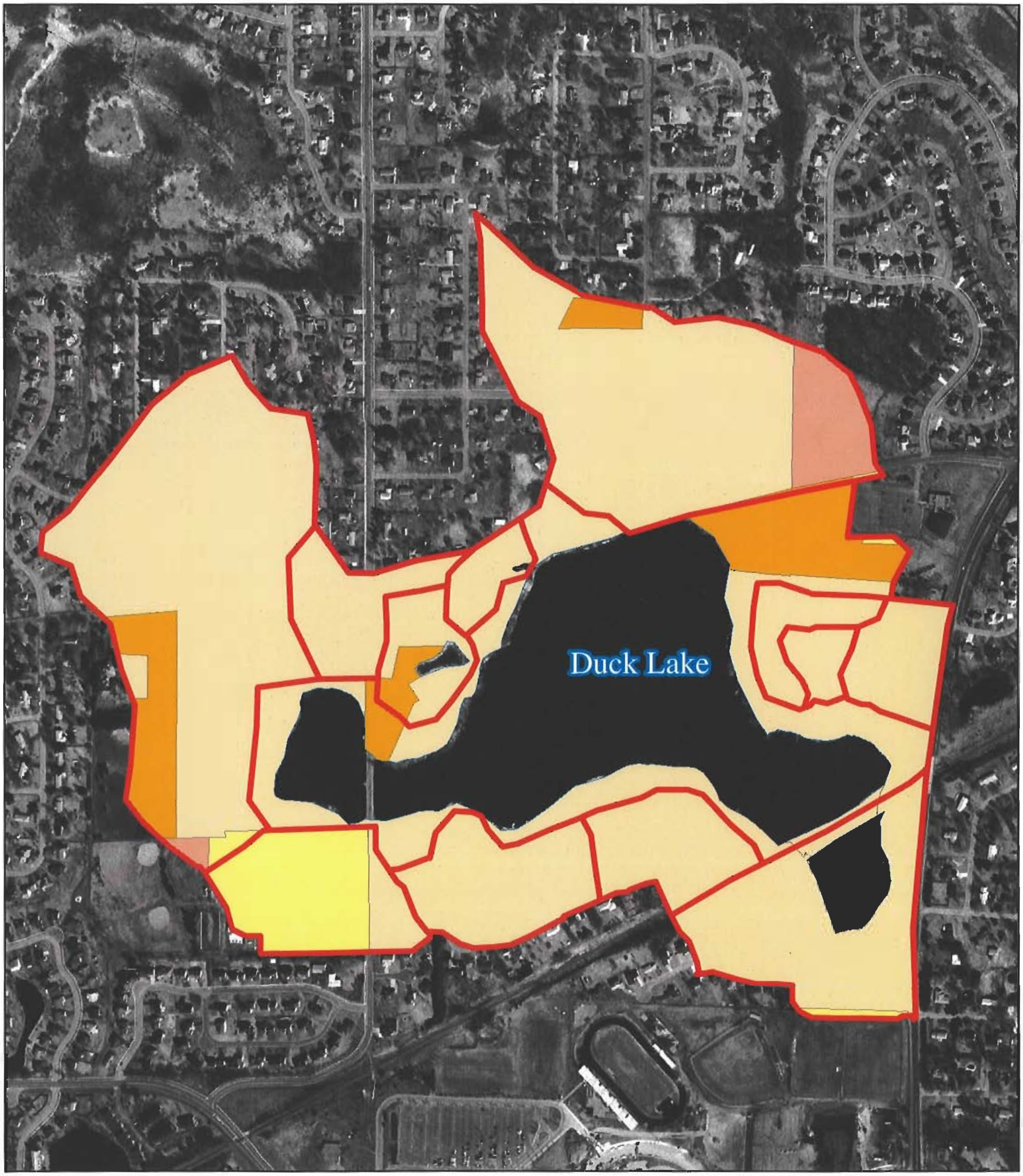
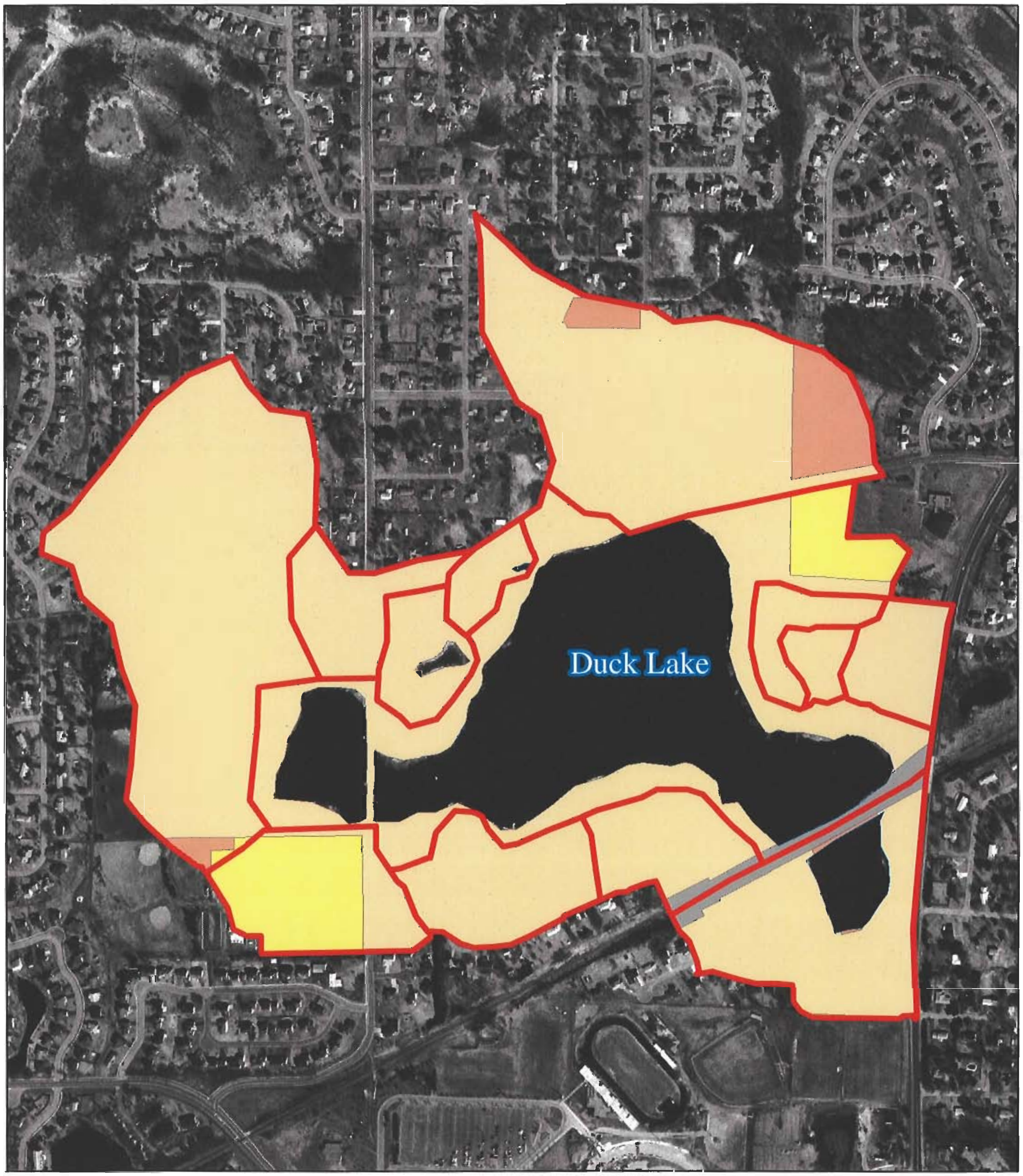


Figure 3. Current Land Use for the Duck Lake Watershed



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2020 Landuse

- Developed Parkland
- Institutional
- Low Density Residential
- Highway
- Water

N

750 375 0 750 Feet

Figure 4. 2020 Land Use for the Duck Lake Watershed

1.2 Major Hydrologic Characteristics

At a normal water elevation of 914.09 feet, Duck Lake has an area of 38 acres and an average depth of 4 feet. The entire lake surface is considered littoral, meaning the entire lake is shallow enough to support aquatic plant growth. Water enters the lake either by direct precipitation or by stormwater inflows from yards and green space directly adjacent to the lake (see Figure 1 for storm sewer locations). Water exits the lake by infiltration to groundwater, and through a piped outlet located on the south east side of the lake. The major hydrologic and hydraulic characteristics of the lake are provided in Table 2.

Table 2 Average Lake Volume, Annual Discharge Volume, Annual Infiltration Volume, and Estimated Hydraulic Residence Time of Duck Lake for a Range of Climatic Conditions (Existing Watershed Landuse)

Climatic Condition (Water Year, Inches of Precipitation)	Average Lake Volume (m^3/ac-ft)	Estimated Annual Lake Outflow by Infiltration (m^3/ac-ft)	Estimated Annual Lake Outflow by Through Outlet (m^3/ac-ft)	Hydraulic Residence Time (years)
*Wet Year (2002, 41 inches)	173,944/141	25,907/21	28,374/23	3.2
Average Year (1999, 34 inches)	203,297/164	32,075/26	24,673/20	3.6
Dry Year (2000, 24 inches)	162,841/132	69,084/56	0/0	2.4

*Calibration performed using the wet year data

As shown in Table 2, the lake's average volume is dependent upon both antecedent and current precipitation conditions. Consequently, the lake's average volume in 1999 was higher than in 2002 despite higher precipitation during 2002. Relatively dry antecedent conditions and dry climatic conditions during the first half of the 2002 water year caused the lake levels to be more than a foot lower than comparable 1999 levels. Very wet conditions during the second half of 2002 caused a rise in lake level, but the levels did not equal comparable 1999 levels until August, two months before the end of the water year (see Figure 5). Hence, the lake's average volume was greater during 1999 than 2002.

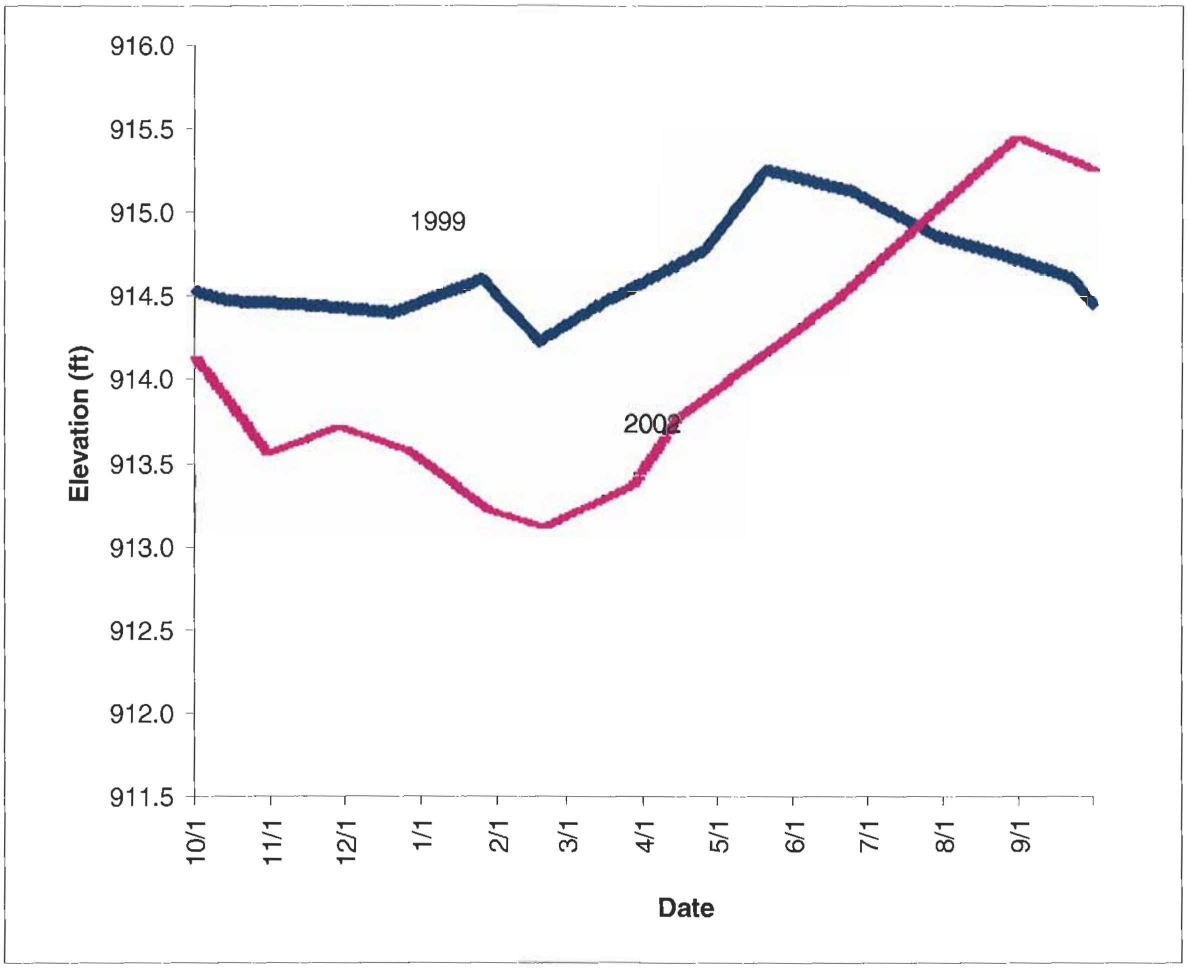


Figure 5 Comparison of 1999 and 2002 Duck Lake Elevations

1.3 Water Quality

The water quality of a lake provides an indication of how a lake functions. A standardized lake rating system is often used to classify the ecological condition of a lake. The rating system uses phosphorus, chlorophyll *a*, and Secchi disc transparency values to classify a lake into four categories: Oligotrophic (clear, low productivity lakes with excellent water quality), Mesotrophic (intermediate productivity lakes with good water quality), Eutrophic (high productivity lakes with poor water quality) and Hypereutrophic (extremely productive lakes with poor water quality).

1.3.1 Data Collection

Water quality data were collected by the District for Duck Lake from 1971 to 2002 (for years 1971, 1975, 1978, 1981, 1984, 1988, 1990, 1993, 1996, and 2002).

From April through September, 2002, a water quality monitoring program was completed for Duck Lake to calibrate a water quality model for the lake. Water sampling and analytical methods used in this study are provided in Appendix B.

1.3.2 Baseline/Current Water Quality

A comparison of baseline and current water quality (total phosphorus, chlorophyll *a*, and Secchi disc transparency) was completed to determine whether changes in the lake's water quality occurred during the 1971 to 2002 monitoring period. Baseline water quality is defined as the average summer water quality for the years 1971 through 1987, while current water quality is defined as the average summer water quality for years 1988 through 2002.

For the baseline and current period, Duck Lake can be classified as hypereutrophic (very poor water quality) (see Figure 6). Although some fluctuation of total phosphorus, chlorophyll *a*, and Secchi disc occurred during the period of record, the lake's water quality was consistently very poor.

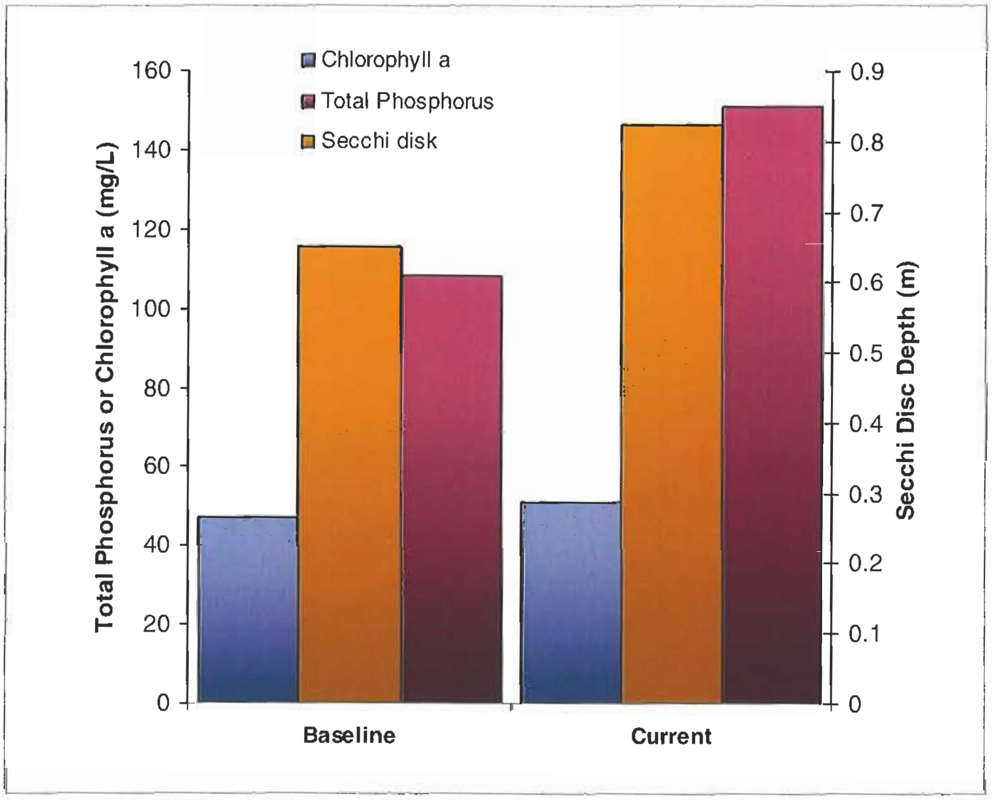
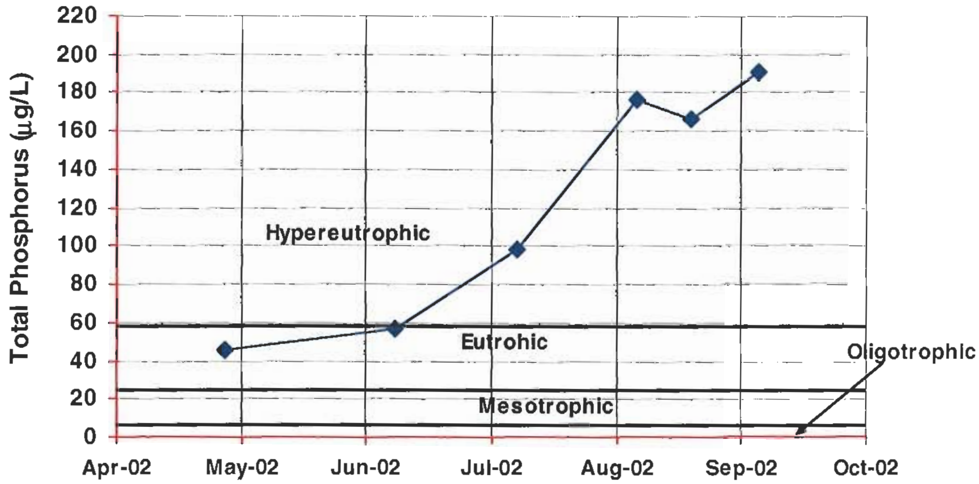
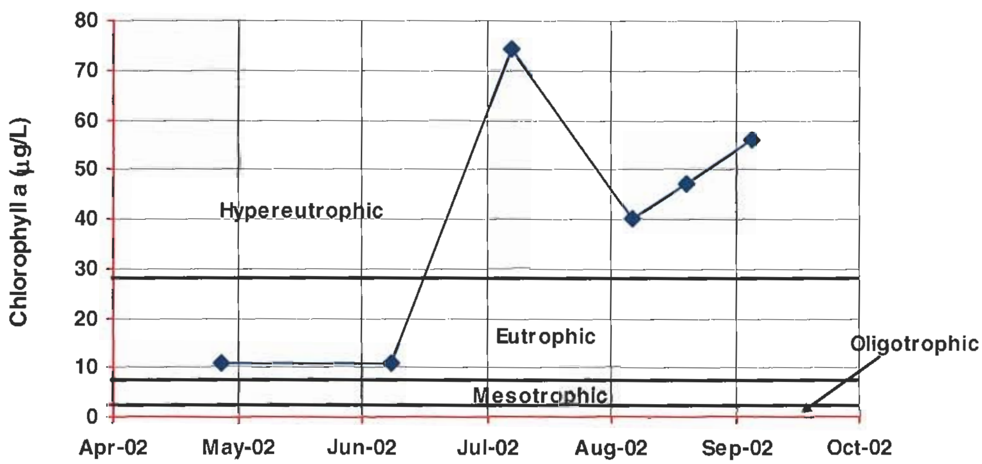


Figure 6 A Comparison of Baseline Water Quality of Duck Lake with Current Conditions Based on Summer (June through August) Averages)

1.3.2.1 Present Water Quality

An evaluation of water quality data for Duck Lake in 2002 was completed to examine the lake's present water quality. The evaluation was based upon a standardized lake rating system. The rating system uses the lake's total phosphorus, chlorophyll *a*, and Secchi disc transparency as the key water quality indicators to determine the lake's present water quality for the following reasons. Phosphorus generally controls the growth of algae in lake systems. Of all the substances needed for biological growth, phosphorus is generally the one present in limited quantity. Consequently, when phosphorus is added to a system, it enhances algal growth. Chlorophyll *a* is the main pigment in algae; therefore, the concentration of chlorophyll *a* in the water indicates the amount of algae present in the lake. Secchi disc transparency is a measure of water clarity, and is inversely related to algal abundance. Water clarity determines recreational use-impairment. Figure 7 summarizes the seasonal changes in concentrations of total phosphorus and chlorophyll *a*, and Secchi disc transparencies for Duck Lake in 2002. The data are compared with a standardized lake rating system.





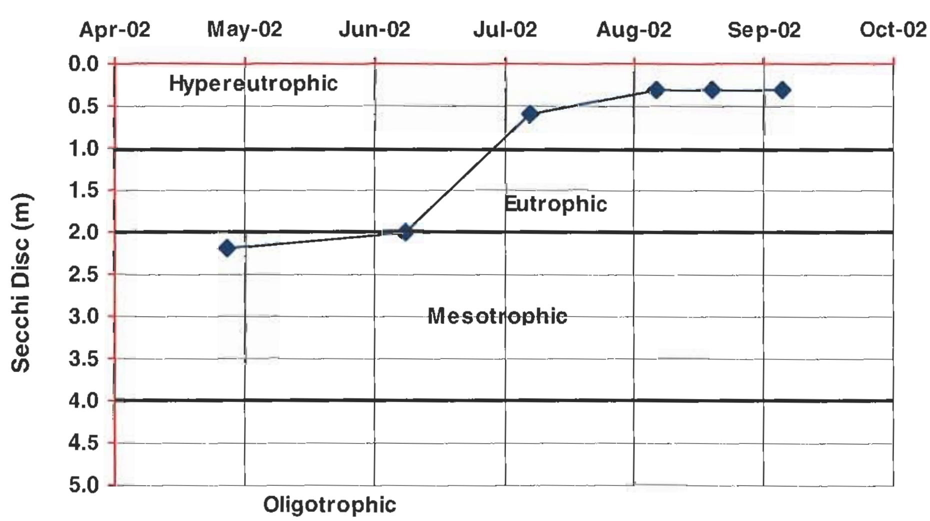


Figure 7 Seasonal Changes in the Concentration of Total Phosphorus and Chlorophyll *a*, and Secchi disc transparency in Duck Lake for 2002.

The water quality in Duck Lake was poor throughout the 2002 growing season. Nonetheless, the lake followed a very distinctive seasonal pattern of water quality degradation from spring through summer. In the spring, the concentrations of phosphorus and chlorophyll *a* were relatively high and the lake's water quality was poor (eutrophic). Phosphorus increases during April through June resulted in very nutrient rich waters (hypereutrophic). The rate of water quality degradation accelerated during June through early July resulting in increasingly poorer water quality. Phosphorus levels continued to rise until early September except for a slight decrease in late August. A die-off of a severe algal bloom occurring in July reduced chlorophyll *a* values by nearly half in early August. Chlorophyll *a* concentrations then increased until early September. Water clarity was severely reduced from July through September. Phosphorus, chlorophyll, and Secchi disc data were consistently in the hypereutrophic or very poor water quality category during July through September (see Figure 7).

Modeling results, sediment sampling, and aquatic plant data (see Section 2.0 and Appendix A) suggest that the release of phosphorus from the lake's bottom sediments are primarily responsible for the observed seasonal change in phosphorus concentrations. Stormwater runoff and curlyleaf pondweed decay both contribute to the lake's phosphorus content, but play a lesser role than the lake's bottom sediments.

1.4 Ecosystem Data

1.4.1 Aquatic Ecosystem

The interactions of the physical, chemical, and biological components of the Duck Lake aquatic ecosystem have a large effect on the capacity of Duck Lake to achieve the recreation, aquatic communities, and water quality goals that have been established for the lake. Hence, this use attainability analysis includes an evaluation of Duck Lake's aquatic ecosystem.

The aquatic ecosystem of Duck Lake is a good example of how the biological community of a lake (i.e., zooplankton, algae, and aquatic plants) can affect the chemical environment of a lake (i.e., pH, phosphorus levels, and dissolved oxygen) which can then also affect the biological community. Data collected for each component of the aquatic ecosystem is reviewed below and then in Section 1.9. A discussion is provided to interpret how these different components function in Duck Lake.

1.4.2 Phytoplankton

The population of phytoplankton in Duck Lake goes through a seasonal transformation where green algae and cryptomonads are dominant in the spring but decline in the summer, while blue-green algae populations are low in spring and dominate in the summer (Figures 8, 9, and 10). Algal blooms are observed in Duck Lake from July through September. The blooms primarily consist of blue-green algae which are large and visible and are often noted to be floating on the surface during periods of severe blooms.

There are several reasons why dominance of blue-green algae during summer is unfavorable for Duck Lake:

- Blue-green algae are not a preferred food source for zooplankton,
- Blue-green algae can float at the lake surface causing highly visible algal blooms,
- Certain blue-green algae can be toxic to animals, and
- Blue-green algae disrupt lake recreation during the summer.

Large populations of blue-green algae are most often associated with high levels of phosphorus. Blue-green algae have a competitive advantage (i.e. grow more quickly) over other algal species when phosphorus levels are high. Hence, phosphorus levels will need to be reduced to reduce blue-green algae populations in Duck Lake.

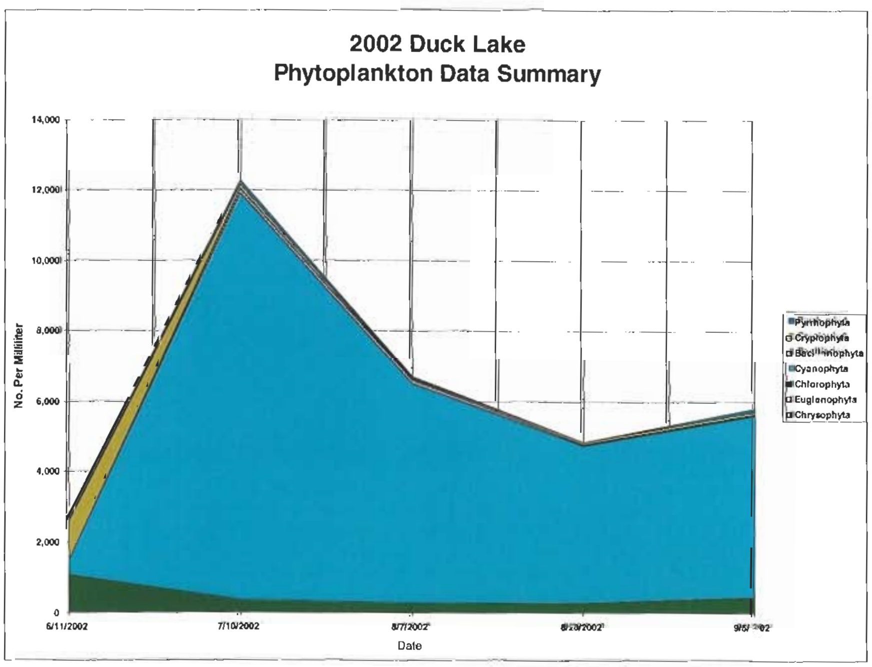


Figure 8 Phytoplankton Abundance and Diversity in Duck Lake

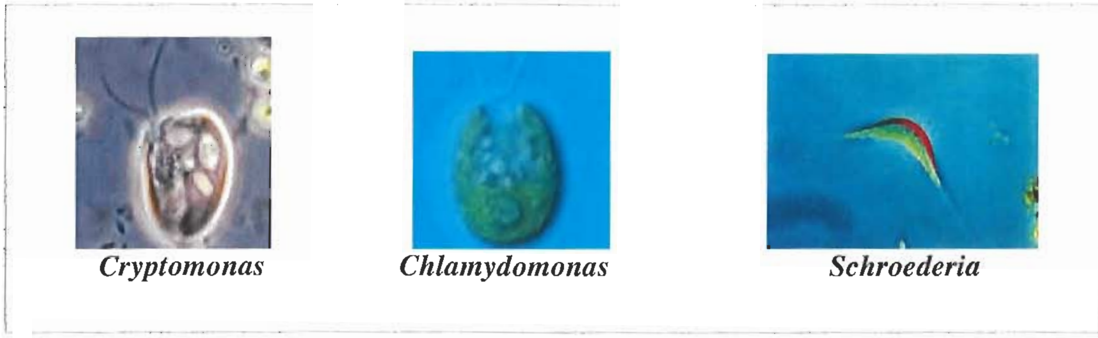


Figure 9 Smaller Phytoplankton (Dominant in Spring of 2002)

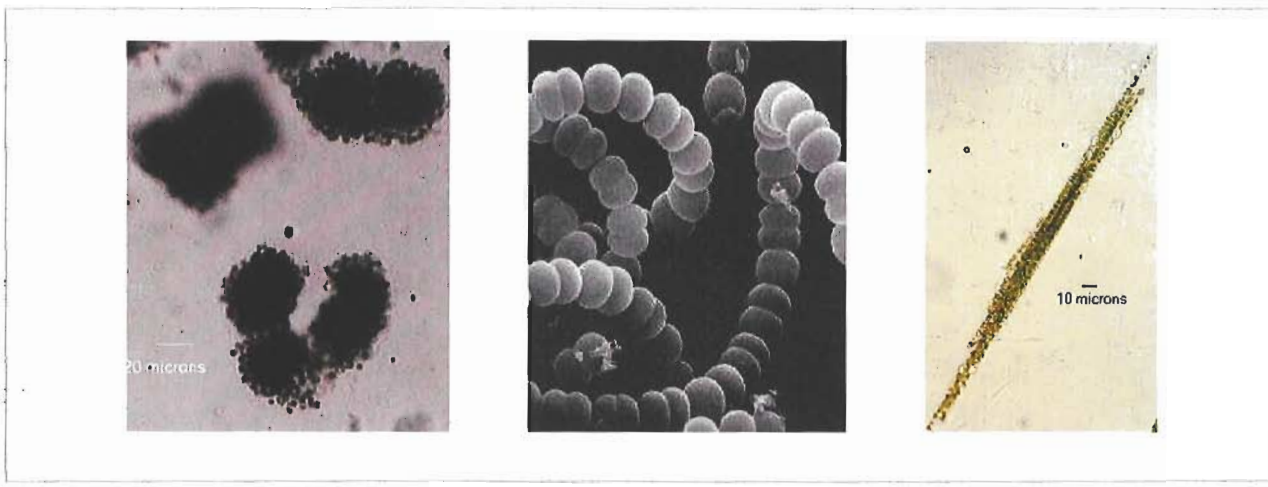


Figure 10 Larger Phytoplankton (Dominant in Summer of 2002)

1.4.3 Zooplankton

Zooplankton are an important component of the aquatic ecosystem of Duck Lake. They are particularly important for the lake's fishery and for the biological control of algae. Healthy zooplankton communities are characterized by balanced densities (number per meter squared) of the three major groups of zooplankton: Cladocera, Copepods, and Rotifers. Fish predation, however, may alter community structure and reduce the numbers of larger-bodied Cladocera.

All three groups of zooplankton were well represented in Duck Lake during 2002 (Figure 11). The community structure changed, however, during June through early August when larger-bodied Cladocera (see Figure 12) decreased significantly and small bodied Cladocera (see Figure 13) increased. This observed drop in the large-bodied Cladocera population is typically caused by predation by newly hatched fish, called young-of-the-year.

Changes in numbers of large-bodied Cladocera affect a lake's water quality because large-bodied Cladocera have the capacity to biologically control algal growth through daily grazing. Daily zooplankton grazing rates of Duck Lake were estimated to range from 4 to 19 percent in 2002. Grazing rates decreased from 17 percent during June to 4 percent during early August (see Figure 14). A decline in large bodied Cladocera and an increase in small bodied Cladocera occurred during the June through early August period.

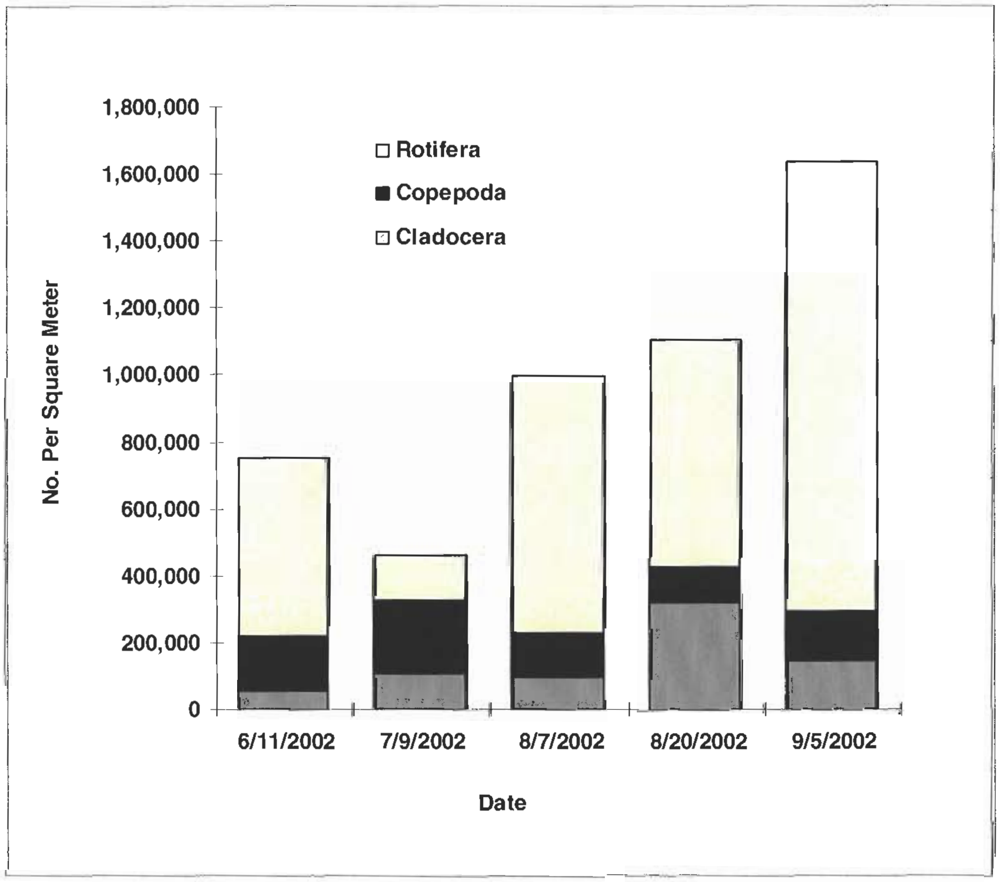


Figure 11 Zooplankton Abundance and Diversity in Duck Lake

Daphnia pulex **Daphnia galeata mendotae**

Figure 12 Large Bodied Cladocera

Bosmina longirostris ***Ceriodaphnia sp.*** ***Chydorus sphaericus***

Figure 13 Small Bodied Cladocera

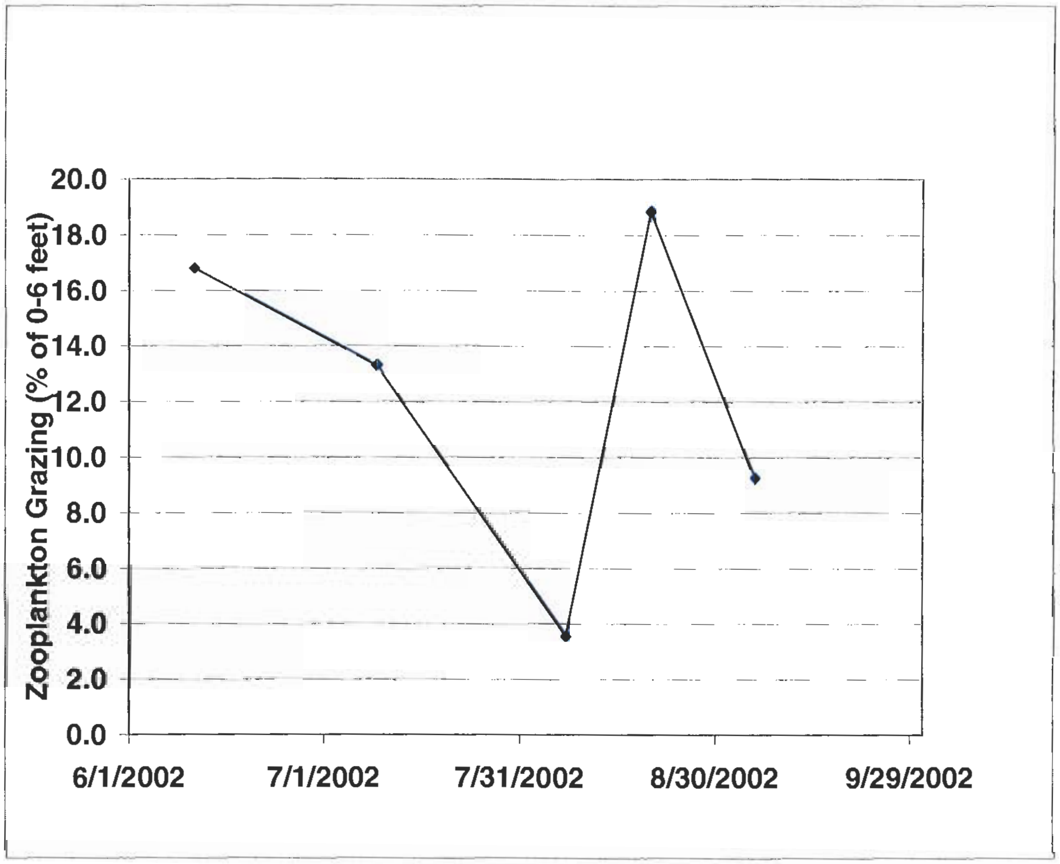


Figure 14 Percent of Duck Lake Waters Grazed by Zooplankton Each Day

During June, the phytoplankton (algae) community was comprised of small-bodied algae that are easily eaten by zooplankters (see Figure 9). However, during June through July small-bodied algae were replaced by large-bodied blue-green algae (see Figure 10). Blue-green algae dominated the lake's phytoplankton community through September (see Figure 8). The concurrent changes in the phytoplankton and zooplankton communities (i.e., increase in size of phytoplankton and decrease in size of zooplankton) prevented biological control of the lake's algal community during July through August. Although numbers of large-bodied cladocera increased in late August, the large blue-green algal filaments and colonies were inedible. Hence, zooplankters were unable to exert control over the algae during August through September, despite increased numbers.

1.4.4 Macrophytes

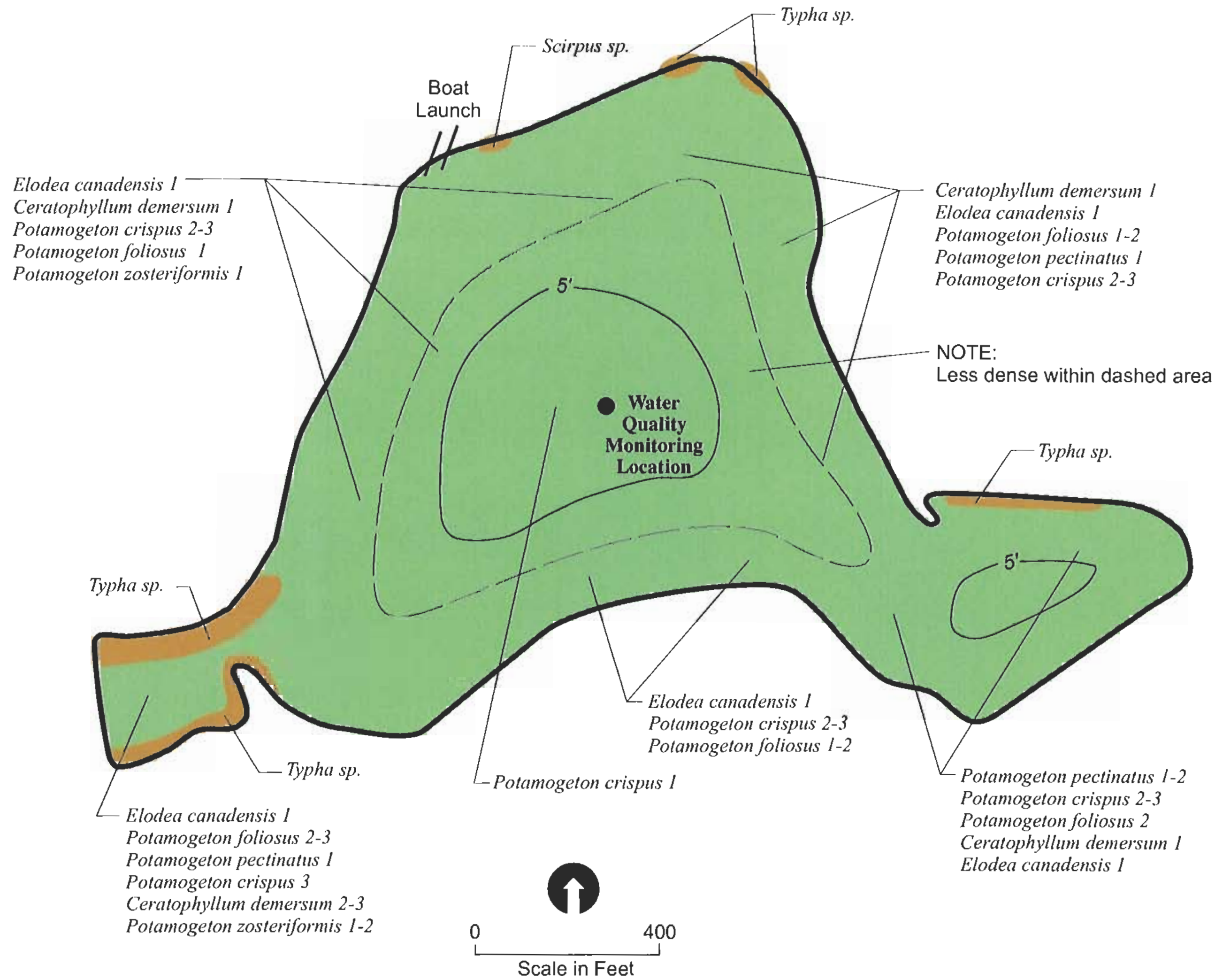
Aquatic plants are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. Typical functions of a lake's macrophyte community include:

- Provide habitat for fish, insects, and small invertebrates
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early-spring
- Help stabilize bottom sediments, marshy borders, and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

Macrophytes (aquatic plants) are an important component of the lake ecosystem (Ozimek, Gulati, and van Donk, 1990). However, the introduction of exotic (nonnative) aquatic plants into a lake may cause undesirable changes to the plant community and to the lake ecosystem. Dense stands of some mat-forming plant species reduce oxygen exchange, deplete available dissolved oxygen, increase water temperatures, and increase internal loading rates of nutrients (Frodge, Thomas, and Pauley, 1991; Frodge et al., 1995; Seki, Takahashi, and Ichimura, 1979). Dense canopies formed by some nonnative species (e.g., curlyleaf pondweed) reduce native plant diversity and abundance (Madsen, et al., 1994), thereby reducing habitat complexity. This reduction in habitat complexity results in reduced macroinvertebrate diversity and abundance (Krull, 1970; Keast, 1984) and also reduces growth of fishes (Lillie and Budd, 1992). The introduction of a nonnative plant species to a lake is not only deleterious to human use of aquatic systems, but is also detrimental to the native ecosystem.

Submersed aquatic macrophytes can play an important role in the phosphorus budget of a lake. In particular, macrophytes can directly recycle phosphorus from the sediment via root uptake, incorporation into tissue, and subsequent senescence (Barko and Smart, 1980; Carpenter, 1980; Landers, 1982; Smith and Adams, 1986; Barko and James, 1998). They can also indirectly recycle phosphorus from the sediment by increasing pH in the water column through photosynthetic activities. Phosphorus release from the sediments can be enhanced at high pH as a result of ligand exchange on iron hydroxides contained in the sediment (Drake and Heaney, 1987).

Duck Lake's macrophytes were surveyed on June 7 (Figure 15) and August 21, 2002 (Figure 16) to identify the conditions of plant growth throughout the lake. A total of eight submerged species and three emergent species were observed in Duck Lake (see Figure 17). These species are common to Minnesota lakes and most provide good habitat for the fish and aquatic animals living within the lake. Although the lake's plant community was primarily comprised of native species, the community included one non-native submerged species, curlyleaf pondweed (*Potamogeton crispus*), and one non-native emergent species, purple loosestrife (*Lythrum salicaria*).



- Macrophytes Found Throughout Entire Lake, Less Dense Near Center
- Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy
- Heavy/Dense *Potamogeton crispus* (Curlyleaf pondweed) Near Shoreline 50' - 150' from Edge

	Common Name	Scientific Name
Submerged Aquatic Plants:	Curlyleaf pondweed Flatstem pondweed Leafy pondweed Sago Pondweed Coontail Elodea	*Potamogeton crispus* *Potamogeton zosteriformis* *Potamogeton foliosus* *Potamogeton pectinatus* *Ceratophyllum demersum* *Elodea canadensis*
Floating Leaf Plants:		
Emergent Plants:	Bulrush Cattail	*Scirpus sp.* *Typha sp.*
No Aquatic Vegetation Found:		

Figure 15

DUCK LAKE
MACROPHYTE SURVEY
JUNE 7, 2002

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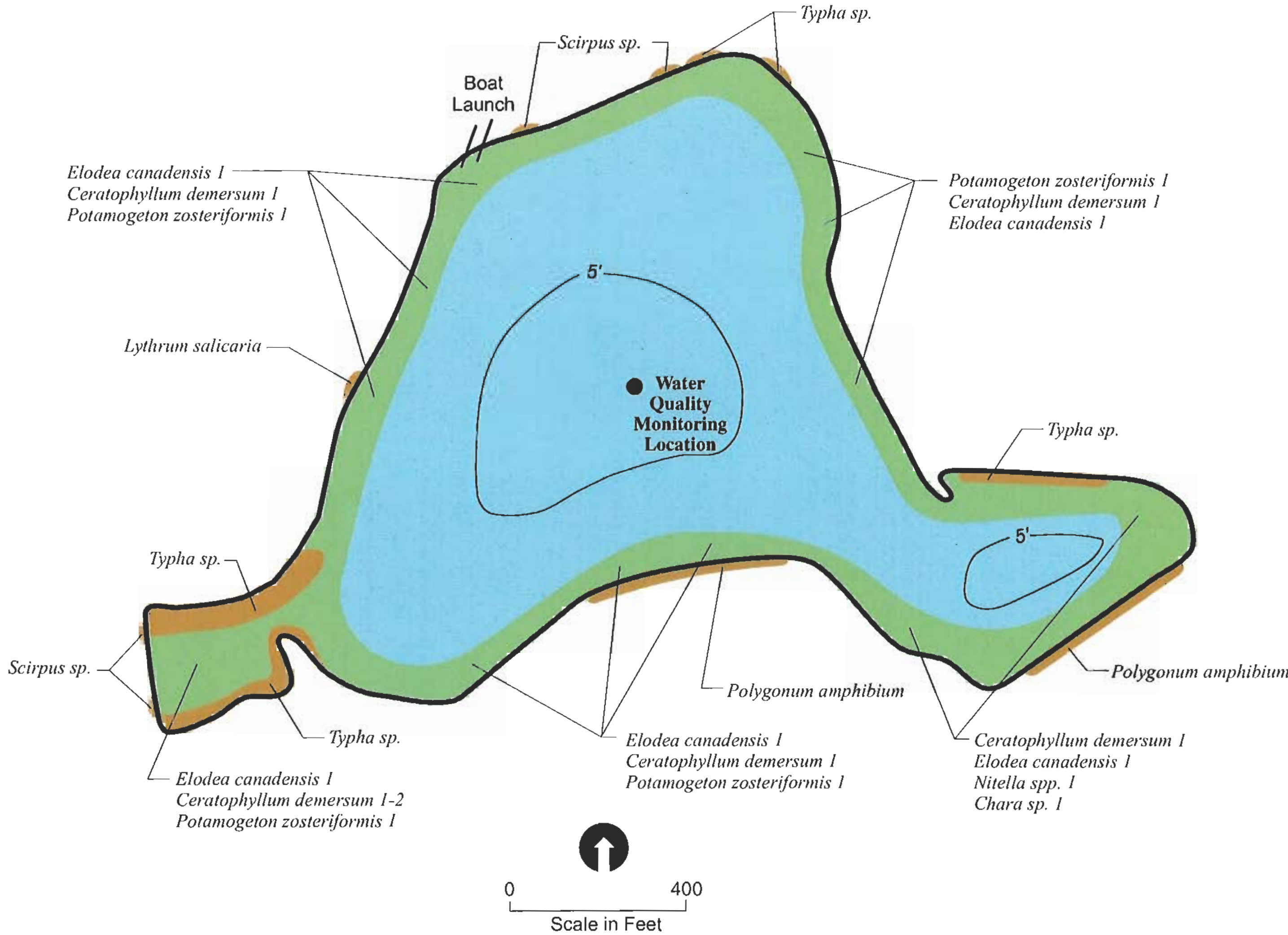

- Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy
- *Lemna trisulca* (Star duckweed) is Present Throughout Lake
- Young *Potamogeton crispus* (Curlyleaf pondweed) Growing from Turions Observed Floating Throughout

	Common Name	Scientific Name
Submerged Aquatic Plants:	Curlyleaf pondweed	*Potamogeton crispus*
	Flatstem pondweed	*Potamogeton zosteriformis*
	Coontail	*Ceratophyllum demersum*
	Elodea	*Elodea canadensis*
	Stonewort	*Nitella spp.*
	Muskgrass	*Chara sp.*
Floating Leaf Plants:	Star duckweed	*Lemna trisulca*
Emergent Plants:	Bulrush	*Scirpus sp.*
	Cattail	*Typha sp.*
	Purple loosestrife	*Lythrum Salicaria*
	Water smartweed	*Polygonum amphibium*
No Aquatic Vegetation Found:		

Figure 16

DUCK LAKE
MACROPHYTE SURVEY
AUGUST 21, 2002

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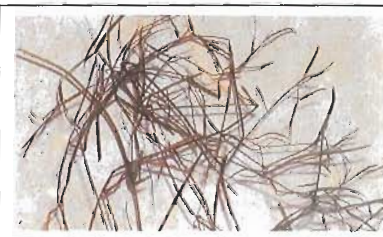
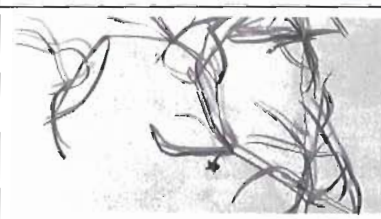
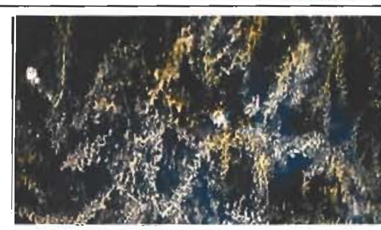
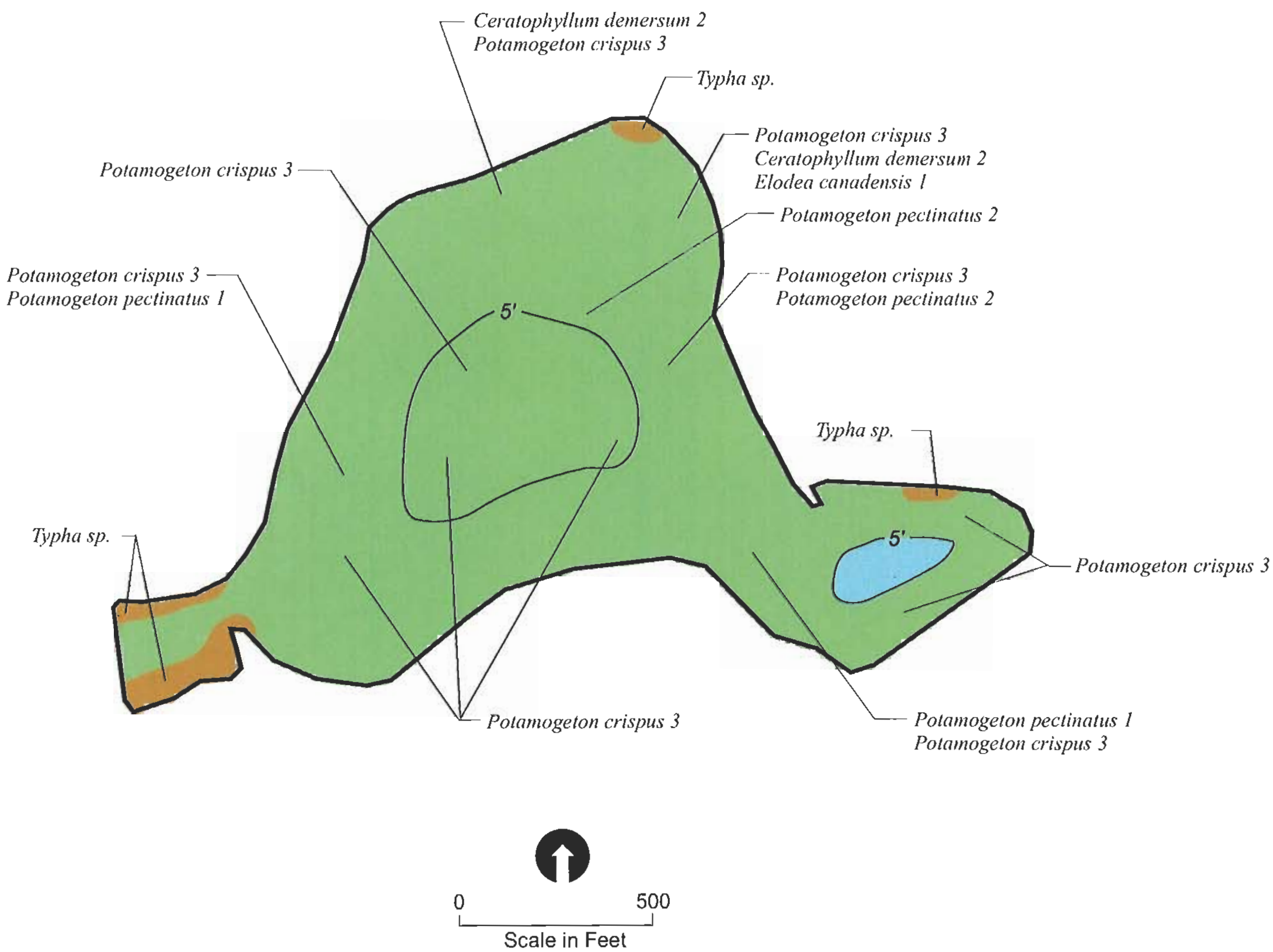
Figure 17 2002 Duck Lake Aquatic Plants			
Common Name	**Scientific Name**	**2002 Density**	**Picture**
Submerged Aquatics			
Curlyleaf pondweed	*P. crispus*	1-3	
Flatstem pondweed	*P. zosteriformis*	1-2	
Sago pondweed	*P. pectinatus*	1-2	
Leafy pondweed	*P. foliosus*	1-3	
Coontail	*Ceratophyllum demersum*	1-3	
Elodea	*Elodea canadensis*	1	

<table>
<tr><th colspan="4">Figure 17 2002 Duck Lake Aquatic Plants (Continued)</th></tr>
<tr><th>Common Name</th><th>Scientific Name</th><th>2002 Density</th><th>Picture</th></tr>
<tr><td colspan="4">Submerged Aquatics</td></tr>
<tr><td>Muskgrass</td><td>Chara sp.</td><td>1</td><td></td></tr>
<tr><td>Stonewort</td><td>Nitella spp.</td><td>1</td><td></td></tr>
<tr><td colspan="4">EmergentPlants</td></tr>
<tr><td>Cattail</td><td>Typha sp.
Left: T. latifolia, broadleaf (native).
Right: T. angustifolia, narrow-leaf (non-native)</td><td>--</td><td> </td></tr>
<tr><td>Bulrush</td><td>Scirpus sp.</td><td>--</td><td> </td></tr>
<tr><td>Purple Loosestrife</td><td>Lythrum salicaria</td><td>--</td><td></td></tr>
</table>

The growth of the exotic (nonnative) species, curlyleaf pondweed (*Potamogeton crispus*), in Duck Lake is of concern. Curlyleaf pondweed (see Figure 18) was found throughout the lake during June. Densities of this plant ranged from light to heavy. Heavier growth was found in depths less than 5 feet and lighter growth was found in depths of five foot or greater.

Figure 18 *Potamogeton crispus* (Curlyleaf pondweed)

Once a lake becomes infested with curlyleaf pondweed, this plant typically replaces native vegetation, thereby increasing its coverage and density. Curlyleaf pondweed growth has been observed throughout Duck Lake since 1993, the year in which the lake's aquatic plants were first surveyed (Figures 19, 20, 21, and 22). The curlyleaf pondweed life cycle starts with germination/initial growth in late-August, continued growth throughout the winter at a slow rate, rapid growth in the spring, and die-off in early-summer (Madsen, et al., 2002).



- No Macrophytes Found In Water > 5.0'.
- Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy
- On 6/24/93 the Perimeter of the Lake Was Treated With Reward and Cutrine Herbicides. This Was Applied by Lake Restoration Inc. (612) 478-9421 Under Permit #6306.

	Common Name	Scientific Name
Submerged Aquatic Plants:	Coontail Curlyleaf pondweed Elodea Sago pondweed	*Ceratophyllum demersum* *Potamogeton crispus* *Elodea canadensis* *Potamogeton pectinatus*
Floating Leaf Plants:		
Emergent Plants:	Cattail	*Typha sp.*
No Aquatic Vegetation Found:		

Figure 19

DUCK LAKE
MACROPHYTE SURVEY
JUNE 25,1993

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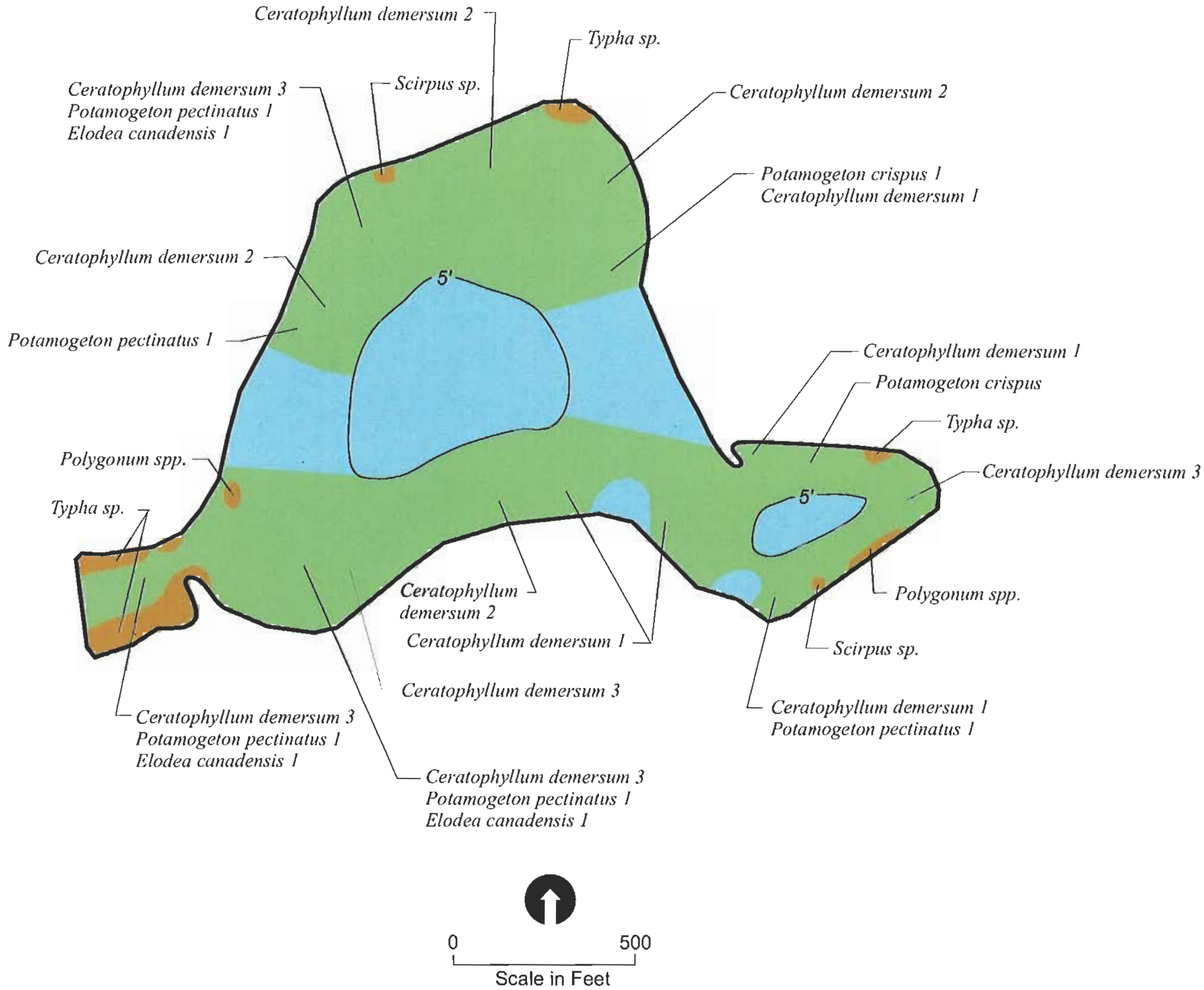

- No Macrophytes Found In Water > 5.0'.
- Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy

		Common Name	Scientific Name
Submerged Aquatic Plants:	(green)	Coontail Curlyleaf pondweed Elodea Sago pondweed	*Ceratophyllum demersum* *Potamogeton crispus* *Elodea canadensis* *Potamogeton pectinatus*
Floating Leaf Plants:	(teal)		
Emergent Plants:	(orange)	Bulrush Cattail Smartweed	*Scirpus sp.* *Typha sp.* *Polygonum spp.*
No Aquatic Vegetation Found:	(blue)		

Figure 20

DUCK LAKE
MACROPHYTE SURVEY
AUGUST 24,1993

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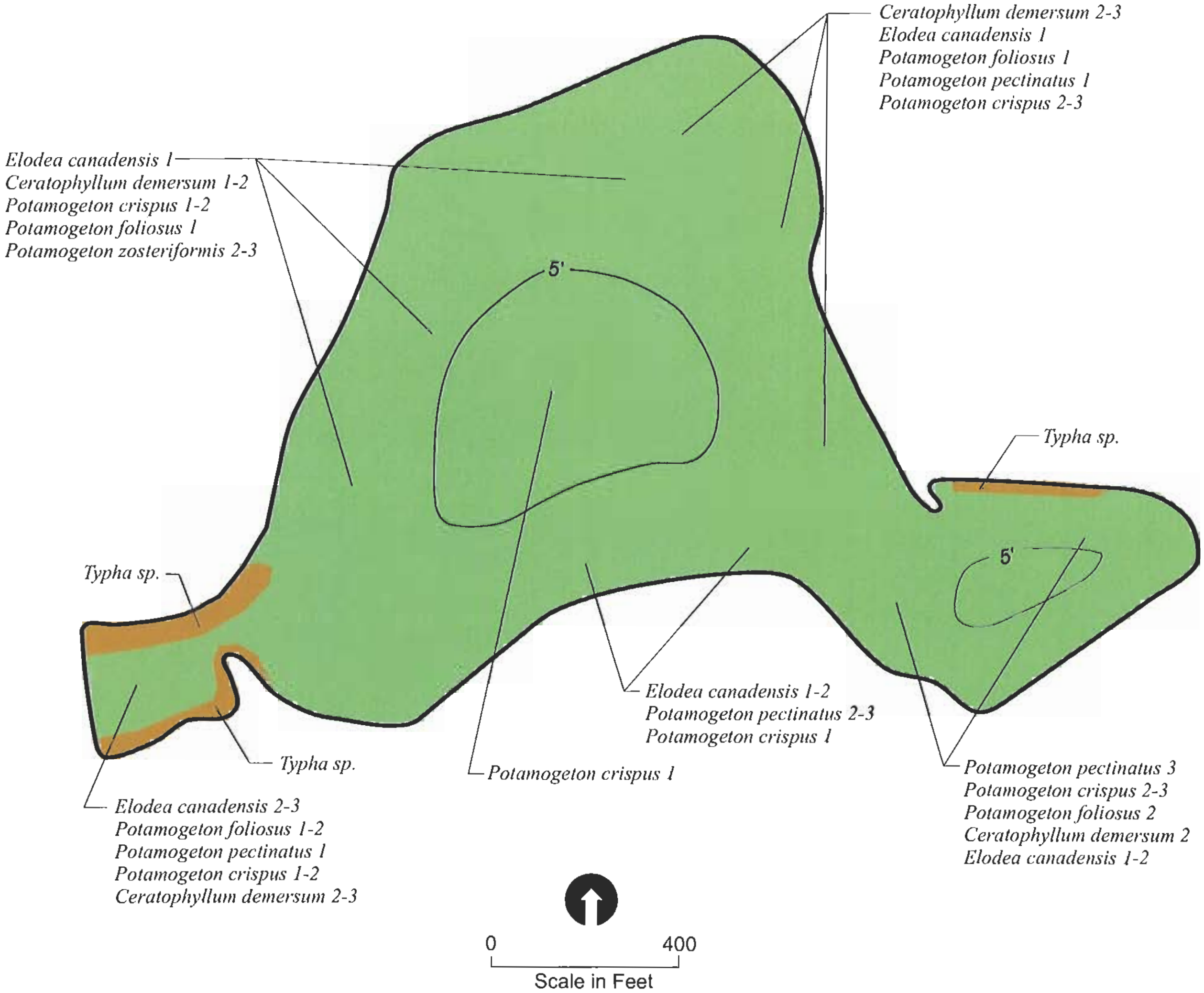

- Macrophytes Found Throughout Entire Lake
- Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Curlyleaf pondweed	*Potamogeton crispus*
	Flatstem pondweed	*Potamogeton zosteriformis*
	Leafy pondweed	*Potamogeton foliosus*
	Sago Pondweed	*Potamogeton pectinatus*
	Coontail	*Ceratophyllum demersum*
	Elodea	*Elodea canadensis*
Floating Leaf Plants:		
Emergent Plants:	Cattail	*Typha sp.*
No Aquatic Vegetation Found:		

Figure 21

DUCK LAKE
MACROPHYTE SURVEY
JUNE 20, 1996

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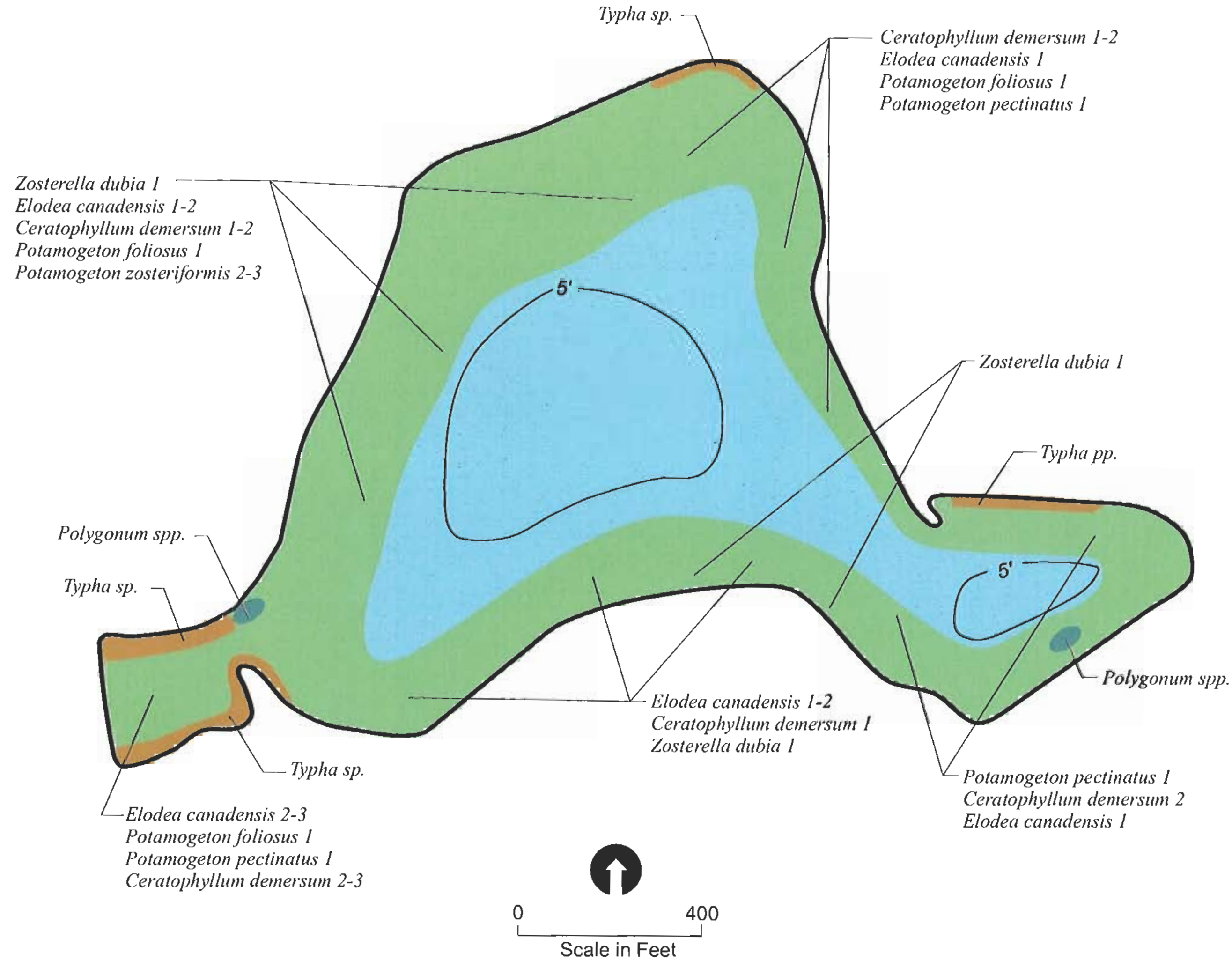

- No Macrophytes Found in Water >3.0' - 4.0'
- Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy
- Young Stalks of *Potamogeton crispus* (Curlyleaf pondweed) Growing from Nodes, Observed in Shallow Areas Around Lake (not shown on above map)

	Common Name	Scientific Name
Submerged Aquatic Plants:	Flatstem pondweed	*Potamogeton zosteriformis*
	Leafy pondweed	*Potamogeton foliosus*
	Sago Pondweed	*Potamogeton pectinatus*
	Coontail	*Ceratophyllum demersum*
	Elodea	*Elodea canadenis*
	Water stargrass	*Zosterella dubia*
	Curlyleaf pondweed	*Potamogeton crispus*
Floating Leaf Plants:	Water smartweed	*Polygonum spp.*
Emergent Plants:	Cattail	*Typha sp.*
No Aquatic Vegetation Found:		

Figure 22

DUCK LAKE
MACROPHYTE SURVEY
AUGUST 22, 1996

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Native plants that grow from seed in the spring are unable to grow in areas already occupied by curlyleaf pondweed, and are displaced by this plant. Curlyleaf pondweed die-off in early-summer releases phosphorus to the lake, thus supporting algal growth for the remainder of the summer.

Shading from increased algal growth severely limited macrophyte growth in Duck Lake for the remainder of the summer. Hence, a reduction in macrophyte coverage was observed in August. In June, macrophytes grew throughout the lake (to depths just over 8 feet). In August, macrophyte growth was limited to a small near-shore area along the lake's periphery (to depths of approximately 2 feet). Algal shading caused the die-off of two native species of pondweed, leafy pondweed (*Potamogeton foliosus*) and sago pondweed (*Potamogeton pectinatus*). They were present in June and absent in August. In late summer, algal shading led to a reduction in native aquatic plant species such as elodea (*Elodea canadensis*), flat-stem pondweed (*Potamogeton zosteriformis*), and coontail (*Ceratophyllum demersum*). They were present throughout the lake in June, but their presence was greatly reduced in August.

Curlyleaf pondweed was the dominant species during June, but died off in early summer. During August, young curlyleaf pondweed plants growing from turions were observed floating throughout the lake. The curlyleaf pondweed die-off in early summer released phosphorus to the lake and further exacerbated the lake's algal blooms.

Management of curlyleaf pondweed is recommended to protect the lake's water quality and native plant community and to improve the lake's fishery. Reduction of the lake's phosphorus concentration is recommended to reduce algal growth and improve water clarity. Improved water clarity is needed to prevent a die-off of some native plant species and a reduction in other native plant species during the summer.

During August of 2002, the non-native emergent plant, purple loosestrife (*Lythrum salicaria*), was observed along the lake's western shoreline. Purple loosestrife was not observed along Duck Lake's shoreline prior to August of 2002. Purple loosestrife, an emergent plant, is native to Europe and the temperate regions of Asia (see Figure 23). Once introduced into an area, the plant typically replaces native vegetation and rapidly becomes the sole emergent species. Management of purple loosestrife is recommended to protect the quality of vegetation along the lake's shoreline.

Figure 23 Purple Loosestrife (*Lythrum salicaria*)

1.5 Water Based Recreation

Duck Lake is primarily used for canoeing, sailing, fishing, and aesthetic viewing. The City of Eden Prairie installed five parking spaces along Duck Lake Trail on the north side of the lake and placed a no motor restriction on the lake in 1996. The paved trail to the lake shore limits boats to carry-on access. The trail provides handicap accessibility to the waters edge. Presently, kids fish on a narrow strip of land between the lake and Duck Lake Road (MDNR, 1998).

1.6 Fish and Wildlife Habitat

The MDNR has developed a classification system for Minnesota lakes relative to the chemical and physical properties of each lake class and the fishery that is supported by each lake (Schupp, 1992). According to its ecological classification, Duck Lake is a Class 40 lake. Class 40 lakes are typically shallow and productive lakes with fish assemblages that include perch, bluegills, walleye, bullhead, carp, northern pike, and crappie (Schupp, 1992). The MDNR has indicated that the average water quality for the ecological class of Duck Lake is a TSI_{SD} (Trophic State Index in terms of Secchi disc transparency) of approximately 54.5 or lower (i.e., a summer average Secchi disc transparency of about 4.8 feet or greater). The recommendation is based upon the water quality needs of the fishery found in a Class 40 lake. Duck Lake's water quality does not meet this recommendation based upon the 2002 data. The lake's current water quality (monitoring year 2002) corresponds to a TSI_{SD} of 63 (a summer average Secchi disc of approximately 2.6 feet). Duck Lake did not meet the TSI_{SD} goal during the 1971 through 2002 monitoring period (TSI_{SD} ranged from 57 to 73).

Duck Lake's fishery currently (1996) consists of panfish and rough fish. The 1996 MDNR fish survey showed that the following species are present in Duck Lake:

- **Panfish**—black crappie and bluegill

Black Crappie

Bluegill

- **Rough fish**—black bullhead.

Black Bullhead

According to the 1996 survey (MDNR, 1996), black bullheads dominate the lake's fish community. Two hundred eighty four black bullheads ranging in length from 7.4 to 10.3 inches were sampled. Panfish sampled included twenty two black crappies averaging slightly over 6.0 inches in length and two bluegills (4.8 and 5.3 inches in length). Area residents have indicated periodic winterkills have severely limited the lake's fishery (MDNR, 1996).

The MDNR has prepared a fisheries management plan for Duck Lake. According to the plan, the MDNR will:

1. Monitor winter oxygen levels in cooperation with Eden Prairie Parks and Recreation;
2. Stock 10 largemouth bass, 10 black crappie, and 10 bluegill adults following a severe winterkill that is expected to occur on average once in 10 to 20 years. The stocking will occur in spring and will provide brood stock.
3. Issue a stocking permit to the lake association to purchase these species if they prefer fish to be stocked more frequently

The MDNR long range goal for the lake is to employ winterkill and periodic stocking as tools to produce occasional good fishing capable of supporting 0 to 50 angler hours per acre. The mid-range objective is to maintain the present level of fishing pressure. The MDNR has recommended installation of a fishing pier on Duck Lake.

Duck Lake provides good habitat for waterfowl such as ducks and geese. MDNR staff reported that a considerable number of waterfowl were seen during the lake's 1996 fish survey (MDNR, 1996).

1.7 Discharges

1.7.1 Natural Conveyance Systems

The natural inflow to Duck Lake consists of direct runoff from the land surrounding the lake and groundwater inflows. All other discharges to the lake are through piped inlets.

1.7.2 Stormwater Conveyance Systems

Stormwater is conveyed from residential neighborhoods surrounding Duck Lake. Figure 1 shows the stormwater conveyance systems. Although most stormwater enters the lake untreated, stormwater in subwatershed DL3 (see Figure 1) is treated by a pond before it is conveyed to Duck Lake. Details of the stormwater treatment pond are provided in Appendix A. A second stormwater detention pond located in subwatershed DL7 (see Figure 1) does not contribute runoff to Duck Lake. The pond does not have an outlet and all the stormwater is infiltrated or evaporated.

1.7.3 Public Ditch Systems

There are no public ditch systems that affect Duck Lake.

1.8 Appropriations

There are no known water appropriations from Duck Lake.

1.9 Summary of Surface Water Resource Data

The current water quality and ecological status of Duck Lake is largely the result of past activities in the Duck Lake watershed. Because the size of the watershed is small relative to the size of Duck Lake, the highly eutrophic status of the lake is the result of historical sediment loading rather than from watershed stormwater runoff. A historical aerial photo of the lake (Figure 2) shows that the watershed of the lake in 1947 primarily consisted of agricultural lands that drained to the lake. Agricultural sediment can be high in nutrients. The concentration of phosphorus in the lake sediments that can release into the water column (i.e. mobile phosphorus) of Duck Lake is relatively high (Figure 24) and corresponds to a potential phosphorus release rate of approximately 2.1 mg per square meter of lake surface per day.

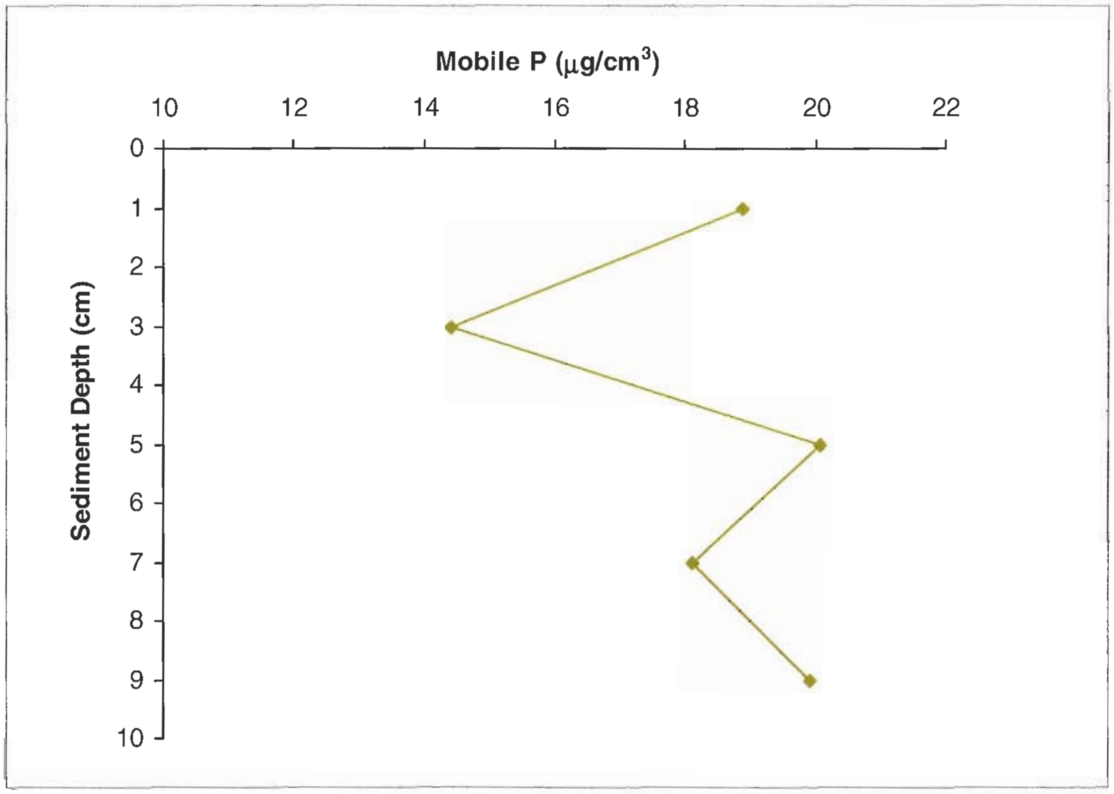


Figure 24 Distribution of Potentially Releasable Phosphorus in Duck Lake Sediment

Currently, the ecology of Duck Lake is being driven by the lake's fertile sediments, although curlyleaf pondweed (*Potamogeton crispus*) also plays a role. Curlyleaf pondweed covers the entire surface of the lake in June and then dies off in early-summer. The rapid growth has the effect of increasing the pH of the lake to very high levels. When curlyleaf pondweed dies off it releases phosphorus into the lake. High pH (James, 2001) caused by the curlyleaf pondweed growth and die-off, as well as an increase in water temperature, also have the potential to enhance the release of phosphorus that is stored in lake sediments into the lake water column (oxic release of phosphorus). Anoxic conditions at the lake's sediment water interface facilitate the release of phosphorus that is stored in lake sediments into the water column (anoxic release of phosphorus). In mid-to late-summer there is a significant increase in phosphorus in the lake that can be primarily attributed to the release of phosphorus from lake sediments and partially attributed to the decay of curlyleaf pondweed. This increase in phosphorus is associated with mid-to late-summer algal blooms (Figure 25).

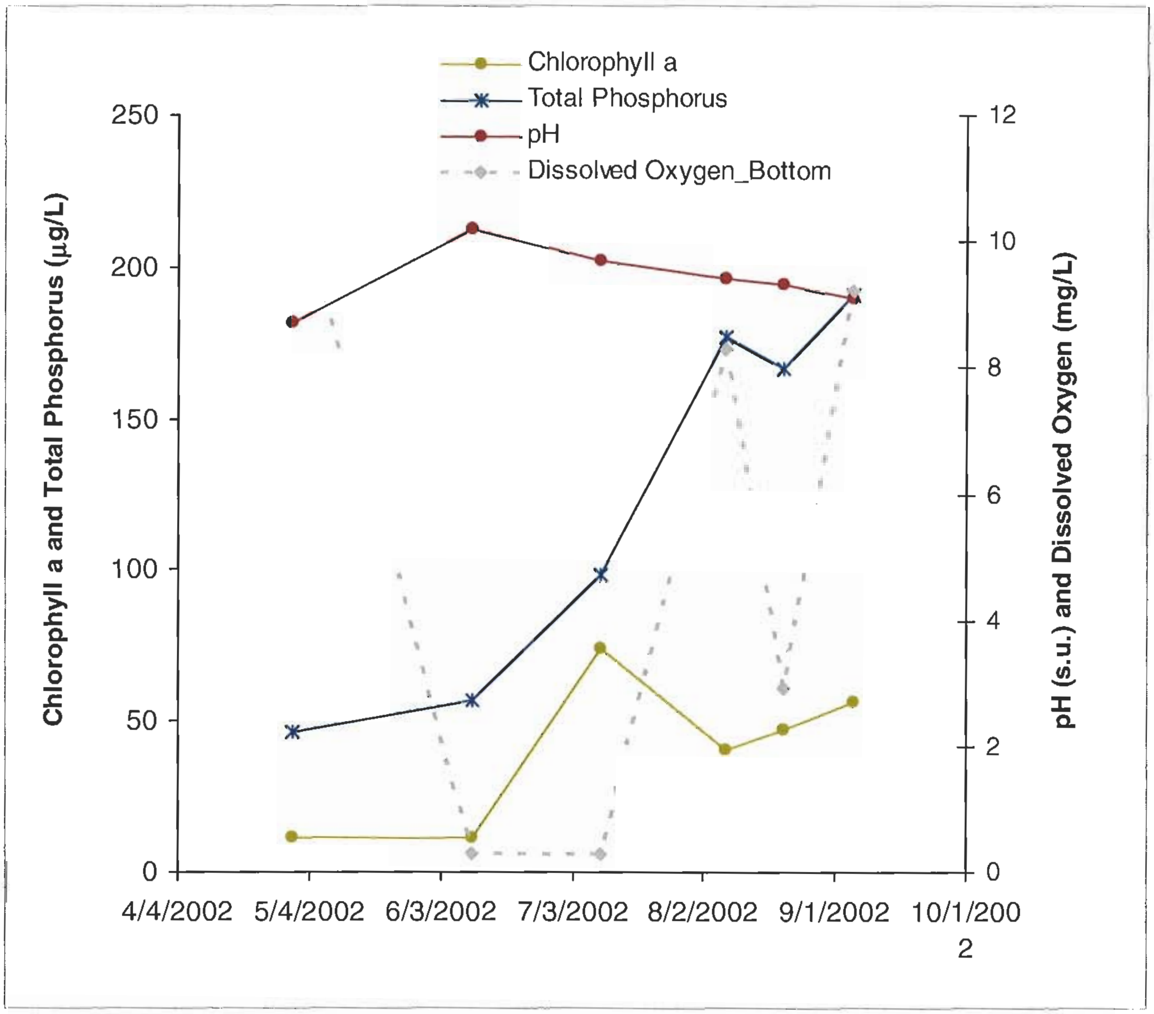


Figure 25 Seasonal Pattern of pH, Total Phosphorus, Temperature, and Chlorophyll *a* in Duck Lake

Figure 26 depicts the sources of the lake's phosphorus concentrations measured during 2002 (calibration year) as determined from in-lake modeling of Duck Lake. The lake's phosphorus content during spring was the primary source of phosphorus through mid-June. For the remainder of the summer, the lake's fertile sediments were the primary source of phosphorus. Stormwater runoff contributed to the lake's phosphorus content (from 24 to 41 percent), but played a lesser role than the lake's spring concentration and internal processes. Internal processes began contributing phosphorus to the lake during June and apparently were the source of approximately one third of the lake's phosphorus concentration during July and nearly two thirds of the lake's phosphorus concentration during August through September. Most of the lake's internal phosphorus load resulted from sediment phosphorus release. However, curlyleaf pondweed decay was the source of from 9 to 12 percent of the lake's phosphorus load during August and September.

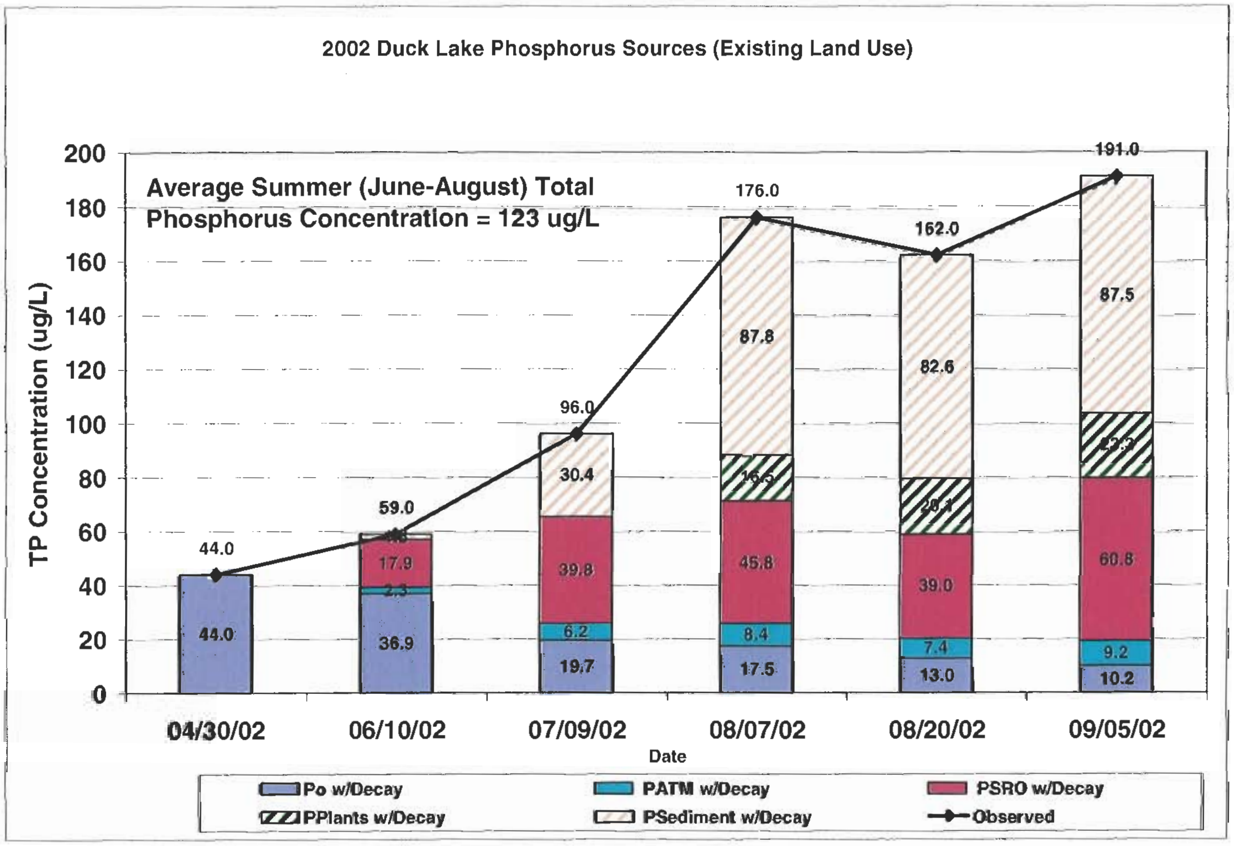


Figure 26 2002 Duck Lake Phosphorus Sources

Key to Figure 26 Legend:

P_0 w/decay = The lake's epilimnetic phosphorus concentration following ice-out in April is the starting phosphorus concentration. Most of the phosphorus present in April left the lake through its outlet during the growing season (meaning of w/decay).

PPlants w/Decay = The fraction of the lake's epilimnetic phosphorus concentration resulting from decay of curlyleaf pondweed plants. A portion of this phosphorus load left the lake through its outlet during the growing season (w/decay).

PATM w/Decay = The fraction of the lake's epilimnetic phosphorus concentration resulting from atmospheric deposition. A portion of this phosphorus load left the lake through its outlet during the growing season (w/decay)

P Sediment w/Decay = The fraction of the lake's epilimnetic phosphorus concentration resulting from sediment release of phosphorus. A portion of this phosphorus load left the lake through its outlet during the growing season (w/decay).

PSRO w/Decay = The fraction of the lake's epilimnetic phosphorus concentration resulting from stormwater runoff. A portion of this phosphorus load left the lake through its outlet during the growing season (w/decay).

Poxic/settle/w/Decay = The fraction of the lake's epilimnetic phosphorus concentration resulting from sediment phosphorus release under oxic conditions. A portion of this load left the lake through its outlet during the growing season (w/decay).

Observed = epilimnetic total phosphorus concentrations measured during 2002

2.0 Assessment of Duck Lake Problems

2.1 Appropriations

There are no known water appropriations from Duck Lake.

2.2 Discharges

The model P8 (IEP Inc., 1990) was used to determine the water and phosphorus loading to Duck Lake from the land surrounding the lake and from conveyed stormwater discharges to the lake (parameters used in the P8 model are presented in Appendix D). Although the discharge of stormwater from the Duck Lake watershed conveys phosphorus to the lake and contributes to the level of phosphorus in the lake, these discharges are not the cause of high phosphorus levels that are observed in Duck Lake. Details of the phosphorus discharges to the lake are provided below.

2.2.1 Natural Conveyance Systems

Natural conveyance systems contribute stormwater to Duck Lake from the land that surrounds the lake. There are no other natural conveyances to Duck Lake such as streams.

2.2.1.1 Direct Watershed

The Duck Lake direct watershed is the land that surrounds the lake. There is no treatment of this runoff. Phosphorus loading from this watershed area was modeled using three climatic conditions:

- **Wet Year**: annual precipitation of 41 inches, the amount of precipitation that occurred during the 2002 water year.
- **Average Year**: annual precipitation of 34 inches, the amount of precipitation that occurred during the 1999 water year
- **Dry Year**: annual precipitation of 24 inches, the amount of precipitation that occurred during the 2000 water year

Loading from the direct watershed to Duck Lake is low and is expected to range from 2.3 to 10.1 pounds per year under existing land uses and from 6.0 to 13.7 pounds per year for future land uses (Table 3). Currently loading from the direct watershed represents approximately 1.7 to 5.5 percent of the total annual phosphorus load to Duck Lake. Under future land use, loading from the direct watershed is estimated to represent approximately 4.0 to 7.2 percent of the total annual phosphorus load to Duck Lake.

Table 3 Estimated Annual Total Phosphorus Loads from the Duck Lake Direct Watershed for Existing and Future Land Uses

Climate Condition (Inches of Precipitation)	Annual Total Phosphorus Load From Direct Watershed (Pounds)	% of Total Annual Duck Lake Total Phosphorus Load
Existing Land Use		
Model Calibration/Wet (41")	10.1	5.5
Average (34")	3.2	2.1
Dry (24")	2.3	1.7
Future Land Use		
Model Calibration/Wet (41")	13.7	7.2
Average (34")	7.8	4.9
Dry (24")	6.0	4.0

2.2.2 Stormwater Conveyance Systems

The annual phosphorus load from all stormwater conveyance systems to Duck Lake (Table 4) under wet, average, and dry conditions (under existing watershed land use) was 37, 29, and 23 percent of all phosphorus loads to the lake (all phosphorus loads include both external and internal phosphorus loads). Under future watershed land use conditions, the annual phosphorus load from all stormwater conveyance systems to Duck Lake is expected to be 38, 30, and 26 percent under wet, average, and dry conditions.

Table 4 Estimated Total Phosphorus Loads from All Duck Lake Stormwater Conveyance Systems Under Varying Climatic Conditions—Existing and Future Land Use

Climate Condition (inches of precipitation)	Annual Total Phosphorus Load From All Conveyance Systems (Pounds)	% of Annual Duck Lake Total Phosphorus Load
Existing Land Use		
Wet (41")	68	37
Average (34")	43	29
Model Calibration/Dry (24")	32	23
Future Land Use		
Wet (41")	72	38
Average (34")	48	30
Model Calibration/Dry (24")	39	26

Phosphorus loading to the lake from storm water runoff is primarily coming from the S-2, S-3, and S-8 storm sewer outlets (Table 5). These three storm sewer outlets contribute nearly three-fourths of the stormwater conveyance system total phosphorus load to Duck Lake. More than half of the Duck Lake watershed (see Figure 1) drains to these three storm sewer outlets.

Table 5 Estimated Total Phosphorus Loading From Each Stormwater Conveyance System to Duck Lake

Stormwater Conveyance System	Annual Total Phosphorus Load in Pounds		
	Wet (41")	Model Calibration/Average (34")	Dry (24")
Existing Land Use			
S-1	3.8	2.6	2.0
S-2	22.0	13.3	10.0
S-3	8.5	6.9	5.1
S-4	4.3	3.2	2.4
S-5	2.9	2.4	1.8
S-6	2.8	1.7	1.3
S-7	2.4	1.3	1.0
S-8	18.7	10.2	7.7
S-9	1.2	0.7	0.5
S-10	1.2	0.6	0.4
Future Land Use			
S-1	3.7	2.5	2.0
S-2	24.0	15.7	12.9
S-3	9.1	7.3	6.0
S-4	4.6	3.7	2.9
S-5	3.7	3.0	2.5
S-6	2.9	1.9	1.6
S-7	2.4	1.5	1.2
S-8	19.0	11.2	9.2
S-9	1.2	0.7	0.5
S-10	1.3	0.7	0.5

Approximately 98 percent of the stormwater entering Duck Lake from its stormwater conveyance system receives no treatment. One pond, P-3, treats runoff from subwatershed DL3 (see Figure 1). The treatment effectiveness of detention pond P-3 was determined for wet, average, and dry conditions under existing watershed land use. Total phosphorus removal ranged from 40 percent during dry conditions to 30 percent during wet conditions (Table 6). Loading from pond P-3 represents approximately 0.4 to 0.7 percent of the total annual phosphorus load to Duck Lake.

Table 6 Estimated Total Phosphorus Removal Efficiency of Detention Pond P-3 in the Duck Lake Watershed Under Existing Land Use Conditions and Varying Climatic Conditions

Stormwater Conveyance System	Pond Name	Total Phosphorus Removal Efficiency (%)		
		Wet (41")	Average (34")	Dry (24")
S-9	P-3	30	37	40

2.2.3 Public Ditch Systems

There are no known ditch systems affecting Duck Lake.

2.3 Fish and Wildlife Habitat

The MDNR has established criteria for the support of Duck Lake's fishery, based upon Duck Lake's classification as a Class 40 lake. The current habitat for Duck Lake fails to meet WDNR criteria of a TSI_{SD} of 54.5 or lower (a summer average Secchi disc transparency of at least 4.8 feet). The lake's poor transparency is caused by algal blooms, which result from excessive phosphorus.

2.4 Water Based Recreation

The recreational uses of Duck Lake include fishing, canoeing, sailing, and aesthetic viewing. These uses are currently being impaired by curlyleaf pondweed growth and algal blooms.

2.5 Ecosystem Data

Development of a more balanced ecosystem at Duck Lake is needed for the lake to achieve the recreation, aquatic communities, and water quality goals that have been set for the lake. There are two primary imbalances in Duck Lake: (1) problematic growths of curlyleaf pondweed, and (2) high phosphorus levels that result in severe summer algal blooms.

It appears that Duck Lake's zooplankton population is generally well balanced. However, an imbalance in zooplankton sizes occurs each summer when numbers of large-bodied Cladocera (see Figure 10) decrease and numbers of small-bodied Cladocera (see Figure 11) increase. Fish predation causes the decrease in numbers of large-bodied Cladocera. The changes in the Cladocera community (decreased sizes) together with changes in the algal community (increased sizes) each summer prevent the zooplankton from exerting biological control on the lake's algal community. Hence, reduction of phosphorus is necessary to reduce algal blooms and improve the lake's water quality.

Periodic winterkills severely limit the lake's fishery. According to a 1996 MDNR fish survey, the existing fish population at Duck Lake is dominated by black bullhead. The fish community also includes black crappie and bluegills.

2.6 Water Quality

2.6.1 Baseline/Current Analysis

Evaluation of the baseline and current trophic state index (TSI) of Duck Lake shows that the lake consistently has not met the MDNR-criteria ($TSI_{SD} \leq 54.5$) for the lake's fishery during the baseline and the current periods (Figure 27).

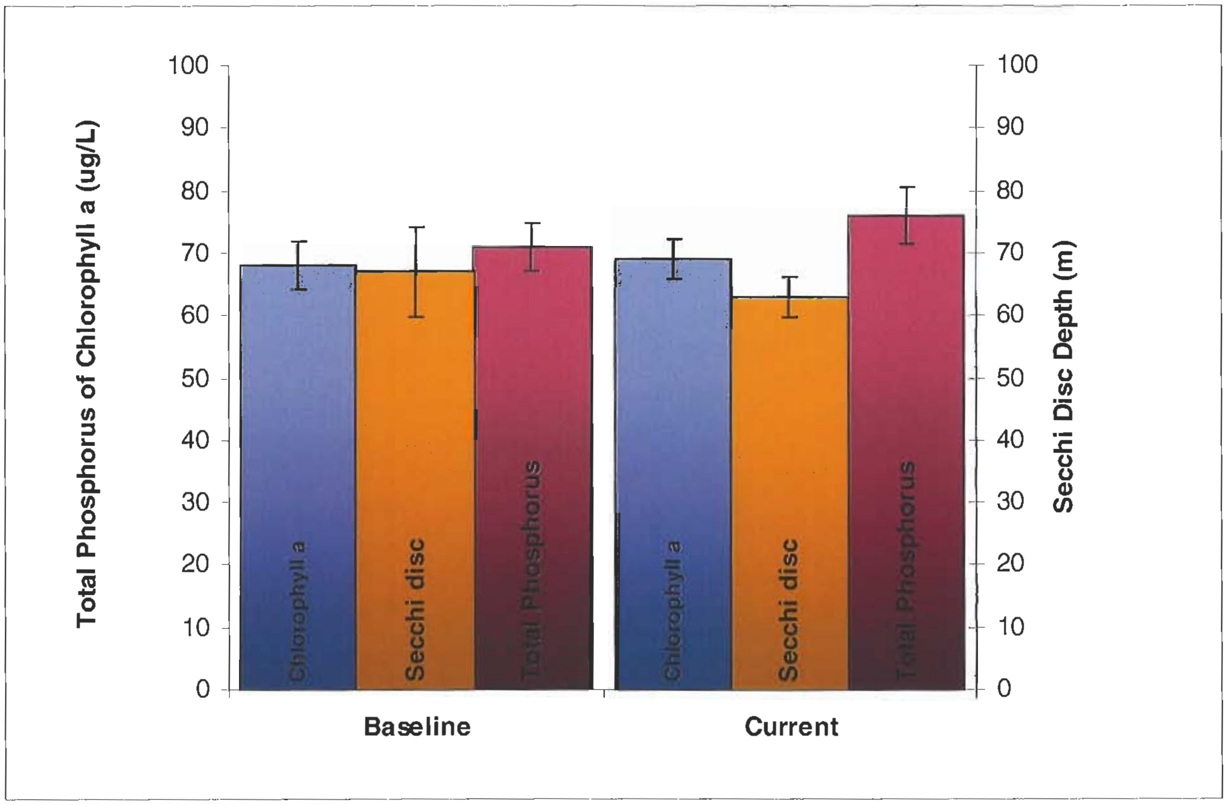
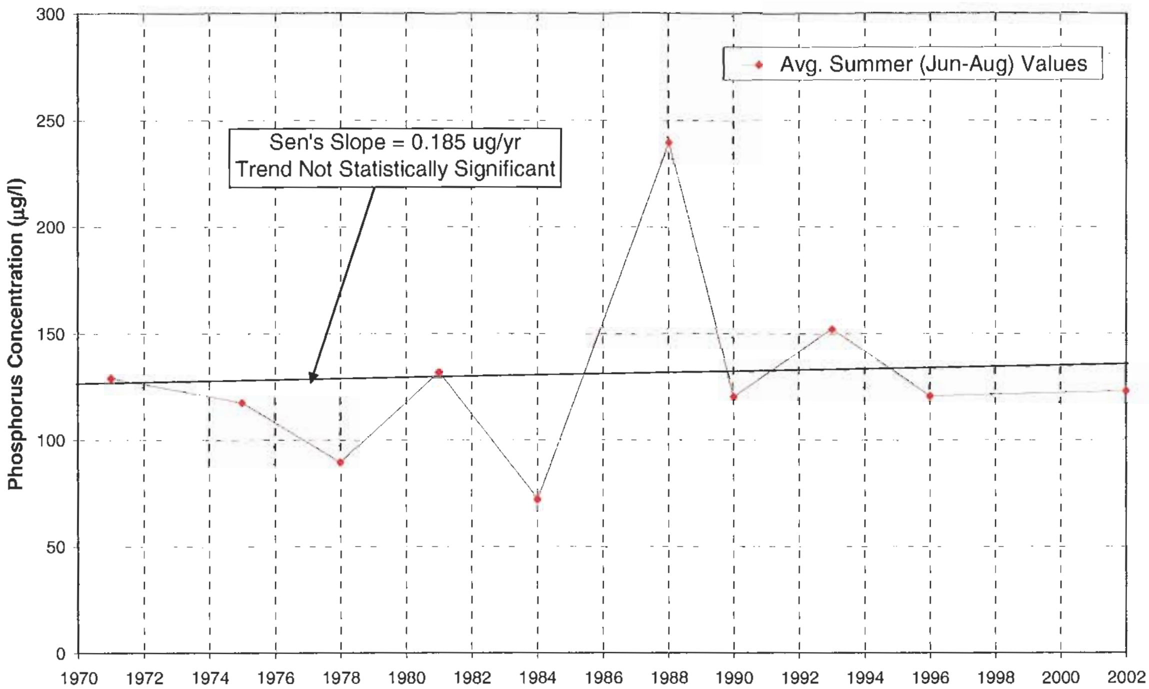


Figure 27 Baseline and Current Trophic State Index (TSI) for Duck Lake

2.6.2 Historical Water Quality-Trend Analysis

A trend analysis for Duck Lake was completed to identify any significant degradation or improvement during years in which water quality data were available. Although there have been fluctuations in phosphorus levels, chlorophyll *a* levels, and in lake clarity, it appears that over time the water quality of the lake has remained relatively stable and changes in phosphorus, chlorophyll *a*, and Secchi disc have not been statistically significant (see statistical analysis below in Figures 28, 29, and 30).

Duck Lake Trend Analysis
Total Phosphorus (µg/l)

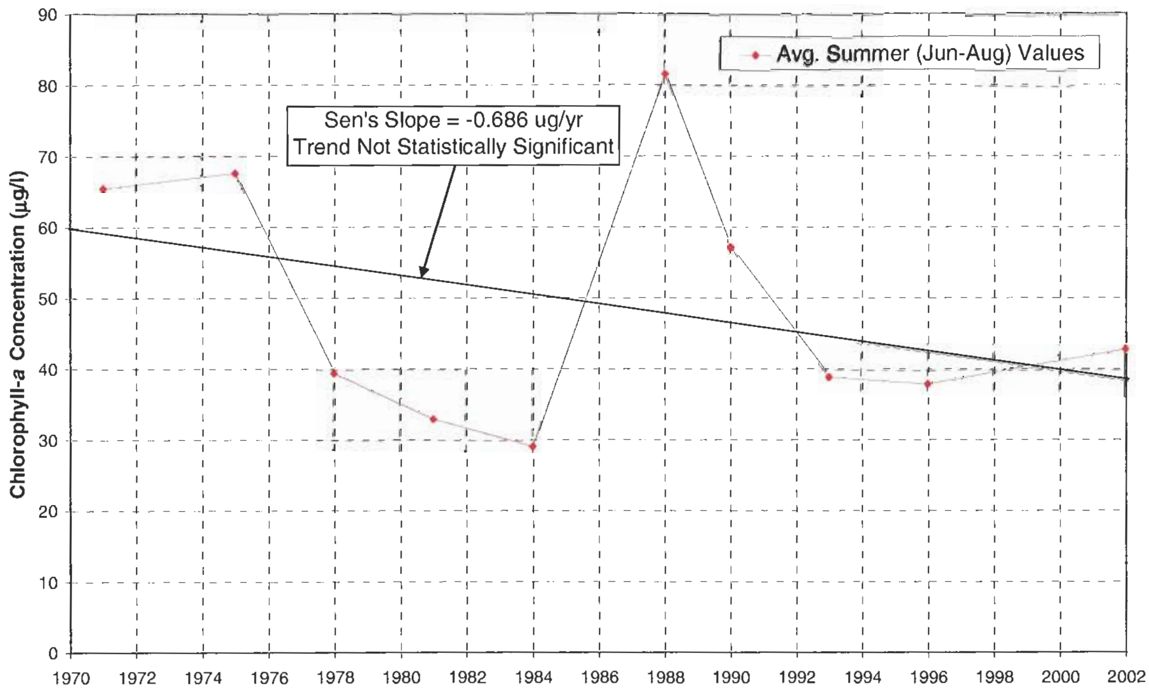


Mann-Kendall/Sen's Slope Trend Test

Confidence Level	Test Statistic = 6	
	Test	Significance
99%	6 < 30	Not Significant
95%	6 < 23	Not Significant
90%	6 < 20	Not Significant
80%	6 < 16	Not Significant
Sen's Slope	0.185 µg/year	

Figure 28 Mann-Kendall Trend Analysis of Total Phosphorus Concentration since 1971 for Duck Lake

Duck Lake Trend Analysis
Chlorophyll-*a* (µg/l)

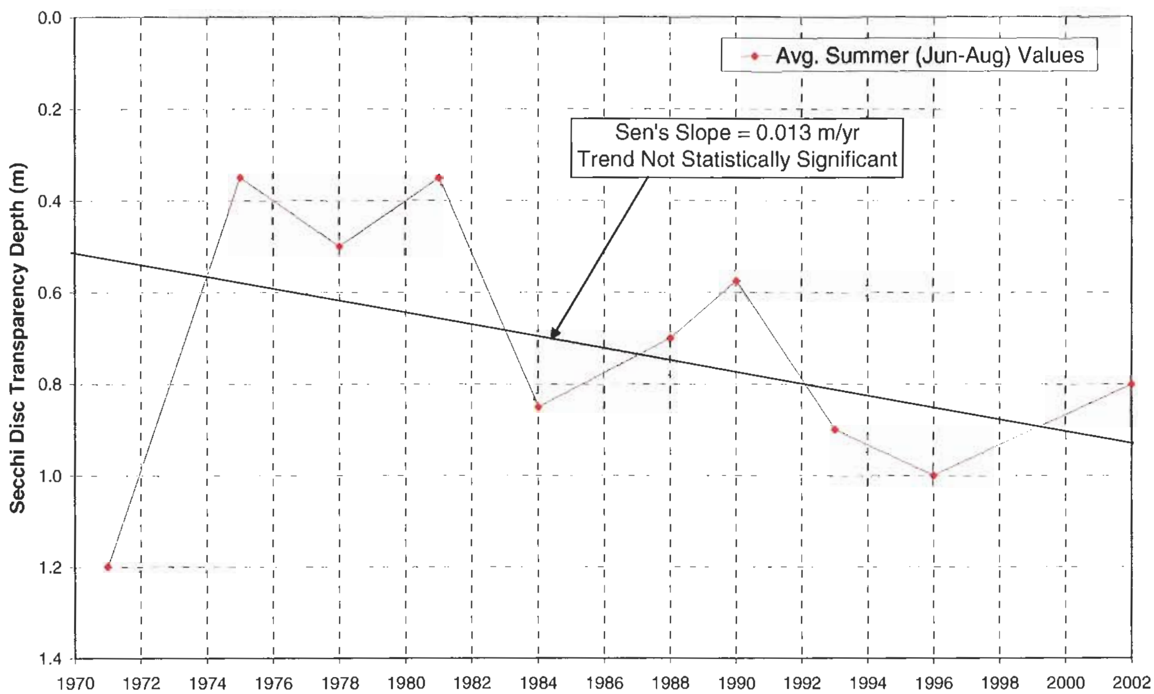


Mann-Kendall/Sen's Slope Trend Test

Confidence Level	Test Statistic = -9	
	Test	Significance
99%	-9 > -30	Not Significant
95%	-9 > -23	Not Significant
90%	-9 > -20	Not Significant
80%	-9 > -16	Not Significant
Sen's Slope	-0.686 µg/year	

Figure 29 Mann-Kendall Trend Analysis of Chlorophyll-*a* Concentration Since 1971 for Duck Lake

Duck Lake Trend Analysis
Secchi Disc (m)



Mann-Kendall/Sen's Slope Trend Test

Confidence Level	Test Statistic = 11	
	Test	Significance
99%	11 < 30	Not Significant
95%	11 < 23	Not Significant
90%	11 < 20	Not Significant
80%	11 < 16	Not Significant
Sen's Slope	0.013 meters/year	

Figure 30 Mann-Kendall Trend Analysis of Secchi Disc Transparency Depth Since 1971 for Duck Lake

2.6.3 Water Quality Modeling Analysis

Water quality modeling was performed to better understand the phosphorus dynamics in the Duck Lake watershed and in Duck Lake, and to understand how phosphorus loading is affecting algal growth in the lake. Watershed modeling, which includes both hydrologic and phosphorus loading, was performed using the P8 (IEP, Inc., 1990) model. In-lake models (Dillon and Rigler, 1974; WDNR, 1997; Thomann and Mueller, 1987; and Barr, 2004) were used to determine how external and internal phosphorus loading (loading within the lake) lead to the observed levels of phosphorus in Duck Lake. Internal loading was divided into two sources: aquatic plants (curlyleaf pondweed die-off) and sediment.

Modeling was performed for three climatic conditions (dry, average, and wet year) and different management efforts to determine the potential effect of these management activities on phosphorus levels in Duck Lake. A regression between phosphorus levels in Duck Lake and Secchi disc transparency was developed from historical monitoring data (1971 to 2002) and was used to predict expected lake clarity improvements (Secchi disc transparency) with different management activities. A detailed description of model development, calibration, and validation is provided in Appendix A.

2.7 Major Hydrologic Characteristics

The major hydrologic characteristics of Duck Lake have changed as the watershed has changed from primarily agricultural to a mixture of park land and residential neighborhoods. Although the watershed is nearly fully developed, some additional development will occur to attain proposed future watershed land use conditions. Park and open spaces will decline and residential, institutional, and highway areas will increase. Following these land use changes, the lake's annual water load is expected to increase by about 3 to 8 percent under proposed future watershed land use conditions.

2.8 Land Use Assessment

Land use in the watershed has changed from the predevelopment period. The watershed's land use changed from wooded to agriculture to urbanized. Watershed urbanization is nearly complete. However, some additional development will occur to attain proposed future watershed land use conditions. The lake's annual phosphorus load is expected to increase by about 4 to 7 percent under proposed future watershed land use conditions. It is recommended that management practices be considered to minimize phosphorus loading increases to the greatest extent possible.

3.0 Duck Lake Goals

3.1 Water Quantity Goal

The water quantity goal for Duck Lake is to provide sufficient water storage during a regional flood. The water quantity goal has been achieved and no action is required.

3.2 Water Quality Goal

The water quality goal of Duck Lake is predicated on the lake's recreational goal. The goal is to achieve a water quality that will fully support the lake's use as a fishery. The District goal is a $TSI_{SD} \leq 54.5$. Table 7 shows that the water quality goal is currently not being achieved. Two lake improvement alternatives will approach but not achieve the District goal for Duck Lake. Because the District goal cannot be attained, it is proposed that the District change the lake's goal. The proposed goal for Duck Lake is based upon the MPCA standard for shallow lakes (proposed changes to Minnesota Rules Chapter 7050.0222, Subp. 4. Class 2B Waters). The second alternative will achieve the MPCA total phosphorus and Secchi disc transparency standards applicable to Duck Lake. The alternatives are:

- WQ-1: Herbicide (Endothall) treatment and alum treatment,
- WQ-2: Herbicide (Endothall) treatment, alum treatment, and rainwater gardens.

The expected benefit of each action is presented in Table 7 and the expected cost of each action is presented in Figure 31. For each alternative to be successful, the prescribed management activities must follow a particular sequence. Herbicide treatment should be performed for a minimum of two years before the alum treatment is completed.

Evaluation of the results of the herbicide treatment and alum treatment are recommended before construction of rainwater gardens. The evaluation will (1) determine benefits of the herbicide and alum treatments; (2) determine whether rainwater garden construction is needed; and (3) if rainwater garden construction is needed, determine whether any warranted changes in the number of rainwater gardens are required to attain the proposed District goal.

Table 7 **Expected Water Quality with Water Quality Management Alternatives**

Management Alternative	Trophic State Index (TSI_{SD}) Value				
	Current District Goal	Proposed District Goal Based Upon MPCA Standard	Dry Year 2000 (24 inches of precipitation)	Average Year 1999 (34 inches of precipitation)	Wet Year 2002 (41 inches of precipitation)
Existing Land Use					
No Action	≤54.5	≤57.7	65.7	64.9	64.9
Herbicide Treatment (4 years) and Alum Treatment (1 year)	≤54.5	≤57.7	58.1	58.2	59.3
Herbicide Treatment (4 years) and Alum Treatment (1 year) and 50 Rain Water Gardens	≤54.5	≤57.7	55.7	56.0	57.1
Future Land Use					
No Action	≤54.5	≤57.7	67.5	65.9	65.3
Herbicide Treatment (4 years) and Alum Treatment (1 year)	≤54.5	≤57.7	59.9	58.7	59.6
Herbicide Treatment (4 years) and Alum Treatment (1 year) and 50 Rain Water Gardens	≤54.5	≤57.7	56.4	57.1	57.0

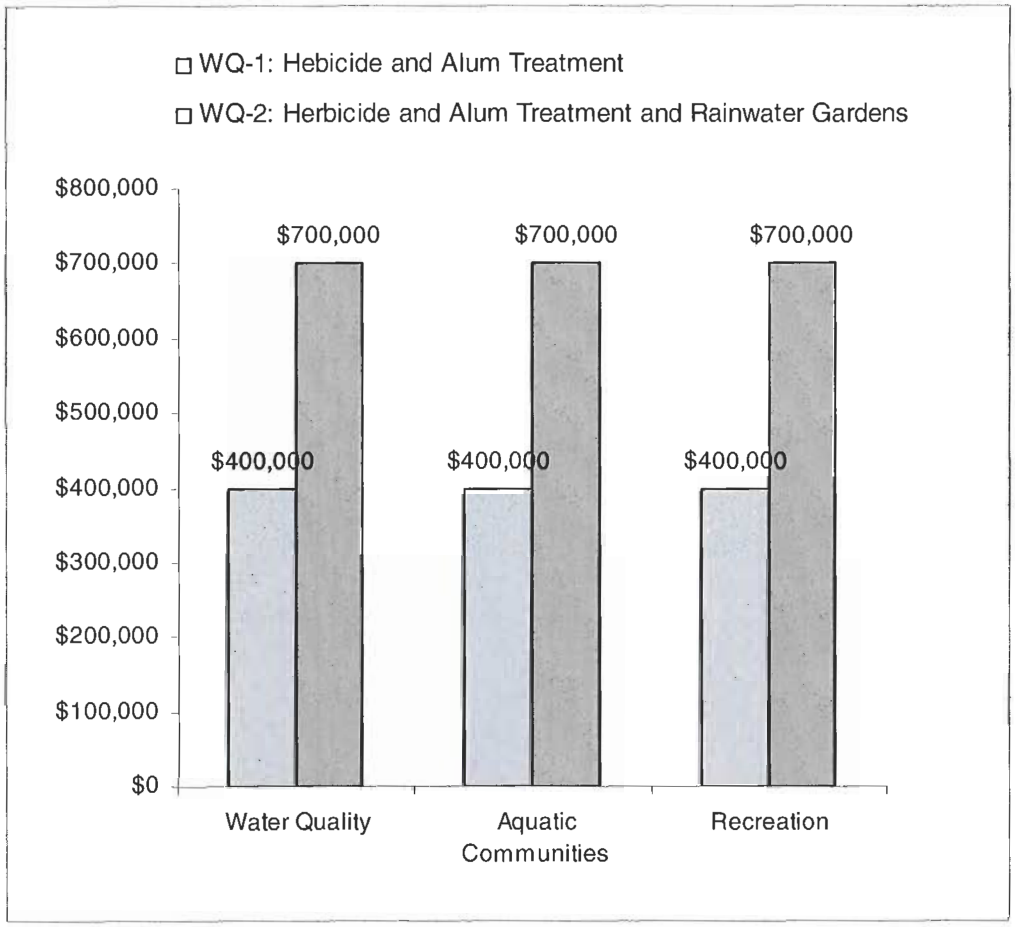


Figure 31 Cost of the Water Quality Management Alternatives

3.3 Aquatic Communities Goal

The aquatic communities goal for Duck Lake is the achievement and maintenance of a water quality that fully supports the lake's fisheries-use classification as determined by the MDNR (Schupp, 1992). The goal is to maintain a $TSI_{SD} \leq 54.5$. From the perspective of the TSI_{SD} goal and the problems with excessive blue-green algae growth, the lake's current water quality does not provide the desired habitat for the lake's fishery. The two alternatives presented in Table 7 will approach but not achieve the District goal for Duck Lake. Because the District goal cannot be attained, it is proposed that the District change the lake's goal. The proposed goal for Duck Lake is based upon the MPCA standard for shallow lakes (proposed changes to Minnesota Rules Chapter 7050.0222, Subp. 4. Class 2B Waters). The second alternative will achieve the MPCA total phosphorus and Secchi disc transparency standards applicable to Duck Lake. The costs to implement the management alternatives are presented in Figure 31.

3.4 Recreation Goal

Because Duck Lake has not been designated a swimming lake by the Riley-Purgatory-Bluff Creek Watershed District, the recreational goal is to fully support the lake's fishery and maintain a $TSI_{SD} \leq 54.5$. From the perspective of the TSI_{SD} goal and the problems with excessive blue-green algae growth, the recreation goal is currently not being achieved. The two alternatives presented in Table 7 will approach but not achieve the District goal for Duck Lake. Because the District goal cannot be attained, it is proposed that the District change the lake's goal. The proposed goal for Duck Lake is based upon the MPCA standard for shallow lakes (proposed changes to Minnesota Rules Chapter 7050.0222, Subp. 4. Class 2B Waters). The second alternative will achieve the MPCA total phosphorus and Secchi disc transparency standards applicable to Duck Lake. The costs to implement the management alternatives are presented in Figure 31.

3.5 Wildlife Goal

The wildlife goal for Duck Lake is to protect existing, beneficial wildlife uses. The wildlife goal has been achieved.

3.6 Public Participation

The public participation goal is to encourage public participation as part of the use attainability analysis. This goal will be achieved through a public meeting to obtain comments on the use attainability analysis.

4.0 Selected Implementation Plan

4.1 Basis for Selected Implementation Plan

Duck Lake is a complex aquatic system. Any management action must be taken with consideration of how the different components of the ecosystem fit together. Monitoring data and modeling results have been used to better understand the ecology of Duck Lake and to estimate what the result may be from different management activities. The root of the imbalances that are observed at Duck Lake (excessive curlyleaf pondweed growth, blue-green algae blooms, and die-off of native pondweed species) is a high level of phosphorus. Although it may appear that the solution is to immediately reduce phosphorus levels, simply reducing phosphorus in a non-systematic manner may not lead to expected improvements and may have some unintended consequences.

The four primary sources of phosphorus inputs to Duck Lake are, in order of largest to smallest: release of phosphorus from lake sediments, aquatic plant senescence, stormwater inputs, and atmospheric deposition.

Curlyleaf pondweed, a nuisance non-native species, is presently found in Duck Lake. Improvement in the lake's water clarity is expected to increase light availability to the plants and may promote additional growth of curlyleaf pondweed. Failure to effectively manage curlyleaf pondweed before improving the lake's water clarity could result in additional coverage or density of this species. This plant grows quickly in the spring, extracts phosphorus from the sediments, and dies off in June, thus releasing phosphorus stored in plant tissue. Increased coverage or density of curlyleaf pondweed would contribute additional phosphorus to the lake. Consideration of curlyleaf pondweed indicates management of this plant should occur before completion of a lake alum treatment to manage phosphorus loads from the lake's sediments. Failure to follow this order during the implementation program could have the unintended consequences of additional problematic plant growths and a failure to attain water quality improvement goals. Management of curlyleaf pondweed should involve removing the species from Duck Lake so that native plants can replace them.

Management of curlyleaf pondweed is expected to attain a 7 percent reduction in the lake's average summer total phosphorus concentration under 2002 climatic conditions (wet) and existing land use. The lake's total phosphorus concentration is expected to be reduced from 123 μg/L to 115 μg/L following management of curlyleaf pondweed with herbicide treatment (see Figure 32). This estimate assumes a conservative 80 percent reduction of phosphorus loading from curlyleaf pondweed even though eradication of the species is the treatment goal. An additional 1 percent reduction in the lake's average summer total phosphorus concentration would be expected to occur once eradication of curlyleaf pondweed from the lake is attained.

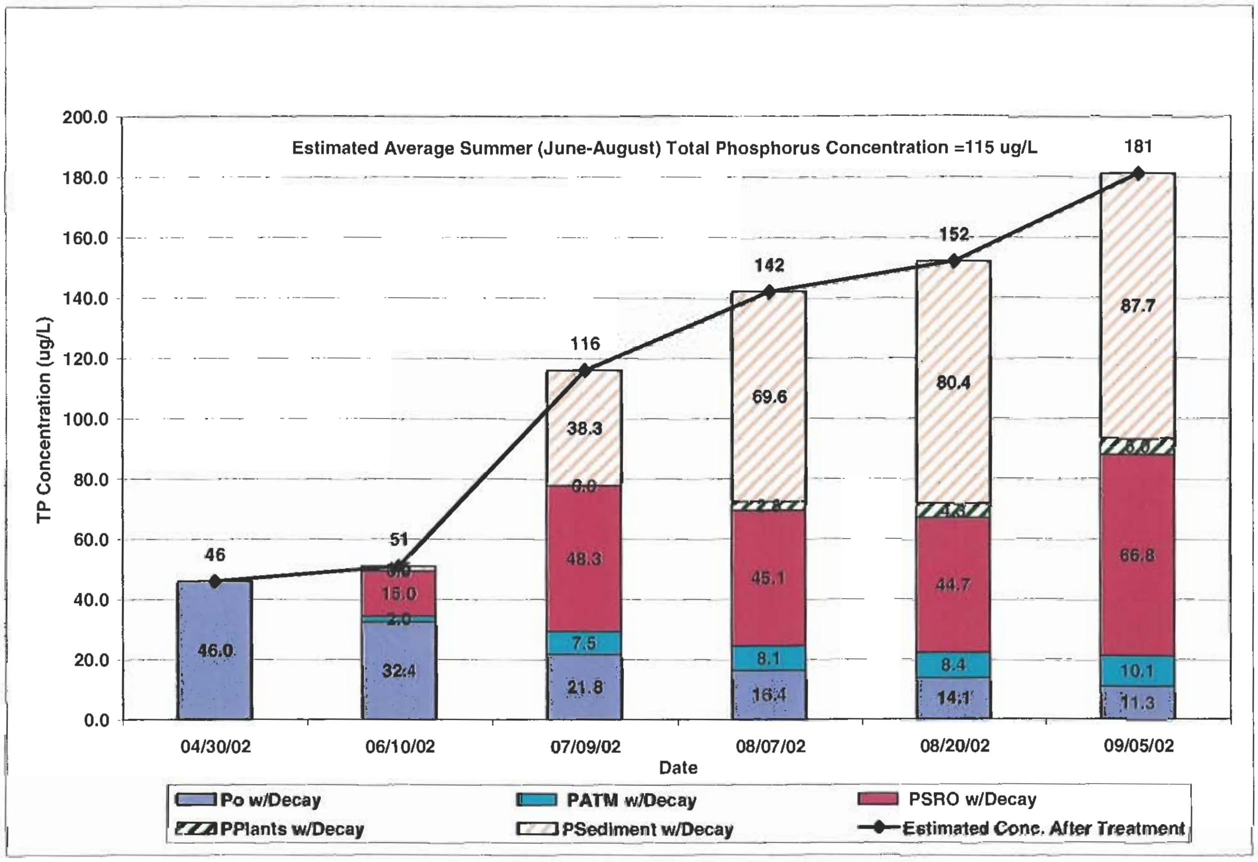


Figure 32 Estimated Duck Lake Total Phosphorus Concentrations With Herbicide Treatment (2002 Climatic Conditions and Existing Watershed Land Use)

Research has shown that the appropriate herbicide for curlyleaf pondweed control is Endothall, and that this herbicide should be applied in the spring (when the water temperature is approximately 55 to 60° F) and at a dose of 1 to 1.5 mg/L (Poovey, et al. 2002, Skogerboe, 2004 – personal communication). Preliminary results from studies in Eagan Minnesota by John Skogerboe of the U.S. Army Corps of Engineers have shown that four subsequent years of Endothall treatment have essentially eliminated curlyleaf pondweed from two of the study lakes and that after the 4th year of treatment no viable turions (pondweed seeds) remained in the sediment (John Skogerboe, 2004 -- personal communication). To remove curlyleaf pondweed, treatment will need to continue until curlyleaf pondweed is no longer observed in Duck Lake and no viable turions are found. Treatment is expected to occur for four years.

Current research is evaluating the effectiveness of lime to control curlyleaf pondweed. In a pilot study at Big Lake, Wisconsin, curlyleaf pondweed did not grow in 1-acre plots treated with lime, even though the plant continued to grow throughout the lake (Barr, 2001). In whole lake studies, curlyleaf pondweed was not observed where lime had been applied in Clifford Lake and Faille Lake, located near Osakis in central Minnesota. The U.S. Army Corps of Engineers is currently conducting a lime slurry research project at the Eau Galle Aquatic Ecology Laboratory near Spring Valley, Wisconsin. Should the project results indicate lime would be the most effective tool to control curlyleaf pondweed in Duck Lake, lime will be used rather than Endothall to manage this plant.

Purple loosestrife along the lake's shoreline threatens to displace native vegetation and reduce the habitat quality of the lake's shoreline area. Introducing a natural predator will control purple loosestrife along the shore. Two beetle species, *Galerucella pusilla* and *Galerucella calmariensis*, effectively prey upon purple loosestrife, inhibit purple loosestrife growth, and greatly reduce flowering seed output. Introducing the beetles to the infested area along the western shoreline of Duck Lake will control purple loosestrife growth and promote the growth of native species.

Phosphorus stored in sediment, together with phosphorus from decaying curlyleaf pondweed plants, are the most treatable sources of phosphorus in the water column of Duck Lake. The concentration of phosphorus in Duck Lake sediments that can release into the water column (i.e., mobile phosphorus) (see Figure 24) corresponds to a potential phosphorus release rate of approximately 2.1 mg per square meter of lake surface per day. Phosphorus released from the lake's sediments comprises approximately half of the lake's annual total phosphorus load under average climatic conditions and existing watershed land use (see Figure EX-2). Alum treatment of the lake and management of the lake's curlyleaf pondweed are expected to reduce the lake's average summer total phosphorus concentration by approximately 43 percent. Under 2002 climatic conditions (wet), the lake's average summer total phosphorus concentration is expected to be reduced from 123 μg/L (Figure 26) to 70 μg/L (Figure 33) following completion of the curlyleaf pondweed management program and alum treatment of the lake.

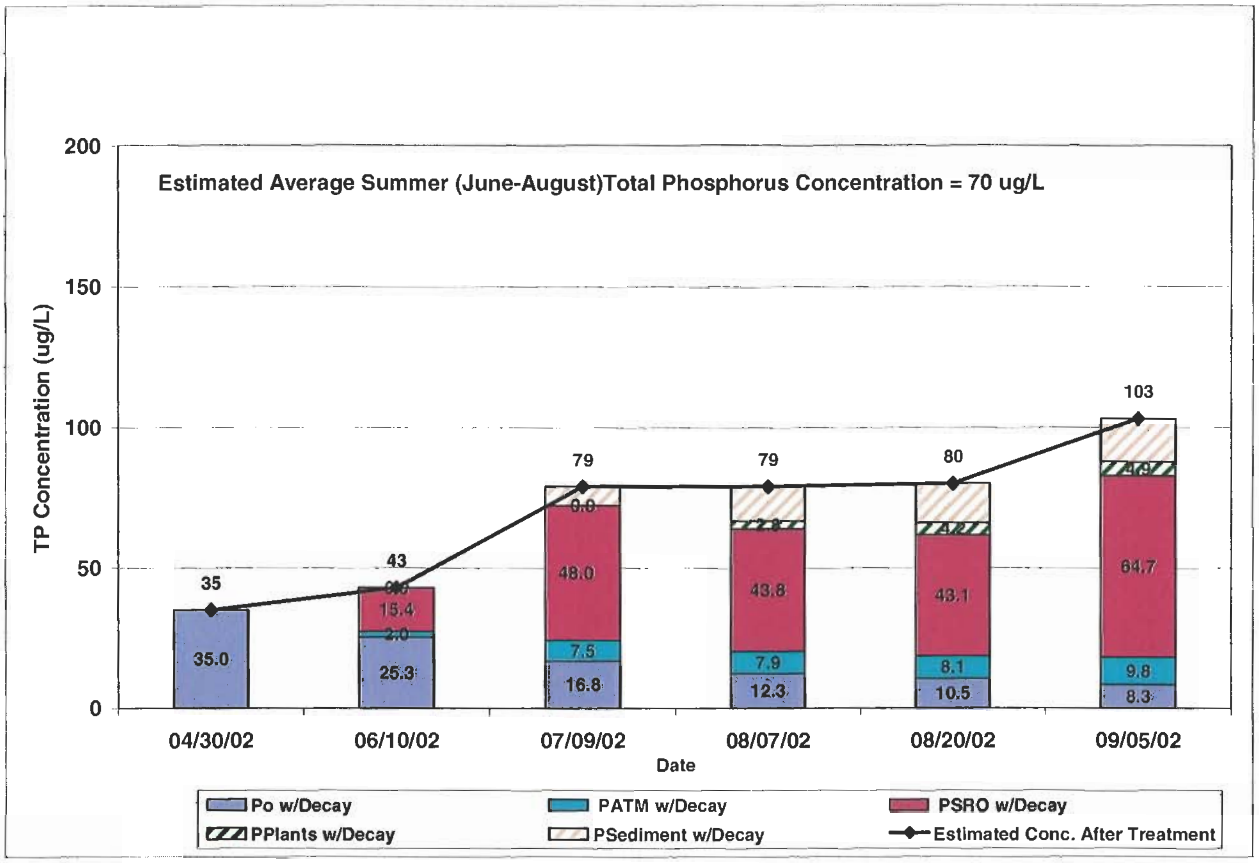


Figure 33 Estimated Duck Lake Total Phosphorus Concentrations With Herbicide Treatment and Alum Treatment (2002 Climatic Conditions and Existing Watershed Land Use)

Stormwater runoff comprises approximately 31 percent of the annual total phosphorus load to Duck Lake under average climatic conditions and existing watershed land use (see Figure EX-2). Increasing infiltration of stormwater runoff by the planting of 50 rainwater gardens in feasible locations would reduce the lake's average summer total phosphorus concentration by approximately 13 percent. Herbicide treatment of curlyleaf pondweed, alum treatment of Duck Lake, and construction of 50 rainwater gardens would reduce the lake's average summer total phosphorus concentration by approximately 56 percent. Under 2002 climatic conditions (wet), the lake's average summer total phosphorus concentration is expected to be reduced from 123 μg/L (Figure 26) to 54 μg/L (Figure 34) following completion of the curlyleaf pondweed management program, alum treatment of the lake, and construction of approximately 50 rainwater gardens throughout the Duck Lake watershed.

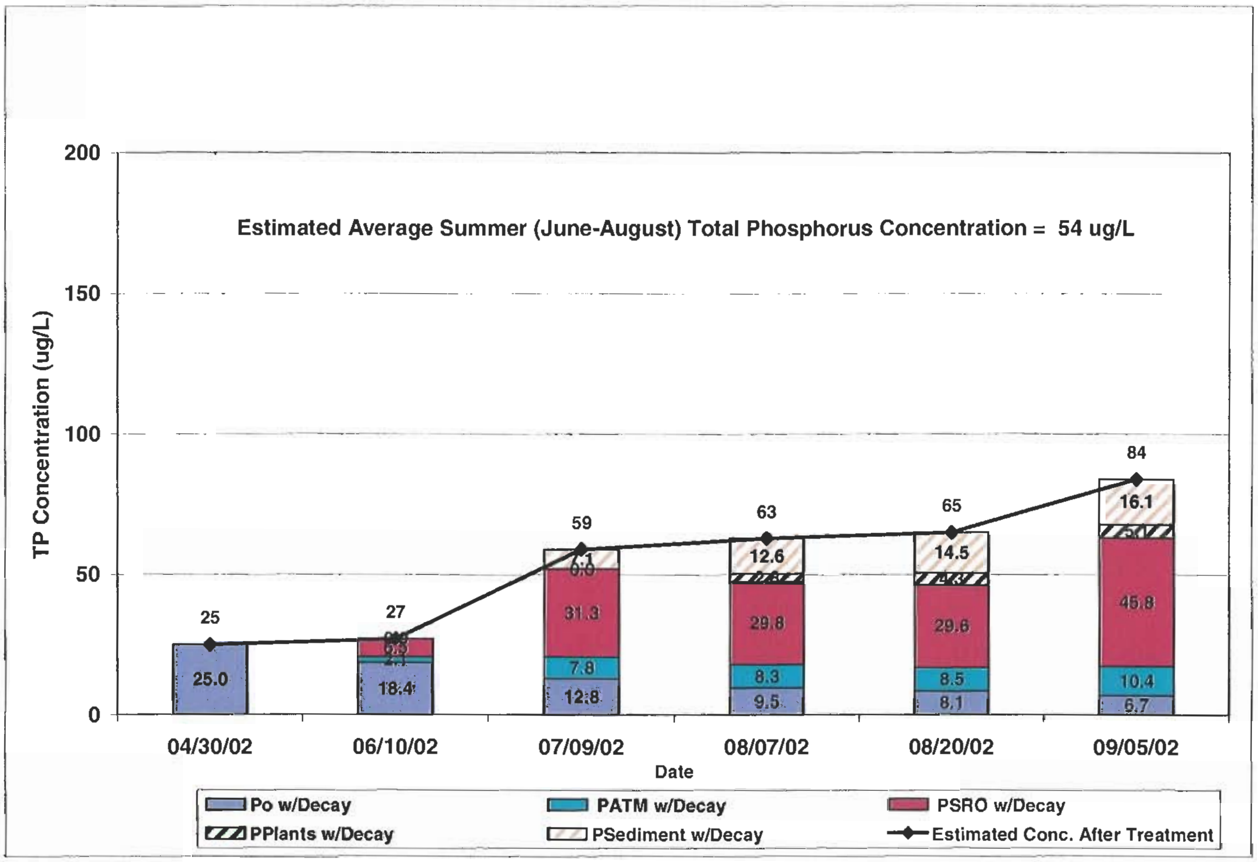


Figure 34 Estimated Duck Lake Total Phosphorus Concentrations With Herbicide Treatment, Alum Treatment, and 50 Rainwater Gardens (2002 Climatic Conditions and Existing Watershed Land Use)

4.2 Manage Curlyleaf Pondweed

The recommended treatment program for curlyleaf pondweed consists of annual spring herbicide treatment until this species is removed from the lake. Treatment will occur in late-April or early-May when the water temperature is approximately 55 to 60° F. Curlyleaf pondweed will be treated with the herbicide Endothall at a dose of approximately 1 to 1.5 mg/L. To remove the species from the lake, treatment will need to continue annually until no curlyleaf pondweed and no viable turions remain. Treatment is expected to continue for four years.

Current research to determine the effectiveness of lime to manage aquatic plants, including curlyleaf pondweed, could potentially conclude that lime is a better management tool than herbicide for control of curlyleaf pondweed. Should lime prove to be a better tool, lime treatment will replace herbicide treatment.

4.3 Manage Purple Loosestrife

The recommended purple loosestrife treatment program includes introduction of beetles, natural predators, into Duck Lake's west shoreline area. The MDNR will provide beetles to the District at no cost. However, introducing the beetles into the purple loosestrife infested area along Duck Lake's west shoreline is the District's responsibility. Management of purple loosestrife generally spans several years (4 years estimated). During the treatment period, annual field surveys will measure beetle population establishment and persistence. Survey results will determine whether the collection and release of additional beetles are warranted.

4.4 Alum Treatment of Duck Lake

The recommended treatment program to reduce phosphorus loading from the lake's sediments is a lake alum treatment. The recommended alum dose is 8.9 g/m^2 by 1 centimeter deep or 972 gallons per acre to treat the top 6 centimeters of sediment in Duck Lake. This is a treatment dose of 46 mg Al L^{-1}.

If applied in one treatment, the large dose of alum that is required to treat Duck Lake's sediments may be too heavy for the sediments to bear. The sediments have a limited weight bearing capacity because the water content of the upper 6 centimeters of the lake's sediments is 91 to 96 percent. Hence, the weight of the alum may cause it to sink far below the sediment's surface.

A second reason to split the alum dose is to avoid an adverse pH change. The large dose of alum required to treat Duck Lake's sediments may depress the lake's pH below a level that is safe for the lake's fish and aquatic life. Splitting the dose would safeguard the lake's pH.

Splitting the large dose into smaller doses (i.e., 243 to 486 gallons per acre or 11.5 to 23.0 mg Al L^{-1}) applied annually for 2 to 4 consecutive years is recommended. The smaller annual doses are expected to remain in the upper 6 centimeters of the lake sediment and effectively treat the sediment's mobile phosphorus.

Unless buffering capacity is added during alum treatment (i.e., lime or sodium aluminate), the dose proposed will need to be divided due to pH concerns. Because Duck Lake is shallow, the buffering capacity of the lake will be low in relation to the amount of alum needed to neutralize excess mobile P. It is likely that the dose will need to be split into approximately four treatments (with no added buffering) to prevent pH depression during treatment based on the alkalinity of similar lakes in the area. This will reduce the volumetric dose from 46 mg L^{-1} to 11.5 mg L^{-1} as Al (243 gallons of alum per acre).

If the dose is split into four treatments, the alum (as Al) may be consumed by available mobile phosphorus within the first year of treatment, depending on conditions in the lake and lake sediment. Single whole lake treatments near this dose (both above and below) have generally had poor results in longevity in the past (Welch and Cooke, 1999). Splitting the dose into two treatments rather than four will increase the alum applied each year and lessen the likelihood that the alum may be consumed by available mobile phosphorus within the first year of treatment. This option may be selected to insure that the water quality improvement attained by the alum treatment is maintained throughout the first year after treatment. If an alum dose of 486 gallons per acre or 23 mg Al L^{-1} is applied for each treatment, lime will be added to increase buffering capacity.

Alum treatment removes water column total phosphorus, generally resulting in a 50 percent reduction of a lake's phosphorus concentration (Lee, 2003). During an average year, splitting the alum dose will attain the proposed District goal during the initial post-treatment phase (Huser 2005). However, over time, the alum layer will become saturated with mobile phosphorus due to incoming sediment from the lake's watershed. Once the alum layer becomes saturated with excess mobile phosphorus, the lake will attain a natural internal load based on incoming sediment from the watershed. This natural return of internal phosphorus loading, although less than the pre-treatment amount, will likely cause the lake's average summer total phosphorus concentration to eventually exceed the 60 µg/L level (i.e., the proposed District goal). During both wet and dry years, splitting the alum dose into two treatments will not achieve the proposed District goal (See Table 8).

Table 8 Expected Water Quality with Alum Treatment

Management Alternative	Proposed District Goal Based Upon MPCA Standard	Dry Year–2000 (24 inches of precipitation)	Average Year–1999 (34 inches of precipitation)	Wet Year–2002 (41 inches of precipitation)
No Action	≤60	147	132	126
Herbicide Treatment (4 years) and Alum Treatment (Results After First Year)	≤60	63	57	65
Herbicide Treatment (4 years) and Alum Treatment (Results After Second Year)	≤60	59	51	62
Herbicide Treatment (4 years) and Alum Treatment (Post-Treatment Results of Split Alum Dose After Lake Attains a Natural Internal Load)	≤60	77	71	76

If current research determines that lime is a better plant management tool than Endothall, 4 years of lime treatment will be substituted for 4 years of Endothall treatment. If this option is selected, then the alum dose may be split into four treatments and applied with the lime (i.e., alum –lime treatment).

Monitoring of the lake and sediments before and after treatment will measure treatment effectiveness and the mobile phosphorus remaining in the lake's sediments. Dose adjustments will be made as warranted.

A letter of support must be obtained from the MPCA and MDNR prior to treating the lake with alum.

4.5 Construct Rainwater Gardens

Rainwater gardens are shallow depressions that are strategically placed to catch runoff from roads, parking lots, driveways, and roofs. Deep-rooted plants are planted to facilitate infiltration, filter pollutants, and create bird and butterfly habitat (see Figure 35). It is estimated that fifty rainwater gardens will be constructed within the Duck Lake watershed to infiltrate a portion of the watershed stormwater runoff. Rainwater garden details are presented in Appendix B (see Section B-2.1).

Figure 35 An Example Rainwater Garden

Evaluation of the results of the herbicide treatment and alum treatment are recommended before construction of rainwater gardens. The evaluation will (1) determine benefits of the herbicide and alum treatments; (2) determine whether rainwater garden construction is needed; and (3) if rainwater garden construction is needed, determine whether any warranted changes in the number of rainwater gardens are required to attain the proposed District goal.

4.6 Expected Sequence of Implementation Plan

Below is the expected sequence of the lake management activities.

Years 1-2	Herbicide (Endothall) treatment of curlyleaf pondweed in the spring; beetle treatment of purple loosestrife in the spring; monitoring and evaluation of aquatic plants, including purple loosestrife; monitoring and evaluation will determine changes in herbicide treatment and whether additional beetles need to be introduced into the purple loosestrife infested area.
Year 3	Herbicide (Endothall) treatment of curlyleaf pondweed in the spring, beetle treatment of purple loosestrife in the spring, monitoring and evaluation of aquatic plants, including purple loosestrife; monitoring and evaluation will determine changes in herbicide treatment and whether additional beetles need to be introduced into the purple loosestrife infested area; Pre-treatment monitoring and evaluation of lake water quality and sediments; Alum treatment in the fall (first half of alum dose applied);
Year 4	Herbicide (Endothall) treatment of curlyleaf pondweed in the spring, beetle treatment of purple loosestrife in the spring, monitoring and evaluation of aquatic plants, including purple loosestrife; monitoring and evaluation will determine changes in herbicide treatment and whether additional beetles need to be introduced into the purple loosestrife infested area; Monitoring and evaluation of lake water quality and sediments to determine results from application of first half of alum dose; alum treatment in the fall (second half of alum dose).
Years 5-8	Monitoring and evaluation of lake water quality, sediments, and aquatic plants, including purple loosestrife; Monitoring data evaluation will (1) determine benefits of the herbicide and alum treatments; (2) determine whether rainwater garden construction is needed to attain the proposed District goal; and (3) if rainwater garden construction is needed, determine whether any warranted changes in the number of rainwater gardens are required to attain the proposed District goal.
Year 9	If required for goal attainment, construct rainwater gardens
Years 10-12	If rainwater gardens are constructed, monitoring and evaluation of lake water quality and aquatic plants to determine benefits of rainwater gardens; Completion of a final report which summarizes the treatment program and monitoring results.

The annual costs of the lake management activities for the 12 year period are shown in Figure 36. The expected reductions in the lake's average summer total phosphorus concentration are summarized in Figure 37.

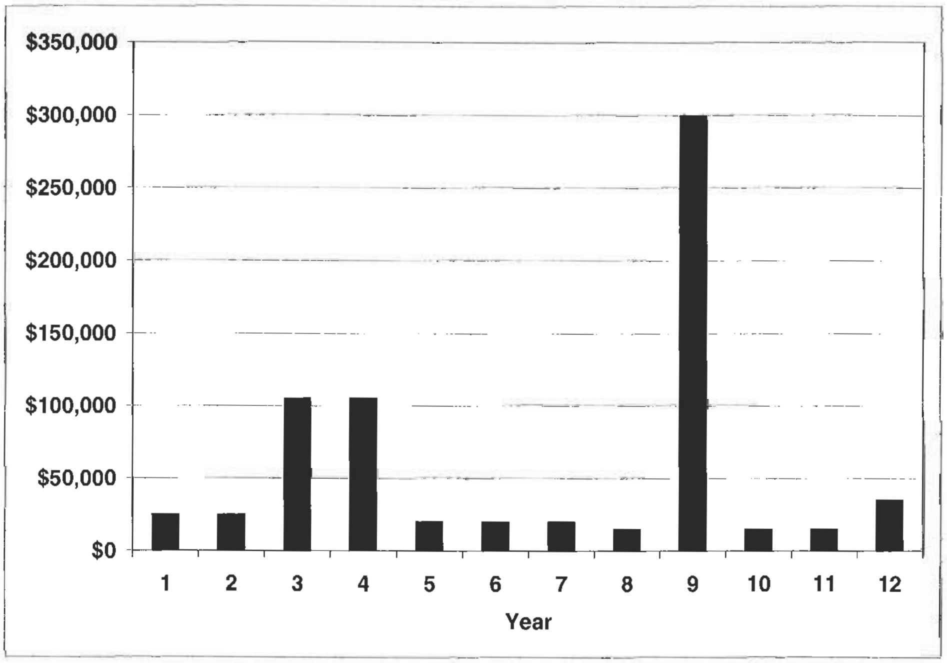


Figure 36 Annual Costs of Duck Lake Implementation Plan

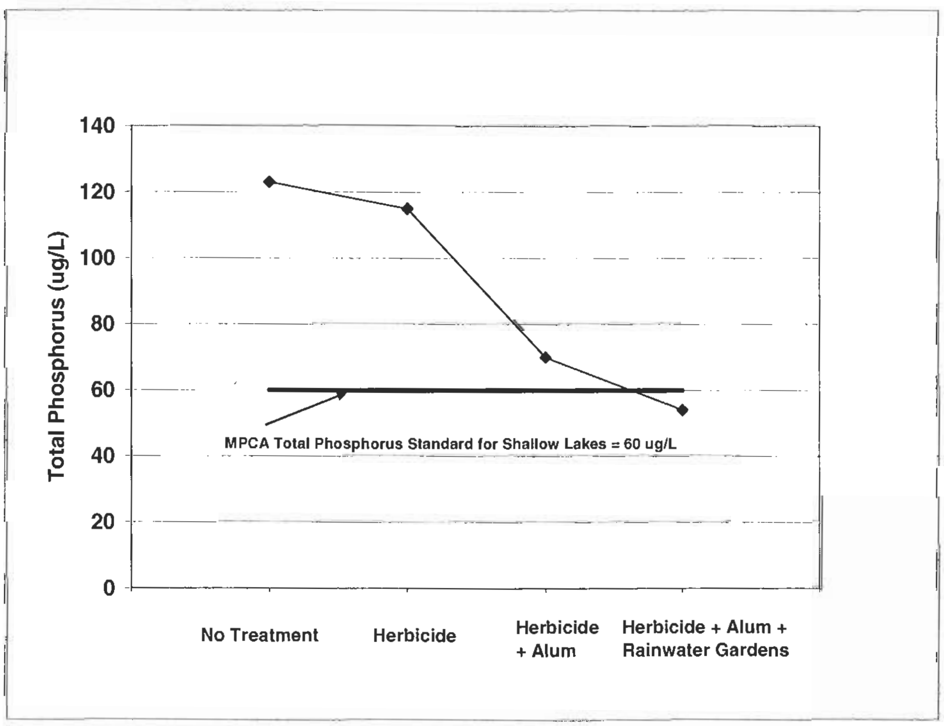


Figure 37 Estimated Duck Lake Average Summer Total Phosphorus Concentration With Implementation Plan (2002 Climatic Conditions and Existing Watershed Land Use)

4.7 Monitoring and Evaluation

An important part of this plan is monitoring and evaluation, including aquatic plant monitoring, purple loosestrife and beetle monitoring, water quality monitoring, and sediment monitoring.

4.7.1 Aquatic Plant Monitoring

During each treatment year, aquatic plant surveys should be completed on three occasions: pre-treatment survey, late-spring survey, and late-summer survey. The three surveys will determine the locations and density of plants in Duck Lake, including curlyleaf pondweed. Because treatment is expected to occur in late-April or early-May, the pre-treatment survey should be completed in either April or May, but before treatment occurs. The late-spring survey should be completed by late-June. The late summer survey should be completed by late-August. During the late-spring survey, turions (curlyleaf pondweed "seeds") should be collected from 10 percent of sample locations.

For four years following treatment, aquatic plant surveys should be completed during June and August. The surveys will determine whether curlyleaf pondweed has been eradicated from the lake. If any curlyleaf pondweed plants are found, the spring herbicide treatment program will resume until no curlyleaf pondweed plants are collected

Annual monitoring will be used to assess plant community changes and to determine treatment changes. It is anticipated that reduced curlyleaf pondweed (and turions) will occur annually during the treatment period. The treatment area is expected to decrease with decreased coverage. The treatment program will be adjusted annually based upon monitoring results and will be terminated when no curlyleaf pondweed plants and no viable turions are collected.

4.7.2 Purple Loosestrife/Beetle Monitoring

Annual field surveys should determine purple loosestrife coverage or eradication and measure beetle population establishment and persistence.

4.7.3 Water Quality Monitoring

Water quality parameters (total phosphorus, chlorophyll *a*, Secchi disc transparency, dissolved oxygen, and pH) should be monitored every 2 weeks from April through September prior to application of the first half of the alum dose, following application of the first half of the alum dose, and for 4 years following completion of the alum treatment. Should rainwater gardens be required to attain the District goal, monitoring will occur for 3 years following rainwater garden construction.

Hence, monitoring will occur for 6 to 9 years, depending upon whether or not rainwater garden construction is required to attain the District goal.

4.7.4 Sediment Monitoring

Sediment monitoring should occur before alum treatment, following application of the first half of the alum dose, and for 4 years following application of the second half of the alum dose. The monitoring will evaluate changes in the mobile phosphorus content of the lake's sediments. The monitoring following alum treatment will also evaluate the location of the alum layer. If the layer is below the sediment's surface, the distance from the surface will be measured.

5.0 Proposed 7050 Rules For Lakes

The 1972 amendments to the federal Clean Water Act require the MPCA to assess the water quality of rivers, streams, and lakes in Minnesota (Code of Federal Regulations, title 40, part 130). Waters determined to be not meeting water quality standards and not supporting assigned beneficial uses are defined as "impaired." Impaired waters are listed and reported to the citizens of Minnesota and to the Environmental Protection Agency (EPA) in the 305(b) report and the 303(d) list. Both listings are named after the relevant sections of the Clean Water Act. The beneficial uses assessed in this context are aquatic life and recreation (swimming) and aesthetics.

Impaired water or impaired condition is defined in Minn. R. pt. 7050.0150 as follows:

> *... a water body that does not meet applicable water quality standards or fully support applicable beneficial uses, due in whole or in part to water pollution from point or nonpoint sources, or any combination thereof.*

The listing of a waterbody on the 303(d) list triggers a regulatory response on the part of the MPCA to address the causes and sources of the impairment. This process is called a Total Maximum Daily Load (TMDL) analysis. The purpose of the TMDL analysis is to focus attention and resources on impaired waters and ultimately bring them back into compliance with water quality standards. Current rules require that a TMDL analysis be completed after a water body is listed on the 303(d) impaired waters list to determine a water quality improvement program to bring the water body in compliance with MPCA standards. The rules also require implementation of the water quality improvement program to bring the water body in compliance with MPCA standards.

The MPCA has developed lake criteria to determine impaired waters. The criteria are found in Guidance Manual for Assessing the Quality of Minnesota Surface Waters For Determination of Impairment. 305(b) Report and 303(d) List (MPCA, 2004). Although Duck Lake has never been assessed by the MPCA, its water quality fails to meet these criteria (see Table 9). If assessed by the MPCA, Duck Lake would be listed on the 303(d) List as an impaired waters of the State.

Table 9 Eutrophication Criteria Used to List Lakes on the 303(d) List for 2004: Lakes in the North Central Hardwood Forests (NCHF) Ecoregion

Parameter	Criteria
Total Phosphorus (µg/L)	<40
Chlorophyll *a* (µg/L)	<15
Secchi Disc (m)	>1.2

*Lakes meeting the criteria are not listed on the 303(d) list.

The criteria found in Table 9 were modified during the 2004 revision of Minnesota's 7050 Water Quality Standards. The 7050 Standards' revisions include the addition of eutrophication standards for lakes (i.e., total phosphorus, chlorophyll *a*, and Secchi disc standards) on a regional basis. Within each region, separate criteria were established for deeper lakes (depths greater than 15 feet) and shallow lakes (depth of 15 feet or less and/or 80 percent or more of the lake is littoral). Duck Lake is located within the North Central Hardwood forests region and, because the lake's depth is less than 15 feet and 100 percent of the lake is littoral, it is a shallow lake. The proposed 7050 standards for Duck Lake are shown in Table 10.

Table 10 Proposed 7050 Standards Under Consideration for North Central Hardwood Forests (NCHF) Shallow Lakes, including Duck Lake

Parameter	Criteria
Total Phosphorus (µg/L)	≤60
Chlorophyll *a* (µg/L)	≤20
Secchi Disc (m)	≥1.2

*Lakes meeting the proposed criteria will not be listed on the 303(d) list.

The proposed changes to the 7050 Standards are expected to be finalized during 2005. Once finalized, the 7050 standards will be used to assess lakes to determine lake impairment. Lakes not meeting the standards will be placed on Minnesota's 303(d) Impaired Waters List (List). Lakes currently on the List must attain the water quality of the 7050 standards to be removed from the List.

Duck Lake's historical water quality has generally failed to meet the proposed 7050 Standards (Standards). During the 1971 through 1999 monitoring period, the lake's water quality failed to meet the proposed Standards for total phosphorus, chlorophyll *a*, and Secchi disc at a frequency of 81, 74, and 74 percent, respectively.

Following implementation of the recommended lake improvement plan, Duck Lake's water quality is expected to meet the proposed phosphorus and Secchi disc transparency standards (see Table 11) during all climatic conditions under both existing and future land use conditions

Table 11 Comparison of Proposed 7050 Standards for Duck Lake With Expected Water Quality Following Implementation of Recommended Plan

Parameter	Proposed 7050 Standard Goal	Wet Year (41")	Average Year (34")	Dry Year (24")
Existing Land Use				
Total Phosphorus (µg/L)	≤ 60	56	48	46
Secchi Disc (m)	≥1.0	1.2	1.3	1.3
Future Land Use				
Total Phosphorus (µg/L)	≤ 60	55	56	51
Secchi Disc (m)	≥1.0	1.2	1.2	1.3

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Appendices

Appendix A

Duck Lake Watershed Pond Data

Table A-1. Duck Lake Pond Data

Pond ID	Overflow Elev. (ft.)*	Primary Outlet Elev. (ft.)	Outlet Size/Type	Average Pond Slope (Outlet to Overflow)	Water Elev. (ft.)	Dead Storage Volume (Acre-Feet)	Live Storage Volume (Acre-Feet	Dead Storage Surface Area (Acres)	Live Storage Surface Area (Acres)
P-3	101.3 (1.3)	0.0	12" RCP	3/1	0.05	0.072	0.142	0.046	0.065

Pond P-3 treats runoff from subwatershed DL3 (conveyance system S-9)

Appendix B

Lake Modeling

Appendix B Lake Modeling

B-1 Modeling Approach

The purpose of developing a watershed and in-lake model for Duck Lake was to determine how different phosphorus sources contribute to the observed levels of phosphorus in the lake. Modeling was performed for a range of climatic conditions (dry, average, and wet years). The in-lake model was calibrated using lake monitoring data from 2002 (wet year). The calibrated in-lake model was then run for an average year (1999) and a dry year (2000) to determine the expected average summer total phosphorus concentration for years with average and dry precipitation levels.

One of the first steps in developing the in-lake model was the determination of water and phosphorus loads from different potential sources. The four phosphorus sources evaluated in this modeling study include: the Duck Lake watershed, aquatic plant senescence, phosphorus release and migration from sediment, and atmospheric deposition.

The in-lake model was run under varying climatic conditions (dry, average, and wet year) to determine expected average summer phosphorus levels under a range of precipitation conditions. The model was also run under different management approaches to assess their benefits. From the predicted total phosphorus levels, average expected Secchi disc transparency was predicted from a relationship between total phosphorus and Secchi disc transparency. Data used to develop this relationship were from historical Duck Lake monitoring data.

B-2 Watershed Modeling

Phosphorus loading from the Duck Lake watershed was determined using the P8 model (IEP, Inc., 1990). Water and phosphorus loading were estimated using input from land use maps, soils maps, aerial photos with elevation contours, and storm sewer maps (see Appendix D). Phosphorus removal by detention basins was also calculated with the P8 model. Daily phosphorus and water loading outputs from this model were used as inputs to an in-lake model.

B-2.1 Rain Water Garden Modeling

A field survey and modeling effort were performed to evaluate the potential beneficial effect of reduced phosphorus loading to Duck Lake with the construction of rainwater gardens at individual residences in the Duck Lake watershed.

During the field survey each subwatershed (see Figure 1) was visited to determine if a rain water garden could be constructed at a given residence. On-site estimates of the percentage of houses where a rainwater garden could be successfully constructed were estimated per subwatershed. With the exception of watersheds DL1a, DL2, DL3, DL6, and DL9, there were far more potential sites for rainwater gardens than would be needed.

B.2.1.1 Analysis of rainwater garden effect on water and phosphorus loads to Duck Lake

The effect of rainwater gardens on water and phosphorus loads to Duck Lake was modeled using the P8 model. The first step was to determine the potential number of rain water gardens that could be constructed for each subwatershed. Standardized rainwater garden dimensions were then designed such that they could be fit into the available area of the houses. The following dimensions were used for each rainwater garden:

- Surface Area: 0.01 acre
- Depth: 1.0 feet
- Bottom Area: 0.0033 acre
- Volume: 0.007 acre-feet
- Side Slopes: 4:1
- Shape: Oval

For modeling purposes, the number of rainwater gardens that would be placed in each watershed was multiplied by the above parameters (surface area, bottom area, and volume) to create one large rainwater garden (which would not actually exist) where the watershed runoff would be routed in the model. The table below (Table B-1) shows the relevant characteristics of the watershed and the large rainwater gardens that were used in the model. After water was routed through the rainwater gardens the uninfiltrated water was then directed to Duck Lake. Modeling was performed using existing and future watershed conditions.

Table B-1 Characteristics of rain water (RW) gardens used for P8 modeling.

Subwatershed	Number of Houses with RW Gardens	Total RW Garden Surface Area (ac)	Total RW Garden Volume (ac-ft)	Soil Type (hydrologic soil group)	Infiltration Rate (in/hr)
DL1a	1	0.01	0.007	B	0.25
DL1b	22	0.22	0.0154	B	0.25
DL4	13	0.13	0.091	B	0.25
DL5	5	0.05	0.035	B,A	0.25
DL6	1	0.01	0.07	B,A	0.25
DL8	5	0.05	0.035	B,B/D	0.25
DL10	5	0.05	0.035	B	0.25

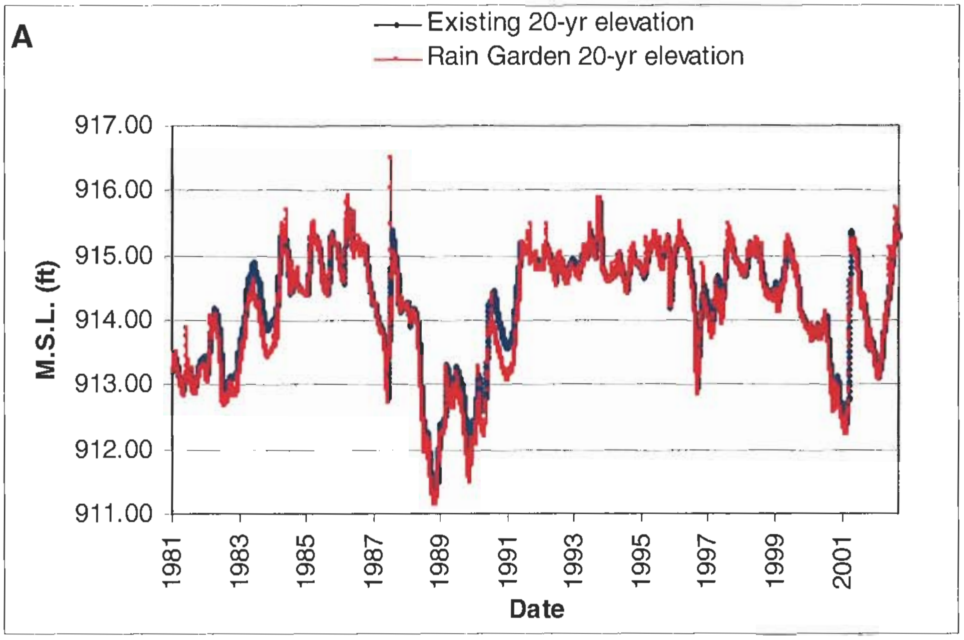
B.2.1.2 Analysis of rainwater garden infiltration effect on lake water level in Duck Lake

Future lake water elevation in Duck Lake with the construction of rainwater gardens was modeled based upon measured precipitation, temperature, and lake level over the previous 20 years. A detailed water budget was developed and from this, different amounts (percent of total flow) of storm water entering the rainwater gardens were removed from the overall water input to the lake. Evapotranspiration was considered the main loss mechanism for stormwater entering the rainwater gardens. The lake level was then calculated with this water absent and the results are presented below in Table B-2 and Figure B-1.

Table B-2 Existing and modeled 20-year average lake levels in Duck Lake based on different percent removals of stormwater (SW) inflow from evapotranspiration in proposed rainwater gardens in the surrounding watershed.

	No Treatment (Existing)	Rainwater Gardens 40% SW Reduction (Modeled)	Rainwater Gardens 100% SW Reduction (Modeled)
Lake Level (M.S.L.)	914.24	914.13	913.99

As Table B-2 shows, if 100 percent of the stormwater entering the proposed rainwater water gardens does not reach the lake, the average elevation will drop 3 inches. This will cause an average decrease in lake area from 39.3 to 37.1 acres. A more likely scenario is based upon previous studies that demonstrated that 40 percent of the water entering a rainwater garden is lost by evapotranspiration and 60 percent of the water infiltrates to groundwater. If 40 percent of the stormwater entering the proposed rainwater gardens is lost by evapotranspiration (i.e., 60 percent infiltrates to groundwater and eventually enters Duck Lake), the average lake level drops from 914.24 to 914.13 M.S.L (1 inch), causing a decrease in lake area from 39.3 to 38.3 acres.



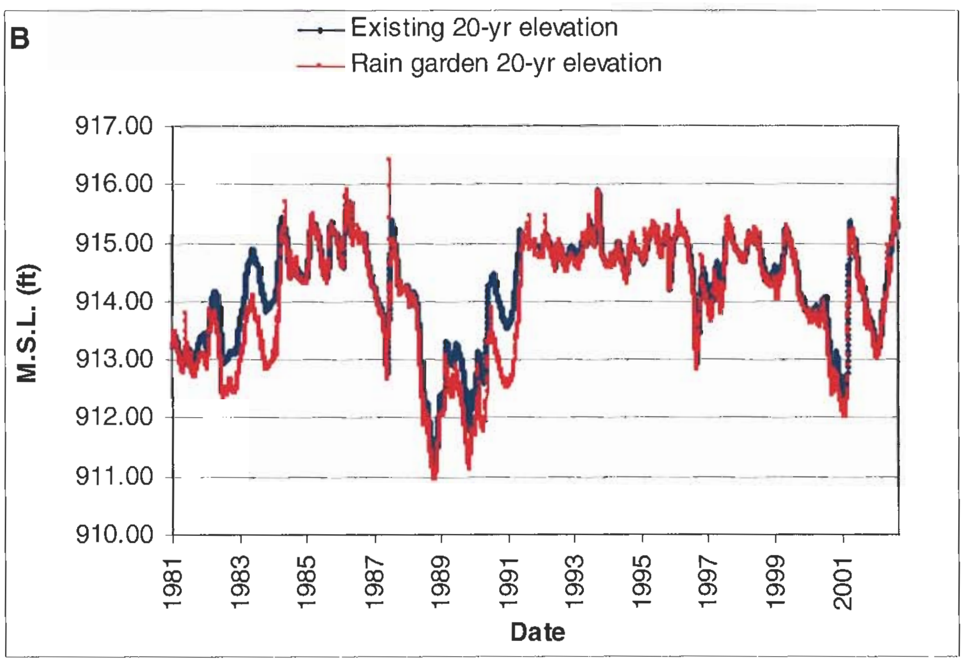


Figure B-1. Existing and expected elevations in Duck Lake based on proposed rainwater gardens assuming 40 percent (A) and 100 percent (B) of the water entering the rainwater gardens is lost by evapotranspiration.

B-3 Lake Modeling

The first step in lake modeling was the identification and evaluation of different phosphorus sources. Both external phosphorus sources, i.e. watershed inputs and direct atmospheric deposition on the lake, and internal phosphorus sources were considered for this model. Because of the significant increases in phosphorus that are observed in the Duck Lake water column from June through September, and the fact that this increase was not associated with storm water inputs, internal phosphorus loading was identified early in this study as a significant source of phosphorus loading (see Figure B-2).

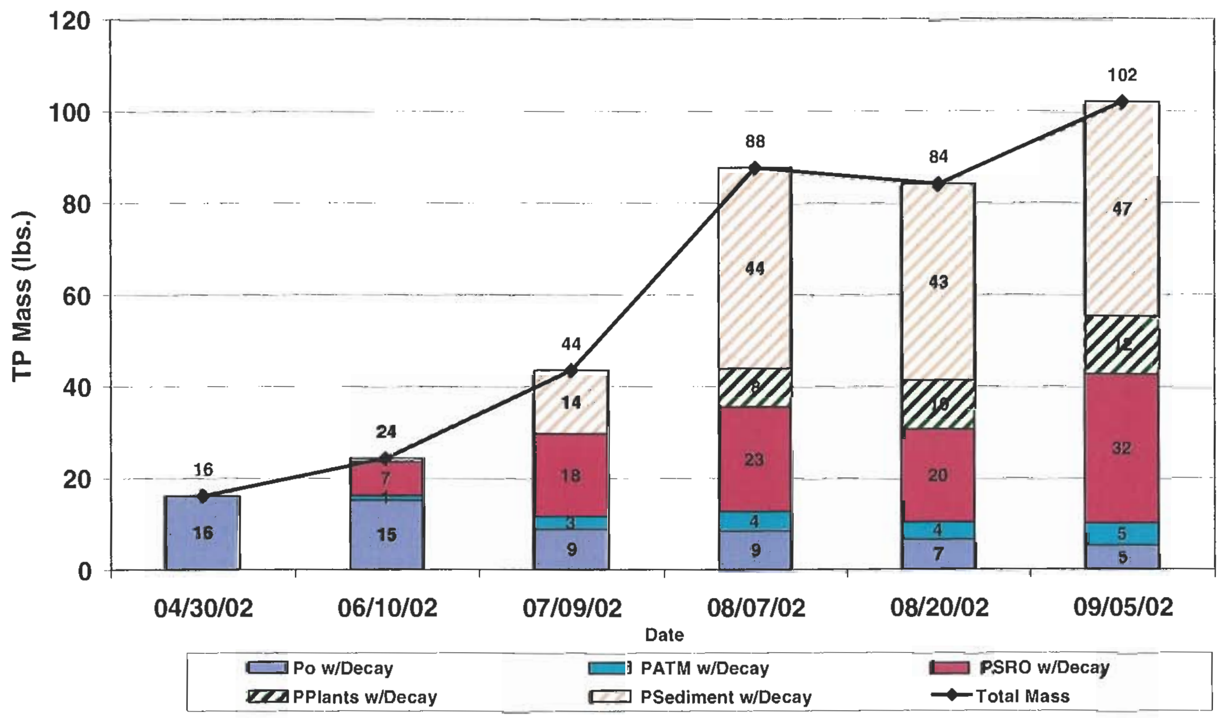


Figure B-2 Estimated 2002 Duck Lake Phosphorus Sources—Internal Sources Compared With Stormwater Inputs

Two types of internal loading were evaluated, aquatic plants and sediments. A macrophyte survey in 2002 showed that curlyleaf pondweed die-off occurred in early-summer (PPlants w/Decay in Figure B-2).

Sediment cores were collected in 2003 and analyzed for total and potentially releasable (mobile) phosphorus. Results of the sediment analysis indicated that sediment was also a potentially significant source of phosphorus loading to Duck Lake (PSediment w/Decay in Figure B-2).

B-3.1 Macrophytes

Because pondweed decomposition was identified as a potentially significant source of internal loading, the total phosphorus mass contributed to the Duck Lake water column by the die-off of curlyleaf pondweed was estimated. 2002 macrophyte densities were semi-quantitatively determined for Duck Lake. At several sampling locations in the lake (see Figures 13 and 14), macrophyte species were identified as light (1), typical (2), or heavy (3). Light approximately corresponds to 30 stems per square foot, typical to 41 stems per square foot, and heavy to 59 stems per square foot (Barr, 2001). Stem density from the light category was used to estimate phosphorus loading from curlyleaf pondweed.

Data from a macrophyte study performed in Wisconsin was used to estimate the mass and phosphorus content of curlyleaf pondweed in Duck Lake (Barr, 2001). This study determined that the mass of each stem was 0.35 grams and the phosphorus content per gram of curlyleaf pondweed material was 2 mg. This corresponds to 226.8 mg of phosphorus per square meter or approximately 0.92 kg phosphorus per acre. Because this value represents the maximum potential phosphorus load by the curlyleaf pondweed this loading estimate was viewed as a starting point from which to calibrate the contribution of phosphorus loading by curlyleaf pondweed. Also, it should be noted that this estimate of phosphorus mass per square meter is comparable to a study on Half Moon Lake, Wisconsin (James et al. 2001) where a dense population of curlyleaf pondweed was estimated to contain between 103 to 216 mg of phosphorus per square meter of lake surface. A literature review by Bolduan et al., 1994, presented phosphorus content for curlyleaf pondweed that ranged from 1.15 mg to 8.0 mg per gram of plant material (0.115 to 0.8 percent). The density of curlyleaf pondweed (stems per square meter) was not presented in this study.

The contribution of phosphorus to the water column by curlyleaf pondweed is a two step process with die-off followed by decomposition and then release of phosphorus. James et al. 2001 estimated that this is a non-linear process with most of the phosphorus release occurring within 30 days of die-off. Because all of the curlyleaf pond weed at Duck Lake does not die-off at the same time, a mathematical model, which was derived from the chemical kinetics literature (Brezonik, 1994), was used to estimate die-off then phosphorus release. This kinetic equation consists of two first order equations called a two-set first order sequence. Figure B-3 shows how pondweed die-off and phosphorus inputs were modeled. It was assumed that phosphorus input from pondweed die-off begins in July of each year.

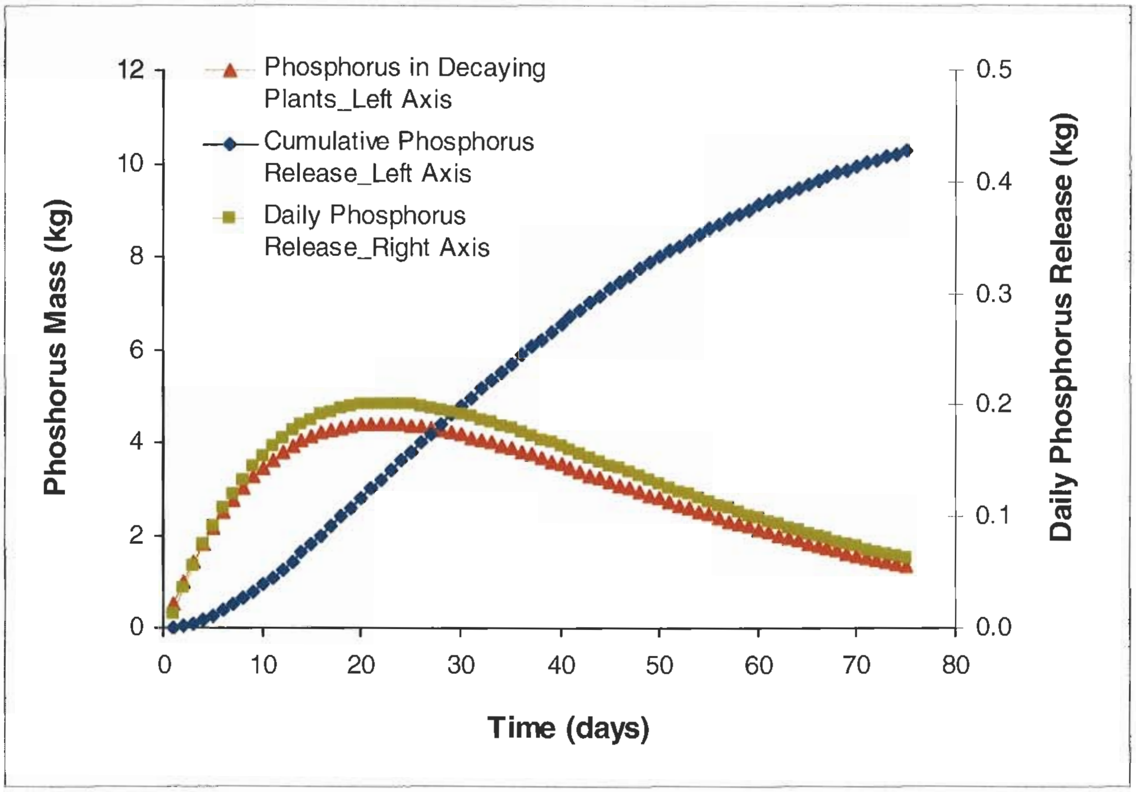


Figure B-3 Phosphorus Release to the Duck Lake Water Column by Curlyleaf Pondweed

B-3.2 Sediment

Total phosphorus monitoring data for Duck Lake (see Figure 7) show that the concentration of phosphorus in the water column can increase significantly in July through early-September. Duck Lake sediment is relatively high in phosphorus that can release into the lake column (see Figure 24). From the sediment phosphorus data it was estimated that the phosphorus release rate was 2.1 mg per square meter per day from mid-June through early-September (Pilgrim, 2002). Partitioning modeling results (see Figure 26) indicate that phosphorus released from sediment increases the lake's phosphorus concentration by approximately 30 μg/L in July and from 83 to 88 μg/L in August and September under 2002 climatic conditions and existing watershed land uses (Barr, 2004). Hence, phosphorus released from sediments comprises from one third to one half of the lake's phosphorus concentration during the July through September period under 2002 climatic conditions and existing watershed land uses.

B-3.3 Calibration

Two parameters were used to calibrate the lake model: (1) phosphorus settling velocity, and (2) the rate of phosphorus release from curlyleaf pondweed. The phosphorus settling velocity was calculated using an equation from Dillon and Rigler (1974) and lake characteristics such as lake volume and mean depth, watershed phosphorus and water loading from the spring of one year to the spring of the next year (1 year of phosphorus loading), outflow discharge volume, and outflow concentration. The phosphorus settling velocity was calculated such that the model-predicted phosphorus concentration was equal to the concentration of phosphorus monitored in the spring (calibrated with 2002 monitoring data). The rate of phosphorus release from curlyleaf pondweed was used as an input to a second mass balance model (adapted from Thomann and Mueller, 1987) to develop a calibrated model. The phosphorus release rate from curlyleaf pondweed was adjusted to minimize the difference between model-predicted and monitored phosphorus concentrations.

The equations used in this study are presented below.

Curlyleaf Pondweed Die-Off

For the process: pondweed (A) $\xrightarrow[k_1]{}$ decaying pondweed (B) $\xrightarrow[k_2]{}$ released phosphorus (C), two equations apply,

$$[B] = \frac{k_1 [A_o]}{k_2 - k_1}\{\exp(-k_1 t) - \exp(-k_2 t)\ \}$$

$$[C] = \frac{[A_o]}{k_2 - k_1}\{k_2(1 - \exp(-k_1 t)) - (1 - \exp(-k_2 t))\ \}$$

where t is time in days.

Dillon and Rigler

There are two equations for the Dillon and Rigler model.

$$R_{\exp} = \frac{Vp}{q_a + Vp}$$

and

$$C = L\frac{(1 - R_{\exp})}{Zp}$$

where R_{exp} = retention coefficient, q_a = overflow rate, Vp = net apparent settling rate, C = lake concentration, L = phosphorus loading, z = average lake depth, and p = the fraction of the lake that is lost by discharge. The first equation was solved for net apparent settling rate variable, Vp. This variable was then input in the equation below. The second equation was used to estimate the concentration of phosphorus that will occur in the spring.

Adapted from Thomann and Mueller

$$\frac{\Delta C}{\Delta t} = \frac{Q_{in} * C_{in} - Q_{out} * C_{lake} - C_{lake} * A * Vp + SedPond}{V}$$

where: C = concentration of total phosphorus in the lake, t = time, Q_{in} = water flow into lake, Q_{out} = water flow out of lake, A = lake area, Vp = net total phosphorus settling "removal" rate, *SedPond* = sediment and pondweed loading, and V = lake volume. This model was used with a daily time step.

B-3.5 Management Estimates

The effect of different management actions on phosphorus loading to Duck Lake was estimated for herbicide treatment, alum treatment, and rainwater gardens.

It was estimated that herbicide (Endothall) treatment can result in curlyleaf pondweed removal to 80 percent. This estimate was approximated from published literature (Poovey, et al. 2002). Elimination of curlyleaf pondweed is expected to occur following several years of annual Endothall treatment because plant reproduction will be prevented by the annual early spring treatment. However, a conservative estimate of 80 percent phosphorus removal from curlyleaf pondweed was used for management estimates. Lime treatment has resulted in pondweed growth inhibition from 50 to 80 percent (Reedyk, et al., 2001). For modeling purposes lime treatment was assumed to have the same effectiveness as Endothall.

The magnitude of phosphorus release inhibition from Duck Lake sediments is based upon the alum dose that is used. Alum dose can be applied that will reduce the sediment phosphorus release rate to 0 mg per square meter per day. However, a conservative 80 percent reduction in sediment phosphorus release was used for modeling. Hence, a release rate equal to 20 percent of the estimated current release rate was used as a model input to simulate the effect of sediment treatment on phosphorus levels in Duck Lake. The recommended alum dose is 8.9 g/m2 by 1 centimeter deep or 972 gallons per acre to treat the top 6 centimeters of sediment in Duck Lake.

B-3.5 Partitioning of Phosphorus Sources

Phosphorus sources to Duck Lake were partitioned to determine the relative contribution of each source to the lake's water quality. A mass balance spreadsheet model was used to proportion the lake's phosphorus sources during 2002. Sample dates were selected for the partitioning time step. Details follow.

- The lake's spring phosphorus concentration (P_0) was the starting phosphorus concentration during April.
- Stormwater runoff contributions (P_{SRO}) to the lake during April through September were determined from P8 modeling results. For each sample date, the P8 modeled stormwater runoff phosphorus load was divided by the lake's epilimnetic volume to estimate the lake phosphorus concentration resulting from stormwater runoff.
- Annual atmospheric deposition (P_{ATM}) was calculated within the Dillon and Rigler model. An atmospheric deposition rate of 0.56 kg/ha/yr. (Tetra Tech., 1982) was applied to the surface area of Duck Lake to determine annual phosphorus loading from atmospheric deposition. Stormwater inflow to Duck Lake from P8 modeling results was used to proportion atmospheric deposition to the individual days throughout the year. Then, the daily atmospheric deposition rate was used to estimate atmospheric deposition during each sample period. The atmospheric deposition load during each sample period was divided by the lake's epilimnetic volume to estimate the lake phosphorus concentration resulting from atmospheric deposition.
- The lake's phosphorus load from decaying plants (P_{Plants}) was comprised of the estimated phosphorus load from decaying curlyleaf pondweed. The load was computed using a mathematical model (see Figure B-3) to estimate curlyleaf pondweed die-off and phosphorus release. The phosphorus load from decaying curlyleaf pondweed during each sample period was divided by the lake's epilimnetic volume to estimate the lake phosphorus concentration resulting from decaying curlyleaf pondweed.
- The lake's phosphorus load from sediment ($P_{Sediment}$) was estimated from mobile phosphorus measurements of the lake's sediment (see Figure 24). From the sediment phosphorus data it was estimated that the phosphorus release rate was 2.1 mg per square meter per day from mid-June through early-September (Pilgrim, 2002). The estimated phosphorus load from decaying sediment during each sample period was divided by the lake's epilimnetic volume to estimate the lake phosphorus concentration from sediment.
- Losses from settling and outflow through the outlet were estimated. The losses were partitioned based upon the contribution of each phosphorus source. Hence, the percent contribution to the lake's losses on each sample date was the same as the percent contribution to the lake's sources. Phosphorus losses were subtracted from phosphorus sources on each sample date to estimate net contributions. Losses are described as "decay".

The partitioned total phosphorus concentrations for Duck Lake during April through September of 2002 are presented in Table B-3 and Figure 26 of this report.

Table B-3 2002 Duck Lake Partitioned Total Phosphorus Concentration

P in Lake (µg/L)						
Date	Po w/Decay	P_{ATM} w/Decay	P_{SRO} w/Decay	P_{Plants} w/Decay	$P_{Sediment}$ w/Decay	P_{sum}
4/30/2002	44.0					44.0
6/10/2002	36.9	2.3	17.9	0.0	1.8	59.0
7/9/2002	19.7	6.2	39.8	0.0	30.4	96.0
8/7/2002	17.5	8.4	45.8	16.5	87.8	176.0
8/20/2002	13.0	7.4	39.0	20.1	82.6	162.0
9/05/2002	10.2	9.2	60.8	23.3	87.5	191.0

B-4 Results

A graphical presentation of the model calibration results are shown below in Figure B-4. The lake model was calibrated by changing the time-distributed input of phosphorus by curlyleaf pondweed die off (see Figure B-3 for the time-distributed input of curlyleaf pondweed phosphorus).

The expected outcome of several alternative management actions was modeled using the calibrated model for dry, average, and wet years. The expected outcome of each management activity is presented as the average summer total phosphorus concentration, the expected Secchi disc transparency given the average total phosphorus concentration, and the TSI that corresponds to the Secchi disc transparency (Table B-4). The expected Secchi disc transparency presented in Table B-4 was calculated using a logarithmic relationship between measured summer phosphorus levels in Duck Lake and corresponding Secchi disc transparency (Figure B-5).

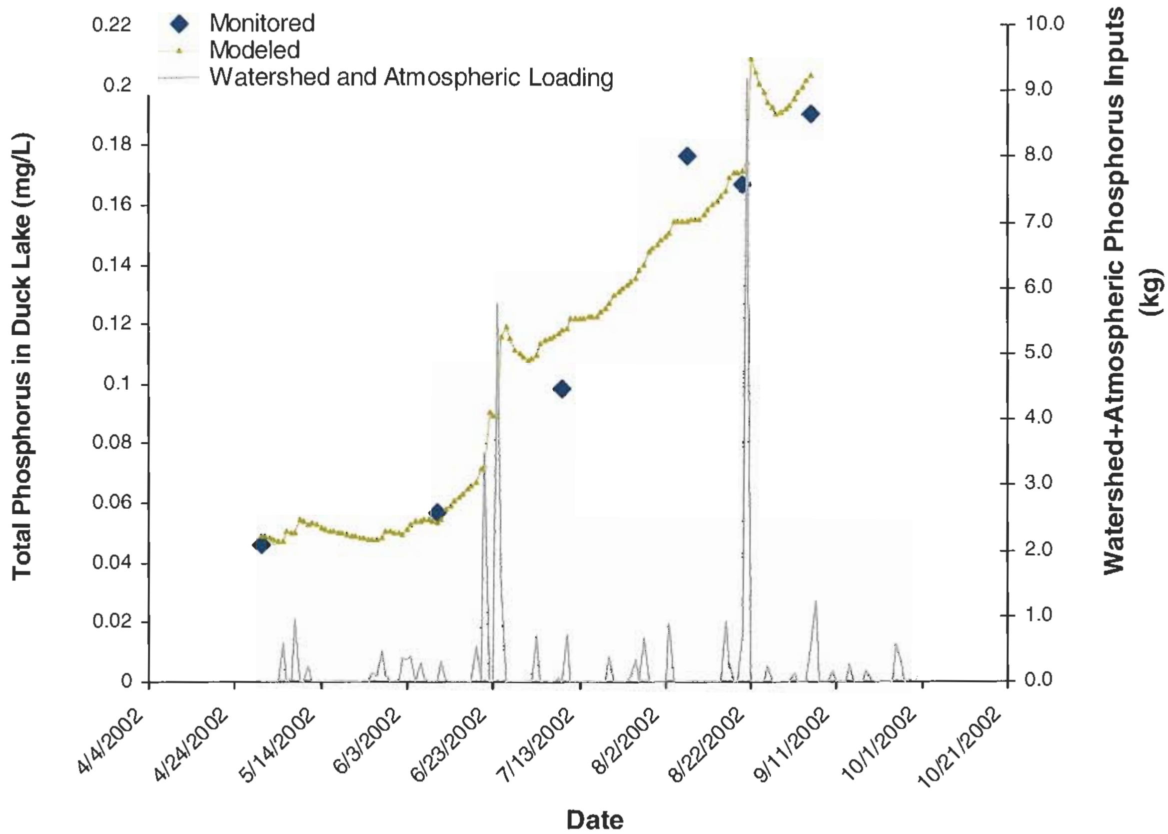


Figure B-4 Calibrated Lake Model

Table B-4 Expected Trophic State Index Values Under Varying Climatic Conditions and Management Approaches

Management Approach	Trophic State Index (TSI_{SD}) Value				
	Current District Goal	Proposed District Goal Based Upon MPCA Phosphorus Standard	Dry Year (24 inches)	Average Year (34 inches)	Wet Year (41 inches)
Existing Watershed Land Use Conditions					
No Action	<54.5	<57.7	65.7	64.9	64.9
Alum Treatment	<54.5	<57.7	59.6	59.3	60.3
Herbicide Treatment	<54.5	<57.7	64.2	64.3	64.2
Alum + Herbicide Treatment	<54.5	<57.7	58.1	58.2	59.3
Alum + Herbicide Treatment + Pond Upgrade	<54.5	<57.7	58.1	58.2	59.3
Alum + Herbicide Treatment + Rainwater Gardens	<54.5	<57.7	55.7	56.0	57.1
Future Watershed Land Use Conditions					
No Action	<54.5	<57.7	67.5	65.9	65.3
Alum Treatment	<54.5	<57.7	61.3	59.8	60.4
Herbicide Treatment	<54.5	<57.7	64.4	64.9	64.4
Alum + Herbicide Treatment	<54.5	<57.7	59.9	58.7	59.6
Alum + Herbicide Treatment + Pond Upgrade	<54.5	<57.7	59.9	58.7	59.6
Alum + Herbicide Treatment + Rainwater Gardens	<54.5	<57.7	56.4	57.1	57.0

Management Approach	Mean Summer Secchi Disc (m)			
	Proposed District Goal Based Upon MPCA Phosphorus Standard	Dry Year (24 inches)	Average Year (34 inches)	Wet Year (41 inches)
Existing Watershed Land Use Conditions				
No Action	<1.2	0.7	0.7	0.7
Alum Treatment	<1.2	1.0	1.0	1.0
Herbicide Treatment	<1.2	0.7	0.7	0.7
Alum + Herbicide Treatment	<1.2	1.1	1.1	1.0
Alum + Herbicide Treatment + Pond Upgrade	<1.2	1.1	1.1	1.0
Alum + Herbicide Treatment + Rainwater Gardens	<1.2	1.3	1.3	1.2
Future Watershed Land Use Conditions				
No Action	<1.2	0.6	0.7	0.7
Alum Treatment	<1.2	0.9	1.0	1.0
Herbicide Treatment	<1.2	0.7	0.7	0.7
Alum + Herbicide Treatment	<1.2	1.0	1.1	1.0
Alum + Herbicide Treatment + Pond Upgrade	<1.2	1.0	1.1	1.0
Alum + Herbicide Treatment + Rainwater Gardens	<1.2	1.3	1.2	1.2

Table B-4 Expected Trophic State Index Values Under Varying Climatic Conditions and Management Approaches

Management Approach	Mean Total Phosphorus Concentration (μg/L)			
	Proposed District Goal Based Upon MPCA Phosphorus Standard	Dry Year (24 inches)	Average Year (34 inches)	Wet Year (41 inches)
Existing Watershed Land Use Conditions				
No Action	<60	130	123	123
Alum Treatment	<60	75	73	81
Herbicide Treatment	<60	116	117	116
Alum + Herbicide Treatment	<60	63	64	73
Alum + Herbicide Treatment + Pond Upgrade	<60	63	64	73
Alum + Herbicide Treatment + Rainwater Gardens	<60	46	48	56
Future Watershed Land Use Conditions				
No Action	<60	147	132	126
Alum Treatment	<60	90	77	82
Herbicide Treatment	<60	118	123	118
Alum + Herbicide Treatment	<60	78	68	75
Alum + Herbicide Treatment + Pond Upgrade	<60	78	68	75
Alum + Herbicide Treatment + Rainwater Gardens	<60	51	56	55

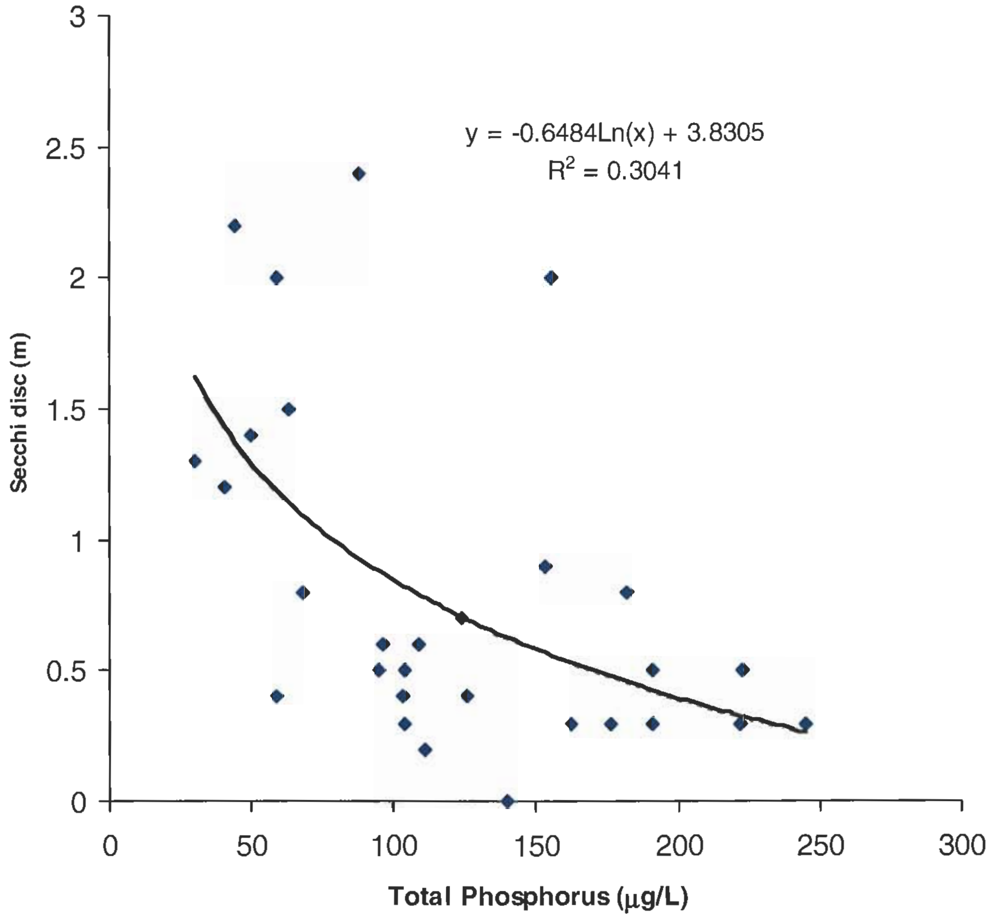


Figure B-5 **Historical Relationship Between Total Phosphorus and Secchi Disc Transparency for Duck Lake**

B-5 Conclusions

This lake model was used to estimate the relative phosphorus loading from watershed inputs, curlyleaf pondweed, and lake sediment, and how management of these different sources would affect phosphorus levels in Duck Lake.

The prescribed management activities should be completed according to the management plan presented in Sections 4.0 through 4.7 of this report. By following this management plan the relative contribution by curlyleaf pondweed to phosphorus levels in Duck Lake can be confirmed because herbicide treatment should eliminate phosphorus contributed by curlyleaf pondweed. Once curlyleaf pondweed is adequately controlled, alum treatment will occur to reduce the dense blue-green algal blooms at Duck Lake in the summer. Following control of phosphorus released from sediments, monitoring for four years should occur before construction of rainwater gardens. The monitoring results will determine whether rainwater gardens are needed to attain the District goal. If needed, any warranted changes in the number of rainwater gardens can be determined. Following rainwater garden construction, monitoring should occur for 3 years to determine whether the implementation program has resulted in attainment of the District goal.

Appendix C

Monitoring and Analysis Methods

Appendix C Monitoring and Analysis Methods

The Duck Lake UAA included the collection of lake water quality data and ecosystem data.

C.1 Lake Water Quality Data Collection

In 2002, a representative Duck Lake sampling station was selected (i.e., located at the deepest location in the lake basin (see Figure C-1 of this report). Samples were collected from April through September of 2002. A total of eleven water quality parameters were measured at the Duck Lake sampling station. Table C-1 lists the water quality parameters and specifies at what depths the samples or measurements were collected. Dissolved oxygen, temperature, specific conductance, turbidity, and Secchi disc transparency were measured in the field. Water samples were analyzed in the laboratory for total phosphorus, soluble reactive phosphorus, total Kjeldahl nitrogen, nitrate + nitrite nitrogen, chlorophyll *a*, and pH. The procedures for chemical analyses of the water samples are shown in Table C-2. Generally, the methods can be found in Standard Methods for Water and Wastewater Analysis.

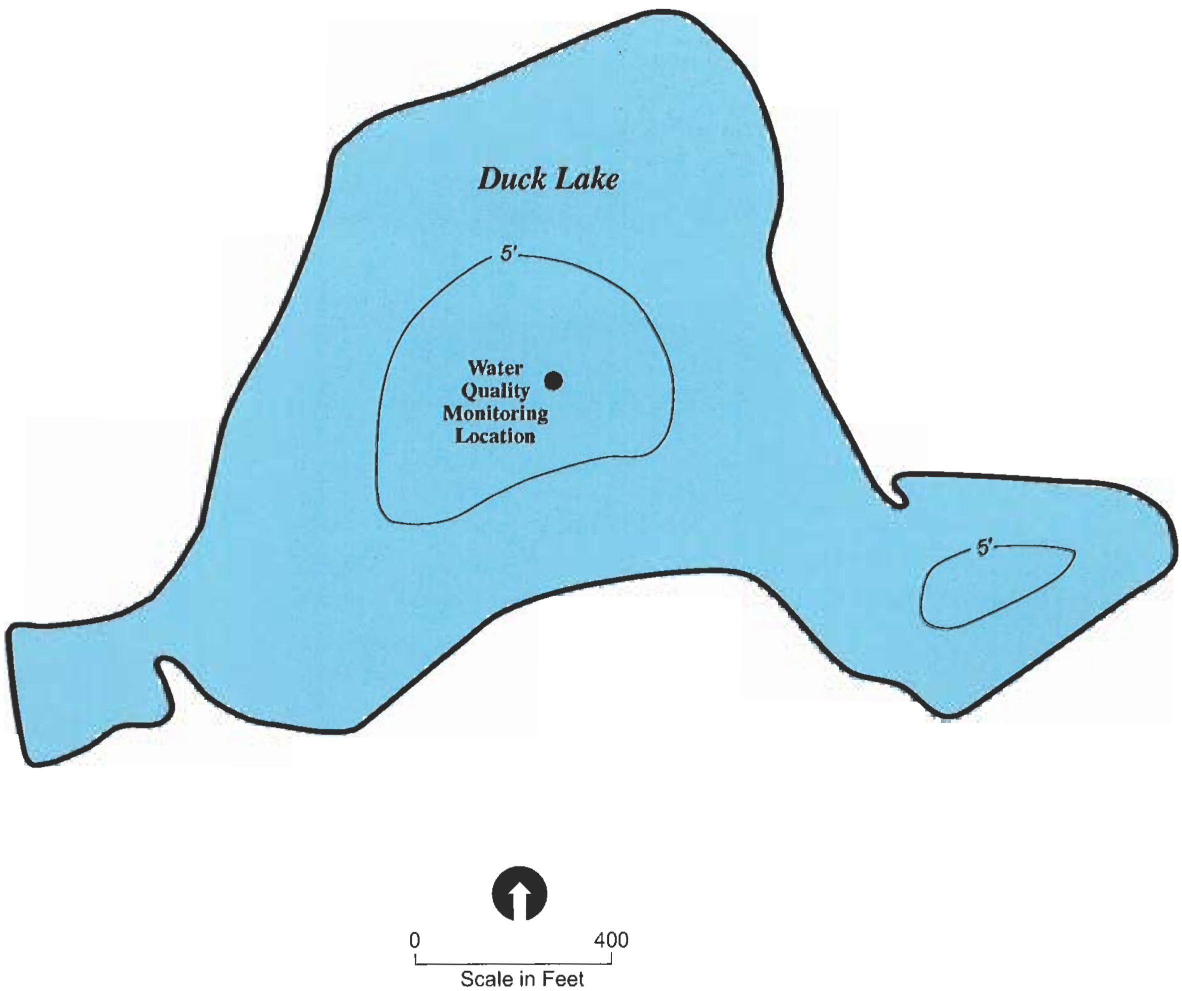


Figure C-1

DUCK LAKE
BASIN MORPHOLOGY AND
SAMPLE LOCATION

Table C-1 Duck Lake Water Quality Parameters

Parameters	Depth (Meters)	Sampled or Measured During Each Sample Event
Dissolved Oxygen	Surface to bottom profile	X
Temperature	Surface to bottom profile	X
Specific Conductance	Surface to bottom profile	X
Secchi Disc	—	X
Total Phosphorus	0 2 meter Composite Sample	X
Total Phosphorus	Near Bottom Sample at 0.5 meters above the bottom	X
Soluble Reactive Phosphorus	0-2 meter Composite Sample	X
Total Kjeldahl Nitrogen, Nitrate + Nitrite Nitrogen	0-2 meter Composite Sample	X
pH	0-2 meter Composite Sample	X
pH	Near Bottom Sample at 0.5 meters above the bottom	X
Chlorophyll *a*	0-2 meter Composite Sample	X
Turbidity	0-2 meter Composite Sample	X

Table C-2 Procedures for Chemical Analyses Performed on Water Samples

Analysis	Procedure	Reference
Total Phosphorus	Persulfate digestion, manual ascorbic acid	Standard Methods, 18th Edition, 1992, 4500-P B, E
Soluble Reactive Phosphorus	Manual ascorbic acid	Standard Methods, 18th Edition, 1992, 4500-P E
Total Kjeldahl Nitrogen	Digestion, treatment with sodium hypochlorite and sodium phenolate, run of Technicon Autoanalyzer II	USEPA Methods of Chemical Analysis of Water and Wastes, 351.1
Nitrate + Nitrite Nitrogen	Copperized reduction column and Lachat Flow Injection Ion Analyzer	USEPA Methods of Chemical Analysis of Water and Wastes, 353.2
Chlorophyll *a*	Spectrophotometric	Standard Methods, 18th Edition, 1992, 10200 H
pH	Potentiometric measurement, glass electrode	Standard Methods, 18th Edition, 1992, 4500-H B
Specific Conductance	Wheatstone bridge	Standard Methods, 18th Edition, 1992, 2510
Temperature	Thermometric	Standard Methods, 18th Edition, 1992, 2550 B
Dissolved Oxygen	Electrode	Standard Methods, 18th Edition, 1992, 4500-O G
Phytoplankton Identification and Enumeration	Inverted Microscope	Standard Methods, 18th Edition, 1992, 10200 F
Zooplankton Identification and Enumeration	Sedgewick Rafter	Standard Methods, 18th Edition, 1992, 10200 G
Transparency	Secchi disc	

C.2 Ecosystem Data Collection

Ecosystem data collected from April to September 2002 included:

- **Phytoplankton—**A composite 0-2 meter sample was collected during each water quality sampling event during the period April 2002 thorough September 2002.
- **Zooplankton—**A zooplankton sample was collected (i.e., bottom to surface tow) during each water quality sample event during the period April 2002 thorough September 2002.
- **Macrophytes—**Macrophyte surveys were completed during June and August 2002.

Phytoplankton and zooplankton samples were identified and enumerated to provide information on species diversity and abundance. The macrophyte community was surveyed to determine species locations, composition, and abundance.

C.3 Watershed Pond Survey

During 2003, Duck Lake and three ponds in the Duck Lake watershed were surveyed. The bathymetry of Duck Lake and the ponds were determined in the survey. This work was completed to establish the bathymetry of Duck Lake and to help establish current conditions of water bodies that affect the flow of storm water runoff from the Duck Lake watershed. The survey of Duck Lake and the wet detention ponds began by recording the type and size of the outlet and estimating the height to the low overflow point. A Global Positioning System (GPS) was then used to record the perimeter of Duck Lake and each pond. Staff walked the perimeter and used the GPS to record the longitude and latitude of selected points along the perimeter. A grid was then marked off on the pond with points approximately 20 feet apart. A depth gage was dropped to the bottom to get the water depth at each survey point. The grid points and associated water depths were then recorded on a map of the pond. The maps were then placed in the Geographical Information System (GIS) and pond volumes, both dead and live storage, were determined. The information was used for P8 modeling of the Lotus Lake watershed to determine the lake's watershed phosphorus load.

Pond data from pond P-3 located in subwatershed DL3 (see Figure 1 of this report) is summarized in Appendix A. The information was used for water quality modeling of the Duck Lake watershed. Data from the other two ponds surveyed are not included in this report. The stormwater detention pond located in subwatershed DL7 (see Figure 1 of this report) does not contribute runoff to Duck Lake. The pond does not have an outlet and all the stormwater is infiltrated or evaporated. A natural wetland located in subwatershed DL2 (see Figure 1 of this report) does not receive runoff from stormwater conveyance system S10. The wetland receives runoff from the land immediately surrounding the wetland. Hence, only pond P-3 treats stormwater runoff from the lake's watershed and conveys the treated runoff to the lake.

Appendix D

P8 Model Parameter Selection

Appendix D: P8 Model Parameter Selection

P8 version 2.4 was used for Duck Lake watershed modeling. The parameters selected for the Duck Lake P8 model are discussed in the following paragraphs. P8 parameters not discussed in the following paragraphs were left at the default setting.

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

- **Time Steps Per Hour (Integer)—2**. Selection was based upon the number of time steps required to eliminate continuity errors greater than 2 percent.
- **Minimum Inter-Event Time (Hours)—10.** The selection of this parameter was based upon an evaluation of storm hydrographs to determine which storms should be combined and which storms should be separated to accurately depict runoff from the lake's watershed.
- **Snowmelt Factors—Melt Coef (Inches/Day-Deg-F)—0.06**. The selection was based upon the snowmelt rate that provided the best match between the observed and predicted snowmelt.
- **Snowmelt Factors—Scale Factor For Max Abstraction—1**. This factor controls the quantity of snowmelt runoff (i.e., controls losses due to infiltration). Selection was based upon the factor that resulted in the closest fit between modeled and observed runoff volumes.
- **Growing Season/Non-Growing Season AMC-II = 1.4 and AMC-III = 2.1 (growing season); AMC-II = 0.5 and AMC-III = 1.1 (non-growing season)**. This indicates that AMC-II is used if the 5-day antecedent moisture is 1.4 inches or greater during the growing season and 0.5 inches or greater during the non-growing season and AMC-III is used if antecedent moisture is 2.1 (growing season) or 1.1 (non-growing season) inches or greater.

Particle Scale Factor (Case-Edit-Components)

- **Scale Fac.—tp—1.0** The particle scale factor adjusts phosphorus loading for site specific factors. A factor of 1.0 indicates no adjustment.

Particle File Selection (Case—Read—Particles)

- **NURP50PAR**. The NURP 50 particle file was used to predict phosphorus loading and settling in wet detention ponds.

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

- **9002duck.PCP**. The precipitation file 9002duck.PCP is comprised of hourly precipitation data during the period 1990 through 2002. Data were obtained from the Minneapolis-St. Paul International Airport prior to 1998. During 1998 through 2002, precipitation for the Duck Lake watershed was calculated using monthly grids created from State Climatologist data. The monthly precipitation amounts were compared with hourly precipitation amounts recorded by a gage in Eden Prairie to determine the adjustment factor that would convert the

Eden Prairie data to equal the monthly Duck Lake watershed data. Then the adjustment factor was applied to the hourly Eden Prairie rainfall amounts to adjust them so that the monthly Eden Prairie rainfall would equal the monthly Duck Lake watershed rainfall amounts.

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

- **MSP4902.TMP**. The temperature file was comprised of temperature data from the Minneapolis—St. Paul International airport during the period 1949 through 2002.

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

- **Pond Bottom**—The surface area of the pond bottom of each detention pond was determined and entered here.
- **Detention Pond—Permanent Pool—Area and Volume—**The surface area and dead storage volume of each detention pond was determined and entered here.
- **Detention Pond—Flood Pool—Area and Volume—**The surface area and storage volume under flood conditions (i.e., the storage volume between the normal level and flood elevation) was determined and entered here.
- **Detention Pond—Orifice Diameter and Weir Length—**The orifice diameter or weir length was determined for each detention pond and entered here.
- **Detention Pond or Generalized Device—Particle Removal Scale Factor—**0.3 for ponds less than 2 feet deep, 0.6 for ponds from 2 to 3 feet deep, and 1 for all ponds 3 feet deep or greater. The particle removal factor for watershed devices determines particle removal by devices.
- **Detention Pond or Generalized Device—Outflow Device No's—**The number of the downstream device receiving water from the detention pond outflow was entered for infiltration, normal, and spillway.
- **Generalized Device—**Infiltration Outflow Rates (cfs)—0 for all ponds.
- **Detention Pond—Infiltration Rate (in/hr)—**0 for all ponds.
- **Pipe/Manhole—Time of Concentration—**The time of concentration for each pipe/manhole device was determined and entered here. A "dummy" pipe/manhole device was placed immediately upstream of each pond and a time of concentration of 0 hours per "dummy" pipe was generally selected. Because the timing of stormwater runoff was not an issue in this watershed, in general, no lag time was needed. However, a lag time of 2 hours was used for subwatershed 1a. A "dummy" pipe called Duck Lake was used to combine all of the inflow pipes into one source. The Duck Lake pipe in each model received all water and phosphorus loads that enter Duck Lake. A time of concentration of 0 was used for the Duck Lake pipe in each model. Use of the pipe forced each model to total the water and phosphorus loads entering the lake, thus avoiding hand tabulation.

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

- **Outflow Device Number—**The device number of the device receiving runoff from the watersheds was selected.
- **Pervious Curve Number—**A weighted SCS curve number was used as outlined in the following procedure. The P8 Pre-Processor (GIS algorithm) was used to compute a SCS curve number for each watershed. The computation was based upon soil types in the watershed, land use, and hydrologic conditions. The computation also weighted the pervious curve number with indirect (i.e., disconnected) impervious areas in each sub watershed as follows:

WCN = {[(Indirect Impervious Area) * (98)] + [(Pervious Area) * (Pervious Curve Number)]}/(Total Area)

The assumptions for direct, indirect, and total impervious areas were based upon measurements from representative areas within the Duck Lake watershed.

- **Swept/Not Swept—**An "unswept" assumption was made for the entire impervious watershed area. A sweeping frequency of 0 was selected for swept. Hence, selected parameters were placed in the unswept category, including impervious fraction, depression storage, impervious runoff coeff, and scale factor for particle loads.
- **Impervious Fraction—**The direct or connected impervious fraction for each subwatershed was determined and entered here. The direct or connected impervious fraction includes driveways and parking areas that are directly connected to the storm sewer system. The P8 pre-processor performed the computations to determine impervious fractions for the subwatersheds. The direct impervious fraction for each subwatershed was based upon measurements from representative areas within the Duck Lake watershed. The direct impervious fraction for each land use type was weighted with the acres of each land use to obtain a weighted average for each subwatershed.
- **Depression Storage—**0.03
- **Impervious Runoff Coef.—**0.94

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

- **Passes Thru Storm File—3**. The number of passes through the storm file was determined after the model had been set up and a preliminary run completed. The selection of the number of passes through the storm file was based upon the number required to achieve model stability. Multiple passes through the storm file were required because the model assumes that dead storage waters contain no phosphorus. Consequently, the first pass through the storm file results in lower phosphorus loading than occurs with subsequent passes. Stability occurs when subsequent passes do not result in a change in phosphorus concentration in the pond waters. It was determined that all three P8 models (i.e., wet, dry, average) achieved stability at 3 passes.

Appendix E

Monitoring Data

Appendix E-1

2002 Monitoring Data

Duck Lake

Date	Max Depth (m)	Sample Depth (m)	Secchi Depth (m)	Chl. a (mg/cu.m)	Turbidity (NTU's)	D. O. (mg/L)	Temp (°C)	Sp. Cond. (µmho/cm @ 25°C)	Total P (mg/L)	Ortho P (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Nitrate + Nitrite Nitrogen (mg/L)	pH (S.U.)
04/30/02	3.0	0-2	2.2	11.0	5.0	--	--	--	0.044	<0.006	1.2	<0.02	8.7
		0.0				12.1	9.8	260					
		1.0				11.9	9.7	260					
		2.0				11.8	9.4	261					
		2.5				11.0	9.3	263	0.048				8.8
06/10/02	2.4	0-2	2.0	11.0	5.0	--	--	--	0.059	0.008	1.2	<0.02	10.2
		0.0				12.2	22.2	239					
		1.0				12.2	22.2	239					
		2.0				0.3	18.5	250	0.054				10.3
07/09/02	2.4	0-2	0.6	74.0	26.0	--	--	--	0.096	<0.006	2.0	<0.02	9.7
		0.0				13.8	28.0	247					
		1.0				13.6	28.0	247					
		2.0				0.3	27.1	250	0.100				9.8
08/07/02	2.4	0-2	0.3	40.0	30.0	--	--	--	0.176	0.013	2.0	<0.02	9.4
		0.0				8.4	23.1	236					
		1.0				8.4	23.1	236					
		2.0				8.3	23.1	236	0.177				9.4
08/20/02	2.4	0-2	0.3	47.0	50.0	--	--	--	0.162	0.010	1.7	<0.02	9.3
		0.0				12.8	22.2	235					
		1.0				12.4	22.2	235					
		2.0				2.9	21.4	239	0.171				9.4
09/05/02	2.4	0-2	0.3	56.0	44.0	--	--	--	0.191	0.019	2.5	<0.02	9.1
		0.0				9.5	23.3	236					
		1.0				9.4	23.3	236					
		2.0				9.2	23.3	236	0.190				9.0

DUCK LAKE

SAMPLE: 0-2 METERS (INT. TUBE)
STANDARD PHYTOPLANKTON CLUMP COUNT

DIVISION	TAXON	6/11/2002 units/mL	7/10/2002 units/mL	8/7/2002 units/mL	8/20/2002 units/mL	9/5/2002 units/mL
CHLOROPHYTA (GREEN ALGAE)	*Ankistrodesmus Brauni*	0	21	0	0	0
	Chlamydomonas globosa	253	42	156	234	195
	Oocystis parva	0	274	0	0	156
	Pandorina morum	232	0	0	0	0
	Pediastrum Boryanum	21	0	0	0	0
	Quadrigula sp.	0	0	39	0	0
	Schroederia Judayi	527	21	39	0	39
	Scenedesmus quadricauda	21	0	0	39	0
	Scenedesmus sp.	0	0	39	0	39
	CHLOROPHYTA TOTAL	**1,053**	**358**	**273**	**273**	**429**
CHRYSOPHYTA (YELLOW-BROWN ALGAE)	*Dinobryon sociale*	0	0	0	0	0
	CHRYSOPHYTA TOTAL	**0**	**0**	**0**	**0**	**0**
CYANOPHYTA (BLUE-GREEN ALGAE)	*Anabaena affinis*	0	169	0	195	39
	Anabaena flos-aquae	0	3,203	39	78	0
	Anabaena spiroides v. crassa	21	21	0	0	0
	Anabaenopsis raciborski	0	0	0	0	39
	Aphanizomenon flos-aquae	0	2,655	0	39	39
	Microcystis aeruginosa	379	5,415	6,168	4,138	5,036
	Microcystis incerta	21	63	0	0	0
	Phormidium mucicola	0	906	1,757	1,874	1,484
	CYANOPHYTA TOTAL	**421**	**11,525**	**6,207**	**4,451**	**5,153**
BACILLARIOPHYTA (DIATOMS)	*Fragilaria capucina*	0	0	117	0	0
	Fragilaria crotonensis	0	63	0	0	0
	Melosira granulata	0	0	0	39	39
	Navicula sp.	0	42	0	0	0
	Stephanodiscus sp.	0	42	0	0	0
	BACILLARIOPHYTA TOTAL	**0**	**147**	**117**	**39**	**39**
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas erosa*	1,117	126	39	78	78
	CRYPTOPHYTA TOTAL	**1,117**	**126**	**39**	**78**	**78**
EUGLENOPHYTA (EUGLENOIDS)	*Euglena sp.*	0	0	0	0	0
	Phacus sp.	0	0	0	0	0
	EUGLENOPHYTA TOTAL	**0**	**0**	**0**	**0**	**0**
PYRRHOPHYTA (DINOFLAGELLATES)	*Ceratium hirundinella*	63	105	39	0	78
	Peridinium cinctum	0	0	0	0	0
	PYRRHOPHYTA TOTAL	**63**	**105**	**39**	**0**	**78**
	TOTALS	**2,655**	**12,263**	**6,676**	**4,841**	**5,778**

DUCK LAKE

ZOOPLANKTON ANALYSIS

DIVISION	TAXON	6/11/2002	7/9/2002	8/7/2002	8/20/2002	9/5/2002
	Vertical Tow (m)					
		#/m2	#/m2	#/m2	#/m2	#/m2
CLADOCERA	*Bosmina longirostris*	0	0	10,522	20,867	0
	Ceriodaphnia sp.	0	43,856	10,522	20,867	118,836
	Chydorus sphaericus	0	21,928	52,610	177,369	9,903
	Daphnia ambigua	0	0	0	0	0
	Daphnia galeata mendotae	44,210	32,892	21,044	93,901	19,806
	Daphnia pulex	11,052	10,964	0	0	0
	Daphnia retrocurva	0	0	0	0	0
	Diaphanosoma leuchtenbergianum	0	0	0	0	0
	Immature Cladocera	0	0	0	10,433	0
	CLADOCERA TOTAL	**55,262**	**109,640**	**94,697**	**323,438**	**148,545**
COPEPODA	*Cyclops sp.*	33,157	43,856	0	0	0
	Diaptomus sp.	0	10,964	10,522	10,433	0
	Nauplii	88,419	164,460	126,263	93,901	148,545
	Copepodid	44,210	0	0	0	0
	COPEPODA TOTAL	**165,786**	**219,280**	**136,785**	**104,335**	**148,545**
	Asplanchna priodonta	110,524	0	0	0	0
	Filinia longiseta	0	0	94,697	281,704	990,297
	Lecane sp.	22,105	0	0	0	0
	Keratella cochlearis	364,730	65,784	641,837	365,172	89,127
	Keratella quadrata	0	0	0	0	0
	Kellicottia sp.	22,105	0	0	0	0
	Polyarthra vulgaris	0	0	0	0	0
ROTIFERA	*Trichocerca cylindrica*	11,052	65,784	31,566	31,300	257,477
	Trichocerca multicrinis	0	0	0	0	0
	ROTIFERA TOTAL	**530,516**	**131,568**	**768,099**	**678,177**	**1,336,902**
	TOTALS	**751,565**	**460,488**	**999,581**	**1,105,950**	**1,633,991**

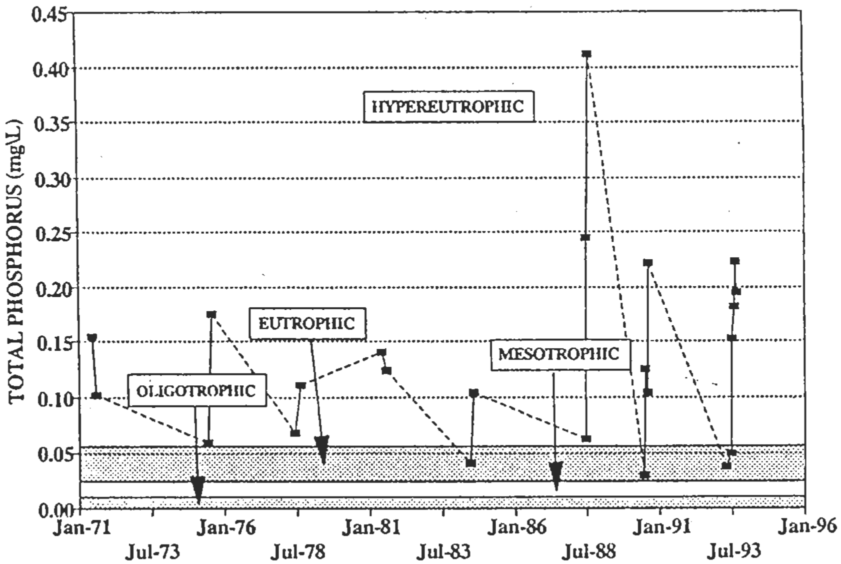
Appendix E-2

Historical Monitoring Data

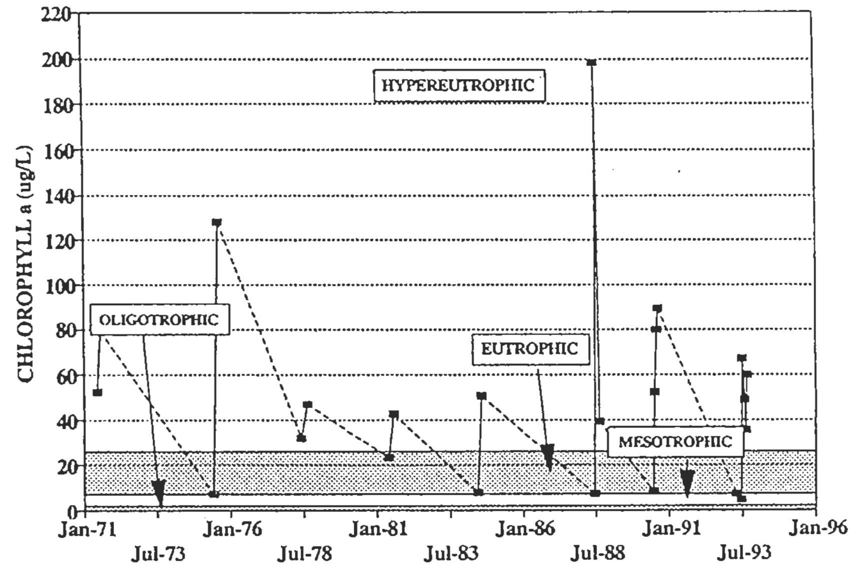
Appendix E-2

Historical Monitoring Data

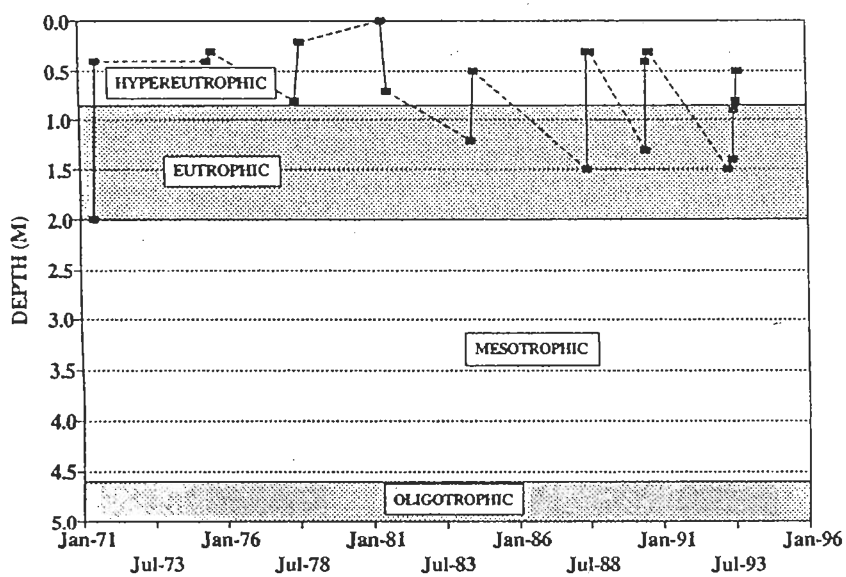
DUCK LAKE: 1971-1993
EPILIMNETIC TOTAL PHOSPHORUS



DUCK LAKE: 1971-1993
EPILIMNETIC CHLOROPHYLL a



DUCK LAKE: 1971-1993
SECCHI DISC TRANSPARENCIES



CHANGES IN CONCENTRATIONS OF TOTAL PHOSPHORUS, CHLOROPHYLL a, AND SECCHI DISC TRANSPARENCIES FOR DUCK LAKE, 1971-1993

Predominant Algal Taxa Encountered in Summer (June-August) Samples from Duck Lake
1975-1993

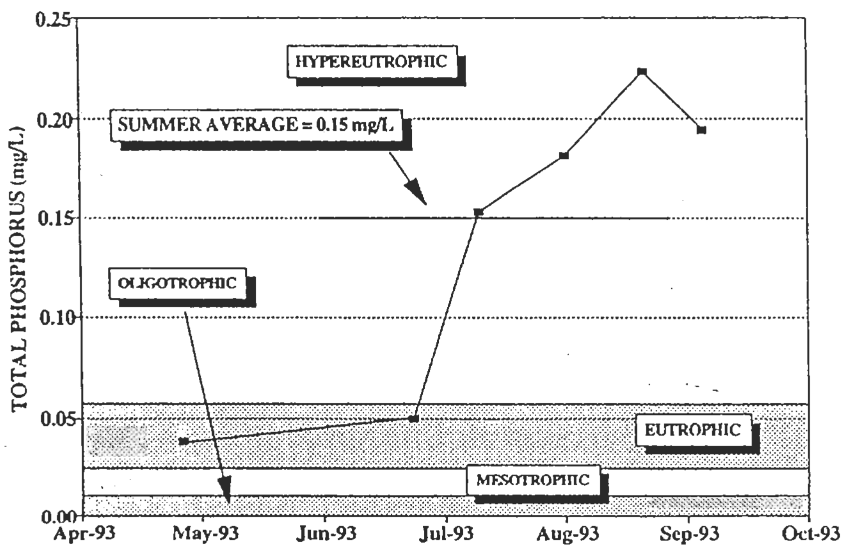
Lake	Year	Division	Taxa
Duck	1975	Cyanophyta (blue-green algae)	Aphanizomenon flos-aquae
	1978	Cyanophyta (blue-green algae)	Aphanizomenon flos-aquae
	1981	Cyanophyta (blue-green algae)	Aphanizomenon flos-aquae
	1984	Cyanophyta (blue-green algae)	Oscillatoria limnetica, Aphanizomenon flos-aquae
	1988	Cyanophyta (blue-green algae)	Microcystis aeruginosa, Aphanizomenon flos-aquae
	1990	Cyanophyta/Chlorophyta (blue-green/green algae)	Aphanizomenon flos-aquae, Merismopedia tennissima/Chlamydomonas globosa
	1993	Chlorophyta/Cyanophyta (green/blue-green algae)	Pediastrum duplex v. clathantum, Schroederia judayi/ Aphanizomenon flos-aquae

2327053\34643-1/YMH

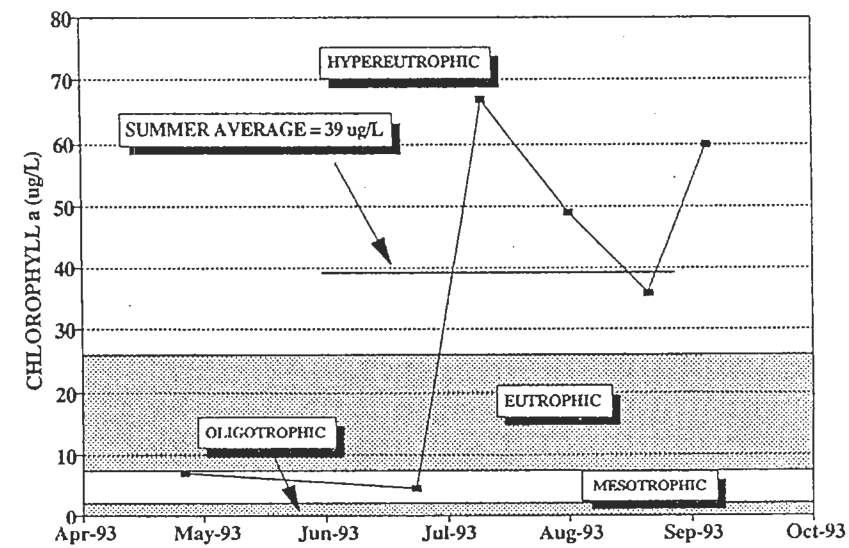
Duck Lake Zooplankton Data Summary
1981-1993

		Thousands of Organisms/m^2		
Year	**Date**	**Cladocera**	**Copepods**	**Rotifers**
1981	8/10	84	853	948
1984	8/2	196	573	995
1988	8/18	9	149	47
1990	6/19	27	286	1,006
	7/10	276	560	910
	8/1	288	176	128
	8/21	33	128	45
	9/11	184	152	58
1993	6/25	248	117	4
	7/12	460	261	36
	8/3	392	331	213
	8/24	146	401	288
	9/7	175	130	159

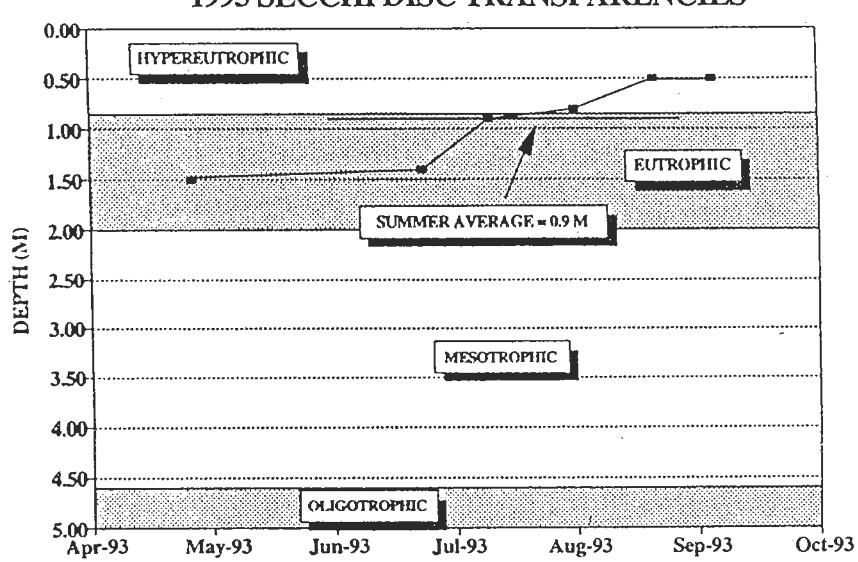
DUCK LAKE
1993 EPILIMNETIC TOTAL PHOSPHORUS



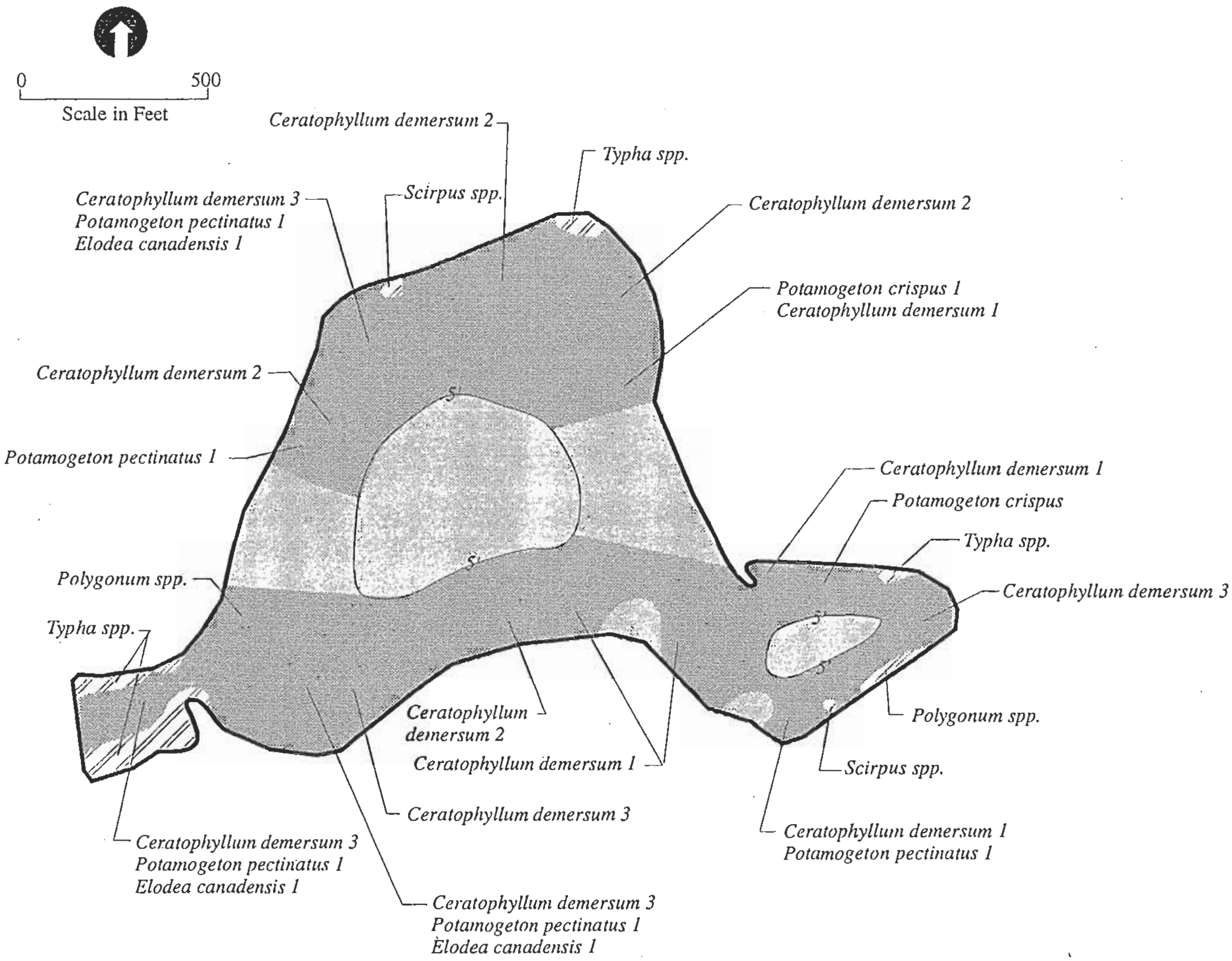
DUCK LAKE
1993 EPILIMNETIC CHLOROPHYLL a



DUCK LAKE
1993 SECCHI DISC TRANSPARENCIES

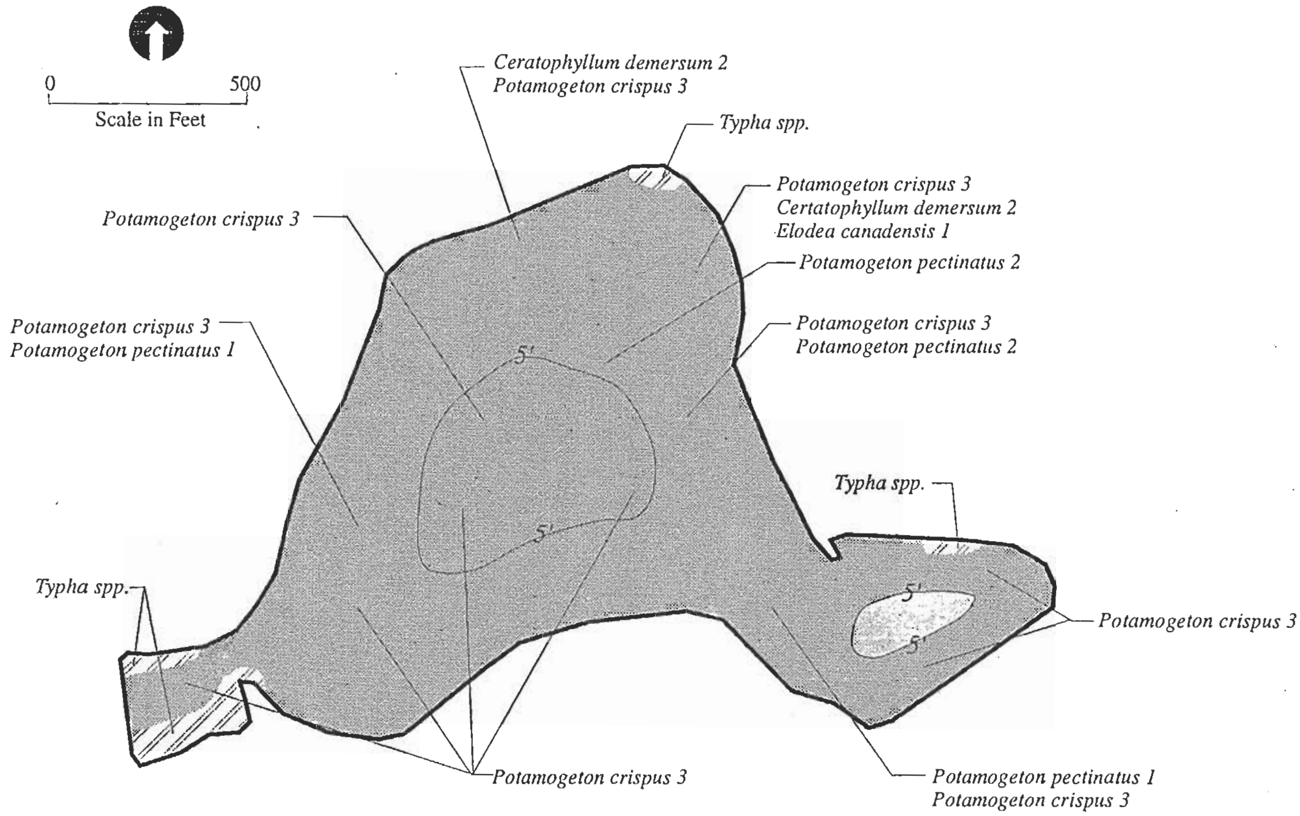


CHANGES IN CONCENTRATIONS OF TOTAL PHOSPHORUS, CHLOROPHYLL a, AND SECCHI DISC TRANSPARENCIES FOR DUCK LAKE, 1993



	Common Name	Scientific Name
Submerged Aquatic Plants:	Coontail Curly Leaf Pondweed Canada Waterweed Sago Pondweed	*Ceratophyllum demersum* *Potamogeton crispus* *Elodea canadensis* *Potamogeton pectinatus*
Floating Leaf Plants:	None	
Emergent Plants:	Bulrush Cattail Smartweed	*Scirpus spp.* *Typha spp.* *Polygonum spp.*
No Aquatic Vegetation Found:		

Duck Lake Plant Communities, August 24, 1993. No Macrophytes Found in Water >5.0' Macropnyte Densities Estimated As Follows: 1= light; 2= moderate; 3= heavy.



	Common Name	Scientific Name
Submerged Aquatic Plants:	Coontail Curly Leaf Pondweed Canada Waterweed Sago Pondweed	*Ceratophyllum demersum* *Potamogeton crispus* *Elodea canadensis* *Potamogeton pectinatus*
Floating Leaf Plants:	None	
Emergent Plants:	Cattail	*Typha spp.*
No Aquatic Vegetation Found:		

Duck Lake Plant Communities, June 25, 1993. No Macrophytes Found in Water >5.0' Macrophyte Densities Estimated As Follows: 1= light; 2= moderate; 3= heavy.

Duck Lake Water Quality Data

Date	Max. Depth (meters)	Secchi Disc (meters)	Depth (meters)	Chl a (ug/L)	Temp. (C)	D.O. (mg/l)	Specific Cond. (umho/cm @ 25 degrees C)	Total P (mg P/L)	Ortho P (mg P/L)	Total N (mg N/L)	TN:TP	pH (S. U.)
04/27/93	2.1	1.5	0-1.5	7.0	--	--	--	0.038	<0.010	0.98	26	8.6
			0.0	--	11.0	10.9	333	--	--	--	--	--
			1.0	--	11.0	10.9	336	--	--	--	--	--
			1.5	--	11.0	10.9	339	0.040	--	--	--	--
06/25/93	2.1	1.4	0-1.5	4.6	--	--	--	0.050	--	0.68	14	8.5
			0.0	--	21.0	5.2	259	--	--	--	--	--
			1.0	--	20.0	2.2	270	--	--	--	--	--
			1.5	--	19.0	1.1	274	0.090	--	--	--	7.9
07/12/93	2.4	0.9	0-1.9	66.8	--	--	--	0.153	<0.010	1.13	7	8.0
			0.0	--	23.0	11.1*	262	--	--	--	--	--
			0.5	--	23.0	11.1*	262	--	--	--	--	--
			1.0	--	23.0	11.1*	262	--	--	--	--	--
			1.5	--	23.0	11.0*	265	--	--	--	--	--
			1.9	--	22.5	4.0	273	0.151	--	--	--	8.0

(shaded) denotes conditions unfavorable for the survival of gamefish

* Values were greater than saturation values.

Duck Lake Water Quality Data

Date	Max. Depth (meters)	Secchi Disc (meters)	Depth (meters)	Chl a (ug/L)	Temp. (C)	D.O. (mg/l)	Specific Cond. (umho/cm @ 25 degrees C)	Total P (mg P/L)	Ortho P (mg P/L)	Total N (mg N/L)	TN:TP	pH (S. U.)
08/03/93	2.1	0.8	0-1.6	49.0	--	--	--	0.182	<0.010	1.80	10	8.0
			0.0	--	23.0	7.5	281	--	--	--	--	--
			1.0	--	23.0	7.4	281	--	--	--	--	--
			1.6	--	23.0	7.3	281	0.182	--	--	--	8.0
08/23/93	2.4	0.5	0-1.9	35.7	--	--	--	0.223	0.040	1.97	9	8.1
			0.0	--	23.5	4.8	258	--	--	--	--	--
			1.0	--	23.5	4.4	258	--	--	--	--	--
			1.9	--	23.5	4.2	258	0.230	--	--	--	8.1
09/07/93	2.1	0.5	0-1.5	59.8	--	--	--	0.195	0.034	1.37	7	9.1
			0.0	--	19.0	8.5	246	--	--	--	--	--
			1.0	--	19.0	8.5	246	--	--	--	--	--
			1.5	--	19.0	8.5	246	0.169	--	--	--	9.1

(shaded) denotes conditions unfavorable for the survival of gamefish

PHYTOPLANKTON UNIT (CLUMP) COUNT

RILEY-PURGATORY-BLUFF CREEK WATERSHED DISTRICT

LAKE: DUCK LAKE

SAMPLE DEPTH: 0-1.5 METERS

SAMPLE DATE: 06/25/93

DIVISION	TAXON	UNITS/ML
CHLOROPHYTA (GREEN ALGAE)	*Schroederia Judayi*	859
	Chlamydomonas globosa	781
	Cosmarium sp.	39
	Selenastrum minutum	39
	Sphaerocystis Schroeteri	39
CHRYSOPHYTA (GOLDEN-BROWN ALGAE)	--	--
CYANOPHYTA (BLUE-GREEN ALGAE)	*Lyngbya sp.*	39
BACILLARIOPHYTA (DIATOMS)	*Synedra ulna*	39
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas erosa*	1,093
EUGLENOPHYTA (EUGLENOIDS)	--	--
PYRROPHYTA (DINOFLAGELLATES)	*Ceratium hirundinella*	39
	TOTAL	2,967

PHYTOPLANKTON UNIT (CLUMP) COUNT

RILEY-PURGATORY-BLUFF CREEK WATERSHED DISTRICT

LAKE: DUCK LAKE

SAMPLE DEPTH: 0-1.9 METERS

SAMPLE DATE: 07/12/93

DIVISION	TAXON	UNITS/ML
CHLOROPHYTA (GREEN ALGAE)	*Schroederia Judayi*	1,796
	Chlamydomonas globosa	625
	Sphaerocystis Schroeteri	234
	Botryococcus sudeticus	195
	Pediastrum duplex v. clathratum	6,090
	Elakatothrix viridis	78
	Closterium sp.	39
	Franceia sp.	39
	Oocystis parva	39
	Scenedesmus quadricauda	39
CHRYSOPHYTA (GOLDEN-BROWN ALGAE)	--	--
CYANOPHYTA (BLUE-GREEN ALGAE)	*Anabaena flos-aquae*	2,030
	Anabaena spiroides v. crassa	117
	Microcystis aeruginosa	39
BACILLARIOPHYTA (DIATOMS)	*Melosira granulata*	156
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas erosa*	1,249
EUGLENOPHYTA (EUGLENOIDS)	*Euglena sp.*	117
PYRROPHYTA (DINOFLAGELLATES)	--	--
	TOTAL	12,883

PHYTOPLANKTON UNIT (CLUMP) COUNT

RILEY-PURGATORY-BLUFF CREEK WATERSHED DISTRICT

LAKE: DUCK LAKE

SAMPLE DEPTH: 0-1.6 METERS

SAMPLE DATE: 08/03/93

DIVISION	TAXON	UNITS/ML
CHLOROPHYTA (GREEN ALGAE)	*Schroederia Judayi*	2,225
	Scenedesmus quadricauda	1,796
	Chlamydomonas globosa	1,562
	Pandorina morum	1,288
	Dictyosphaerium Ehrenbergianum	1,015
	Pediastrum duplex v. clathratum	586
	Oocystis parva	468
	Botryococcus sudeticus	312
	Selenastrum minutum	234
	Sphaerocystis Schroeteri	156
	Staurastrum sp.	78
	Closterium sp.	39
	Scenedesmus sp.	39
	Tetraedron minimum	39
CHRYSOPHYTA (GOLDEN-BROWN ALGAE)	--	--
CYANOPHYTA (BLUE-GREEN ALGAE)	*Aphanizomenon flos-aquae*	468
	Microcystis aeruginosa	468
	Microcystis incerta	156
	Anabaena spiroides v. crassa	117
	Coelosphaerium Naegelianum	117
	Merismopedia tenuissima	78
	Oscillatoria Agardhii	78
	Anabaena flos-aquae	39
BACILLARIOPHYTA (DIATOMS)	*Stephanodiscus Hantzschii*	1,952
	Melosira granulata	351
	Cocconeis placentula	39
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas erosa*	742
EUGLENOPHYTA (EUGLENOIDS)	*Phacus sp.*	78
PYRROPHYTA (DINOFLAGELLATES)	--	--
	TOTAL	14,523

PHYTOPLANKTON UNIT (CLUMP) COUNT

RILEY-PURGATORY-BLUFF CREEK WATERSHED DISTRICT

LAKE: DUCKLAKE

SAMPLE DEPTH: 0-2 METERS

SAMPLE DATE: 08/23/93

DIVISION	TAXON	UNITS/ML
CHLOROPHYTA (GREEN ALGAE)	*Chlamydomonas globosa*	664
	Botryococcus sudeticus	195
	Oocystis parva	117
	Actinastrum Hantzschii	78
	Ankistrodesmus falcatus	78
	Closterium sp.	78
	Franceia sp.	78
	Dictyosphaerium Ehrenbergianum	39
	Selenastrum minutum	39
CHRYSOPHYTA (GOLDEN-BROWN ALGAE)	--	--
CYANOPHYTA (BLUE-GREEN ALGAE)	*Aphanizomenon flos-aquae*	1,640
	Oscillatoria limnetica	937
	Anabaena flos-aquae	429
	Oscillatoria Agardhii	156
	Anabaena affinis	78
	Merismopedia tenuissima	78
	Microcystis aeruginosa	78
	Anabaena spiroides v. crassa	39
	Aphanocapsa delicatissima	39
	Microcystis incerta	39
BACILLARIOPHYTA (DIATOMS)	*Stephanodiscus Hantzschii*	117
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas erosa*	1,249
EUGLENOPHYTA (EUGLENOIDS)	--	--
PYRROPHYTA (DINOFLAGELLATES)	*Ceratium hirundinella*	586
	TOTAL	6,832

PHYTOPLANKTON UNIT (CLUMP) COUNT

RILEY-PURGATORY-BLUFF CREEK WATERSHED DISTRICT

LAKE: DUCK LAKE

SAMPLE DEPTH: 0-1.5 METERS

SAMPLE DATE: 09/07/93

DIVISION	TAXON	UNITS/ML
CHLOROPHYTA (GREEN ALGAE)	*Chlamydomonas globosa*	468
	Scenedesmus quadricauda	156
	Ankistrodesmus Brauni	78
	Pediastrum duplex	78
	Tetraedron minimum	78
	Closterium sp.	39
	Oocystis parva	39
	Schroederia Judayi	39
	Selenastrum minutum	39
	Sphaerocystis Schroeteri	39
CHRYSOPHYTA (GOLDEN-BROWN ALGAE)	--	--
CYANOPHYTA (BLUE-GREEN ALGAE)	*Coelosphaerium Naegelianum*	4,685
	Oscillatoria Agardhii	3,787
	Anabaena affinis	781
	Aphanizomenon flos-aquae	703
	Microcystis aeruginosa	117
	Microcystis incerta	78
	Anabaena spiroides v. crassa	1,523
BACILLARIOPHYTA (DIATOMS)	*Fragilaria capucina*	195
	Melosira granulata	78
	Amphora ovalis	39
	Asterionella formosa	39
	Cocconeis placentula	39
	Navicula sp.	39
	Stephanodiscus Hantzschii	39
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas erosa*	312
EUGLENOPHYTA (EUGLENOIDS)	--	--
PYRROPHYTA (DINOFLAGELLATES)	--	--
	TOTAL	13,508

ZOOPLANKTON COUNT
VERTICAL TOW (BOTTOM TO SURFACE)

Lake: **Duck**
Sample Date: **6/25/93**

Division	Taxon	#/M2	Avg Body Length (mm)
Cladocera	*Daphnia galeata mendotae*	28,294	0.62
	Diaphanosoma sp.	14,147	0.33
	Chydorus sphaericus	31,831	0.19
	Ceriodaphnia sp.	130,861	0.63
Copepoda	Nauplii	74,272	--
	Cyclops sp.	3,537	--
	Mesocyclops sp.	21,221	--
	Diaptomus sp.	17,684	--
Rotifera	*Keratella cochlearis*	3,537	--
	Total:	325,383	

ZOOPLANKTON COUNT
VERTICAL TOW (BOTTOM TO SURFACE)

Lake: **Duck**
Sample Date: **7/12/93**

Division	Taxon	#/M2	Avg Body Length (mm)
Cladocera	*Daphnia galeata mendotae*	87,005	0.97
	Diaphanosoma sp.	14,501	0.23
	Bosmina sp.	116,006	0.34
	Chydorus sphaericus	61,628	0.29
	Ceriodaphnia sp.	181,260	0.60
Copepoda	Nauplii	195,761	--
	Cyclops sp.	3,625	--
	Mesocyclops sp.	21,751	--
	Diaptomus sp.	39,877	--
Rotifera	*Keratella cochlearis*	3,625	--
	Polyarthra vulgaris	32,627	--
	Total:	757,666	

ZOOPLANKTON COUNT
VERTICAL TOW (BOTTOM TO SURFACE)

Lake: **Duck**
Sample Date: **8/3/93**

Division	Taxon	#/M2	Avg Body Length (mm)
Cladocera	*Daphnia galeata mendotae*	53,228	0.54
	Daphnia parvula	7,604	0.19
	Diaphanosoma sp.	19,010	0.13
	Bosmina longirostris	83,645	0.36
	Chydorus sphaericus	3,802	
	Ceriodaphnia sp.	171,092	0.54
Copepoda	Nauplii	277,549	--
	Mesocyclops sp.	30,416	--
	Diaptomus sp.	22,812	--
Rotifera	*Keratella cochlearis*	212,914	--
	Total:	882,072	

ZOOPLANKTON COUNT
VERTICAL TOW (BOTTOM TO SURFACE)

Lake: **Duck**
Sample Date: **8/24/93**

Division	**Taxon**	**#/M2**	**Avg Body Length (mm)**
Cladocera	*Daphnia galeata mendotae*	33,157	0.70
	Diaphanosoma sp.	36,473	0.42
	Bosmina longirostris	56,367	0.36
	Chydorus sphaericus	19,894	0.23
Copepoda	Nauplii	358,099	--
	Mesocyclops sp.	29,842	--
	Diaptomus sp.	13,263	--
Rotifera	*Keratella cochlearis*	288,468	--
	Total:	835,563	

ZOOPLANKTON COUNT
VERTICAL TOW (BOTTOM TO SURFACE)

Lake: **Duck**
Sample Date: **9/7/93**

Division	Taxon	#/M2	Avg Body Length (mm)
Cladocera	*Daphnia galeata mendotae*	10,610	0.31
	Diaphanosoma sp.	21,221	0.44
	Bosmina longirostris	132,629	0.31
	Chydorus sphaericus	10,610	
Copepoda	Nauplii	95,493	--
	Cyclops sp.	7,958	--
	Mesocyclops sp.	21,221	--
	Diaptomus sp.	5,305	--
Rotifera	*Keratella cochlearis*	159,155	--
	Total:	464,202	