LIMNOLOGICAL STUDY AND AQUATIC PLANT MANAGEMENT PLAN

LITTLE ELKHART LAKE SHEBOYGAN COUNTY, WISCONSIN

May 8, 2003

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1.0 EXECUTIVE SUMMARY

Little Elkhart Lake is a ground water seepage lake located in north-central Sheboygan County, Wisconsin. Excessive aquatic plant growth and fishery issues were believed to be hindering full utilization of the Lake's resources. The Little Elkhart Lake Rehabilitation District received a grant to evaluate water quality and complete an Aquatic Plant Management Plan (APM Plan). The District contracted Northern Environmental Technologies, Incorporated (Northern Environmental) to complete the study.

In summary, water quality in Little Elkhart Lake is fair to good. The lake's trophic status is mesotrophic. According to a relatively simple model, agricultural and rural residential land uses are the greatest contributors of the external sources of nutrients to Little Elkhart Lake. Internal sources of phosphorus are also present. Phosphorus in the water likely precipitates out in marl and bound in the sediments. However, it can be released back to the water column following spring and fall lake mixing events.

The aquatic plant survey identified 21 floating leaf and submersed aquatic plant species in Little Elkhart Lake. Certain shoreline areas contain high value species, such as *Brasenia schreberi* (watershield) and *Potamogeton amplifolius* (large-leaf pondweed). During the June and August 2002 aquatic plant surveys, the most abundant species found presently in Little Elkhart Lake was *Myriophyllum sibiricum* (Northern watermilfoil). *Myriophyllum spicatum* (Eurasian watermilfoil) was the second most abundant species during both surveys. These two watermilfoil species have grown to nuisance levels across much of Little Elkhart Lake. Based on the density and distribution of watermilfoil species and the presence of high value aquatic plant species, it appears that approximately 12 acres of dense milfoil stands can be managed for watermilfoil control and remain protective of sensitive areas and high value species. Aquatic plant management options considered included mechanical harvesting, contract harvesting, chemical treatment with 2,4-D based aquatic herbicides, and chemical treatment with fluridone based herbicides. Northern Environmental recommended the following elements be included in the management plan:

- Decrease nutrient loading from storm water runoff by establishing natural vegetative buffers along the shore. Ensure agricultural best management practices are being implemented.

- Consider evaluating potential lake water phosphorus removal by alteration to the water outlet structure.

- Manage excessive aquatic plants in the proposed management area using chemical treatment with 2,4-D based aquatic herbicide. Evaluate the effectiveness of management by completing an aquatic plant survey after 5 years. Evaluate the cost and feasibility of treatment with fluridone based herbicides in 3 to 5 years.

Details of the findings and plan elements are found in the attached report.

2.0 INTRODUCTION AND STUDY GOALS

Little Elkhart Lake is located in Sections 33 and 34, Town 16N, Range 21E in the town of Rhine located in northwest Sheboygan County, Wisconsin (hereafter referred to as "the Lake"). The Lake location is shown in Figure 1. Historical problems at the Lake include water levels, undesirable fish, periodic winterkills, and aquatic plants. The Little Elkhart Lake Rehabilitation District (the District) was formed in 1975 to manage and improve the quality of the Lake. The District encompasses all of the Lake's shoreline. The District has historically organized and implemented various lake management studies and projects to achieve their goals. This report summarizes the lake management history, discusses the study's goals, describes the methods used to complete the study, summarizes the lakes physical and chemical properties, describes the aquatic plant community, discusses aquatic plant management techniques, and provides a recommended action plan for lake and Aquatic Plant Management (APM).

2.1 Lake Management History

The lake was reportedly chemically treated in 1961 to eradicate an undesirable fish population. A water quality study was completed by Environmental Resource Assessments (ERA) in 1976 and 1977. This study documented the relationship between ground water and lake water levels, in-lake water chemistry, sediment composition, and aquatic plants in the lake. In 1979, a paper titled "Computer Modeling the Effects of Lake Drawdown on the Groundwater System of Little Elkhart Lake" was published for a university project by Jim Ruff and Larry Bardwell. A report discussing management alternatives was prepared by the Wisconsin Department of Natural Resources (WDNR) Office of Inland Lake Renewal (date unknown). The culmination of these efforts provided a good deal of baseline information for management activities on the lake and within the watershed. In 1975 and 1983 in response to resident complaints of high water levels and flooding septic systems, the WDNR artificially pumped the Lake lowering the water level. In the early 1980s, a sanitary sewer system was installed to solve septic system problems from high water levels. The Lake has reportedly had periodic fish winterkills in which only bullheads survive. Winterkills were documented in 1936, 1952, 1959, and 1975. In 1981-1982, the fishery was again eradicated and restocked with largemouth bass and bluegills.

A high level outlet was installed in 1986 to control the water level problems. The District contracted RA Smith to complete a water level control project in 1996. The study prepared a plan for permanent restoration of the existing high level lake outlet, determined the potential impacts of private wells on water levels in the lake, and developed a plan for managing both high and low water levels. In 1990, the WDNR completed an aquatic plant sensitive area report detailing areas requiring protection from certain aquatic plant management activities. In the 1990s, the lake reportedly had an aggressive and successful aquatic plant management program using chemical herbicides. The last treatment occurred in 1998. Since then, aquatic plants have grown to nuisance levels, impeding recreation on the lake.

Current perceived problems on the Lake include an over-abundant aquatic plant community and potential fish winterkills if lake oxygen levels drop too low. The current fishery contains largemouth bass, bluegills, perch, and crappies. The District applied for a Lake Management Planning Grant to develop an APM Plan. The District was awarded the WDNR Lake Management Planning Grant and hired Northern Environmental to complete a limnologic study and prepare an APM Plan.

2.2 Study Goals

The District established goals in their grant application to set long-term management goals for nuisance aquatic vegetation and to protect native plant communities and sensitive areas. Specific components of the long-term goals included:

- Preserve native aquatic plants
- Protect sensitive areas
- Control and prevent the spread of exotic and nuisance plants
- Protect and improve fish and wildlife habitat
- Improve recreation opportunities
- Research potential sources of pollutants in the Lakes' watershed

3.0 INVESTIGATIVE METHODS

The goal of this study is to collect and interpret basic data and produce recommendations allowing the District to make better-educated decisions regarding APM options. The study primarily followed the outline in the grant application, which included aquatic plant surveys, collection of chemical water quality data, and an evaluation of potential pollutant sources within the watershed. These actions not only helped develop an APM Plan, but will assist in the potential management of the overall lake ecosystem in the future.

3.1 Existing Data Review

Many factors influence lake water quality. Water quality governs the assemblage of plants and animals inhabiting a lake. Northern Environmental consulted a wide variety of existing resources to produce data that help illustrate water quality. These data sources include:

- Local and regional pedologic, geologic, limnologic, hydrologic, and hydrogeologic research
- Discussions with District members
- Relevant predictive models
- Available topographic maps and aerial photographs
- Sheboygan County Land Information or Geographic Information System (GIS) data
- Data from WDNR files

These data sources are instrumental to understanding the past, current, and potential future conditions of the lake and to ensure that study efforts are not duplicated. Important references are listed in Section 9.0 of this report.

3.2 Water Quality Sampling

Water quality data were collected at locations across the Lake as illustrated in Figure 2. Surface water grab samples were analyzed for total phosphorus and/or chlorophyll *a*. Water samples were also collected from the deepest portion of the Lake using a Kemmerer bottle. Water transparency was evaluated using an 8-inch diameter secchi disk. Phosphorus and chlorophyll *a* samples were placed in plastic bottles provided by the Wisconsin State Lab of Hygiene (SLoH). Phosphorus samples were preserved using acid ampules provided by SloH. Samples were shipped or transported by Northern Environmental to SloH in Madison, Wisconsin for laboratory analysis.

Water quality profiles were completed in deeper portions of the Lake. Select samples were analyzed for dissolved oxygen, temperature, and water clarity. Oxygen concentrations and temperature were measured using a YSI 55 dissolved oxygen meter. Field data collected during 2002 – 2003 is summarized in Table 1. A copy of the laboratory reports is included in Appendix A.

3.3 Land Use Characterization and Nutrient Loading Model

The Lake is located within the Little Elkhart Lake watershed (Figure 3) composed of forested, agricultural, and rural residential land uses. An evaluation of land use within the watershed (Figure 4) was completed. The land area draining into the management area was evaluated for potential sediment and nutrient runoff.

A relatively simple land management screening model, the Wisconsin Lake Modeling Suite (WiLMS® Version 3.3.13), was used to estimate limited nutrient loading from the watershed. The WiLMS® model predicts phosphorus sediment delivery rates given certain land uses. Unlike more complicated and thorough models, topography of the watershed is not considered. Default data for Sheboygan County was used for net precipitation and annual runoff. Appendix B presents hydrological and morphometric data and land use types used to construct the model, in addition to the predicted phosphorus loadings. Results of the WiLMS® model are discussed in Section 4.3

3.4 Aquatic Plant Survey

One aquatic plant survey was completed in June 2002 and another was completed in August 2002. Completing two surveys allowed us to observe any changes in the Lake's plant community throughout the growing season. The aquatic plant surveys were completed in general accordance with the methodology of Jensen and Lound's "An Evaluation of a Survey Technique for Submerged Aquatic Plants". A base map was developed with seven transects distributed evenly around the perimeter of Little Elkhart Lake (Figure 5). Transects extended perpendicular to the shoreline and were located at points that allowed adequate lake and bay coverage.

Latitude and longitude coordinates at the intersection of the shoreline and the termination of the transect were measured with a global positioning system (GPS). A compass was used to determine transect bearings. Transects proceeded in the direction of the established bearing. Each transect was traversed with a sonar to determine depth. Along each transect, a 10-foot diameter circle (station point) was selected in various depth ranges. The circle was subdivided into four quadrants. A general density rating was determined for each quadrant by eye or with a modified aqua-rake. In areas where the bottom could be clearly observed, visual means were used. The rake was thrown into each quadrant, allowed to settle, and was slowly retrieved. A density rating, based on the following criteria, and observations regarding substrate type were recorded along with the depth in feet.

RAKE RECOVERY OF SPECIES

Recovery	General Density Rating
Rake teeth full in all four quadrants	5
Rake teeth partially full	
▲ In four quadrants	4
▲ In three quadrants	3
▲ In two quadrants	2
▲ In one quadrant	1

At each sample point, the species encountered were also recorded. If a species could not be identified in the field, a representative specimen was collected and placed on ice in a cooler for transportation. If a specimen could not be identified to the species level, it was referred to by the generic name followed by "sp". Various dichotomous keys and technical publications were used to classify the specimens. Applicable references are listed in Section 9.0.

Estimates of species abundance and density were determined using the recorded data. Specifically, the percent frequency of occurrence was determined by dividing the number of sampling sites at which a species occurred by the total number of sampling sites. Relative frequency was calculated by dividing the number of sample points a species was found in by the total number of occurrences of all species. Species mean density rating was obtained by averaging the density rating for all points where the species occurred.

It should be noted that only primarily floating leaved and submergent plant species were surveyed. Access to shallow water areas by boat was restricted by floating-leaved and submergent plants, therefore emergent plant communities were not surveyed.

4.0 LAKE AND WATERSHED PHYSIOGRAPHY

4.1 Lake Morphology

The size of Little Elkhart Lake has been reported at 59 acres, 54 acres, and 48 acres. Planimetric data was used in 1995 to calculate the Lake's surface area at 59 acres (AERO-METRIC, 1995). The Lake has a mean depth of 8 feet and a maximum depth of 25 feet. The Lake is a ground water seepage lake with the western two thirds of the lake being a ground water recharge area and the eastern third of the lake being a ground water discharge area (Ruff and Bardwell, 1979; R.A. Smith, 1997). An artificial outlet structure was installed on the east side of the Lake in 1986 and repaired in 1997 to manage high water levels.

The most detailed bathymetric map available is the WNDR Lake Survey map from 1974 (Figure 6). The Lake has shallow water areas (<10 feet) and a distinct deep area located at the easternmost bay. The Lake volume is reported as 445 acre-feet (WDNR, 2002). Bottom sediments are primarily muck deposited in a very flocculant manner (Environmental Resource Assessments, 1978), although gravel and sand substrate were observed along shallow shoreline areas during the 2002 macrophyte surveys. The total depth of these highly organic sediments is between 5 and 15 feet.

4.2 Geology and Soils

The Lake's basin was formed from the melting of an irregular ice mass that was buried in a pre-glacial Sheboygan river valley (Alden, 1918). Glacial deposits vary from between 135 and 200 feet and consist of permeable glacial outwash to the northwest and less permeable ground moraines elsewhere. These glacial sediments overly Niagra limestone bedrock.

The Sheboygan County Soil Survey indicates that the watershed exists on two soil associations.

Hochheim-Theresa: These soils are well drained and have a subsoil of clay loam, silty clay loam, and are underlain by gravelly sandy loam glacial till. This association is located in the watershed's east.

Casco-Fox-Rodman: This soil association is well drained to excessively well drained having a subsoil of mainly silty clay loam, sandy clay loam or gravelly sandy loam. These soils are underlain by stratified gravel and sand outwash. This association is located in the watershed's west.

4.3 Watershed Land Use and Hydrology

The Little Elkhart Lake watershed is approximately 550 acres in size. The watershed is illustrated on Figure 3. Development within the watershed is limited to low density residential. Based on information from the Sheboygan River Priority Watershed Plan, the watershed has the following land uses:

Cropland	59 acres (12%)
Farmstead	8 acres (2%)
Grassland	102 acres (21%)
Woodlands	209 acres (44%)
Commercial/residential	68 acres (14%)
Developing	17 acres (4%)
Wetland	15 acres (3%)

There are no major channelized drainage systems in the watershed and direct runoff is minimal. Drainage is primarily overland flow. Slopes within the watershed are between 20 and 30 percent. Of the 550 total watershed acres, approximately 233 acres of land are internally drained. Therefore, approximately 317 acres contribute runoff to Little Elkhart Lake.

Phosphorus is typically an important nutrient to a lake's biological dynamics (see also section 5.3.1). Phosphorus can be contributed to a lake ecosystem through storm water runoff. Existing land uses within the watershed were modeled to allow current phosphorus loading to be estimated. Several zoning categories were also determined based on Geographic Information System (GIS) data from the Sheboygan County Land Information Office. These zoning categories were assigned a general land use that could be used in the WiLMS® model to evaluate phosphorus loading. The zoning categories and corresponding land uses follow:

Sheboygan County Zoning	WiLMS® Model Land Use
Prime agricultural land	Mixed agriculture
Agricultural land	Mixed agriculture
Local business district	Medium density urban
Highway business district	High density urban
Upland conservancy	Forested
Recreational park district	Rural residential
Institutional park district	Medium density urban
Single and two family residential	Rural residential
Road	Road

Land uses are illustrated in Figure 4. In addition to Little Elkhart Lake's water surface, the above land use categories were analyzed for current phosphorus loading. Rural residential is the largest land use in the watershed (129 acres), however, it only contributes approximately 13 percent of total amount of phosphorus entering the Lake. Mixed agriculture land use encompasses 62 acres and contributes approximately 50 percent of the phosphorus loading to the Lake. This number calculated by the model is believed to be somewhat higher than reality because the model does not take natural buffering capacity or best management practices into account. The lake itself contributes approximately 17 percent phosphorus loading. The remaining land use categories collectively contributed less than 20 percent of phosphorus entering the Lake. Model results are included in Appendix B

4.4 Lake Improvements

Of the 2.25 miles of lake shoreline, approximately 50 percent is developed by residential properties. The north and east shorelines are owned by a YMCA camp and are primarily undeveloped. One public boat launch is present at the west end of the Lake. A high level water outlet structure is present at an elevation of 884.6 feet above mean sea level (msl) on the east end of the lake.

5.0 WATER QUALITY STUDY

The Little Elkhart Lake Management Planning Grant application and the request for proposal detailed sampling of select water quality parameters, specifically secchi depth readings, chlorophyll *a* levels, and phosphorus levels during each season of the year. The results of water quality sampling for 2002 and 2003 are summarized in Table 1. Sampling locations are illustrated in Figure 2. Water quality is very dynamic and varies greatly over time. Therefore, in addition to evaluating the results of the sampling events and parameters, Northern Environmental has included an evaluation of historical water quality data found in past reports and WNDR file data. Historical water quality is summarized in Table 2.

5.1 Temperature

Water temperature profoundly affects lake characteristics. Temperature influences water circulation patterns, solubility of various compounds, chemical reaction rates, and species and distribution of aquatic plants and animals. The temperature regimens of a lake are controlled by climatic and wind conditions, lake basin morphology, surrounding topography and vegetation, water inflows and outflows, and water chemistry.

Most deeper lakes in Wisconsin thermally stratify. In such lakes, temperature-induced density changes cause a lake to develop three distinct temperature zones. During summer, these zones include the epilimnion (warm surface layer), metalimnion (transitional layer), and the hypolimnion (cold bottom layer). Little mixing occurs between these layers while the lake is stratified. Since the hypolimnion is not exposed at the lake surface, it does not exchange gases with the atmosphere. In eutrophic lakes, decomposing organic debris in the hypolimnion can deplete oxygen, leading to an anoxic hypolimnion. Anoxic water is not habitable for most aquatic life and encourages dissolution of phosphorus from bottom sediment (Shaw, et al., 1994).

In most lakes, thermal stratification breaks down each fall as the atmosphere cools, allowing deeper water formerly trapped in the hypolimnion to mix with surface layers. During winter, many lakes once again stratify. Since water reaches its maximum density at 4° Centigrade (a temperature slightly above the freezing point of water), warmer water is found at depth, while cooler, near-freezing water is found directly below the ice. This inverse temperature stratification is easily disrupted, and lakes usually mix during spring. Mixing can bring large amounts of nutrients to the surface of a lake, enhancing productivity. Lakes that stratify and undergo two periods of mixing are termed “dimitic.”

Temperature / depth profiles were measured seasonally in the 1978 study by Environmental Resource Assessments. Review of this data indicates that Little Elkhart Lake does thermally stratify in the summer and winter, and is therefore, dimitic. Northern Environmental also collected depth profiles in the fall of 2002 and winter 2002/2003. Reviewing the temperature profile data (Table 3), one can see that the lake was mixed in the fall of 2002 indicating that autumn thermal mixing (turnover) had occurred prior to the October sampling event. The February 2003 temperature / depth profile (Table 3) indicate that the lake had inversely thermally stratified as expected. Reported profiles for October 2002 and August 2003 are illustrated in Figure 7 and Figure 8, respectively.

5.2 Oxygen

Oxygen solubility varies with temperature, water purity, and atmospheric pressure. More oxygen can dissolve into pure cold water at low elevations. Increasing water temperature, salinity, and elevation decrease oxygen saturation potential. Dissolved oxygen is also affected by biological productivity. Aquatic plants produce oxygen, but plant and animal decomposition and respiration use oxygen. When respiration and decomposition use more oxygen than can be replenished by exchange with the atmosphere and plant oxygen production, oxygen levels decrease. Oxygen can be exhausted in some cases, especially when water cannot freely mix and exchange gases with the atmosphere. Fish kills can occur during winter because ice does not allow air to water oxygen transfer while ice and snow limit light penetration, hindering photosynthetic oxygen production. Although less common, excessive aquatic plant growth and subsequent decomposition of dead organic matter can also cause excessively low dissolved oxygen concentrations. In some lakes, abundant aquatic plant growth can cause dissolved oxygen concentrations to rise above saturation values. Supersaturated oxygen concentrations can also be detrimental to aquatic organisms.

Water should contain at least 5 milligrams per liter (mg/l) oxygen to support a healthy warm-water fishery. To support trout, at least 7 mg/l oxygen should be present. Even though fish can tolerate lower oxygen concentrations for variable periods, low oxygen levels stress the fish, and often promote the success of less desirable species, such as carp and bullheads.

Little Elkhart Lake receives significant quantities of ground-water seepage. Under many conditions, ground water contains very little oxygen. When the water is exposed to the atmosphere, however, oxygen concentrations increase to near saturation. The deepest sections of Little Elkhart Lake thermally stratify and therefore cannot contact the atmosphere. Decaying organic material consumes oxygen in this deeper water; consequently, little oxygen is found in the deepest portions of the Lake. Oxygen / depth profiles were measured seasonally in the 1978 study by Environmental Resource Assessments. Review of these and data from DNR files indicate that Little Elkhart Lake does experience oxygen depletion in the hypolimnion. A summary of historical water quality data collected on the Lake is included as Table 2.

Oxygen measurements in the fall of 2002 suggested that there were severe depletions in oxygen levels in portions of the lake deeper than 9 feet. Temperature data indicated that fall mixing had occurred and the oxygen depletion is likely due to the decomposition of excessive aquatic plants that died in the fall and the decomposing of organic sediments. Winter 2002/2003 dissolved oxygen levels were adequate showing moderate depletion in deeper portions of the lake. A summary of water quality data collected as part of this study is included as Table 1.

5.3 Nutrients

Nitrogen and phosphorus are macronutrients essential to plant growth. While plants require many compounds to live, most are readily available in sufficient quantities to allow growth. Nitrogen and phosphorus are typically not as available, and the concentrations of one or the other usually limit aquatic plant growth. Consequently, knowing the concentration of these compounds in lake water can help us understand current and potential plant growth limitation factors.

5.3.1 Phosphorus

In 80 percent of Wisconsin lakes, phosphorus is the key nutrient controlling excessive aquatic plant and algae growth (Shaw, et al., 1994). Lake water phosphorus concentrations are usually measured as soluble reactive phosphorus and total phosphorus. Soluble reactive phosphorous is readily available to plants. Consequently, its concentration can vary widely over short periods. A potentially better measure of lake water phosphorus level is total phosphorus, which measures dissolved phosphorus as well as phosphorus in plants and animal fragments suspended in lake water.

Phosphorus is very reactive in the environment, being absorbed by plants and attaching itself tightly to sediments. Consequently, sediments carried by surface water are typically the largest external source of phosphorus to lakes. Phosphorus does not readily dissolve in lake water, forming insoluble precipitate with iron, calcium, and aluminum. Consequently, most fully oxygenated lakes have a net flux of phosphorus to the lake bottom. However, if lake water lacks oxygen, iron precipitates become unstable and release phosphorus to the overlying water. The hypolimnia in eutrophic lakes are often devoid of oxygen during summer, increasing the concentration of phosphorus available to plant growth.

Lake water samples were collected for total phosphorus seasonally and at various depths in the 1978 study by Environmental Resource Assessments. DNR staff has also historically collected samples for total phosphorus. Review of these data indicated that phosphorus levels are variable, however, a trend of higher phosphorus concentrations at greater depths was observed. This indicates that during periods of anoxia in the hypolimnion, phosphorus is likely released from the sediments. Surface water phosphorus levels have typically decreased since 1977. A summary of historical water quality data collected on the Lake is included as Table 2.

As part of this study, total phosphorus concentrations were collected seasonally from surface water samples and in deeper portions of the Lake. Little Elkhart Lake total phosphorus levels collected at the surface seasonally ranged from 15 to 23 µg/l. Total phosphorus levels at 25 feet in fall 2002 and winter 2002/2003 were 31 µg/l and 26 respectively. A summary of water quality data collected as part of this study is included as Table 1. Copies of laboratory analytical reports are included in Appendix A.

Lakes with total phosphorous levels below 2 µg/l will generally not have nuisance algae blooms (Shaw, et al., 1994). The median total phosphorous concentration measured in 61 southeastern Wisconsin lakes is 3 µg/l (Lillie and Mason, 1983). The average to below average phosphorus concentrations found in Little Elkhart Lake likely relate primarily to in-lake cycling of phosphorus and not to external sources of phosphorus. If conditions are right, the phosphorus levels in Little Elkhart Lake may occasionally fuel an algae bloom. However, this would probably be associated with a turnover event or dying macrophytes.

5.3.2 Nitrogen

Nitrogen is another nutrient limiting the growth of aquatic plants, usually second in importance to phosphorus. Nitrogen limits the growth of plants in a few Wisconsin lakes. Nitrogen can be found in lakes in many forms including nitrate (NO_3^-), nitrite (NO_2^-), and ammonium (NH_4^+). These inorganic forms of nitrogen can be readily used by aquatic plants and algae. Nitrite is usually present in only trace quantities and is readily transformed to nitrate in oxygenated water. Nitrogen can enter a lake via precipitation (which can have concentrations of nitrogen as high as 0.5 mg/l), breakdown of organic compounds (forming ammonia), and human-induced sources of nitrogen such as fertilizers, sewage effluent, and animal waste.

Even though nitrogen demand in vegetated terrestrial soils is high during active growing periods, nitrogen can move through soil and reach ground water if:

- Vegetation is not actively growing
- Nitrogen supply exceeds vegetative demand
- Nitrogen is injected directly to subsurface sediment (e.g., septic system drainfields)

Once nitrate "leaches" to the ground-water table, nitrate migrates freely with ground water moving towards discharge points such as surface waters, wetlands, and drinking water wells.

Kjeldahl nitrogen includes nitrogen contained in suspended organic matter and ammonium. Total nitrogen is calculated by adding nitrate and nitrite to kjeldahl nitrogen. Inorganic nitrogen is the sum of nitrate, nitrite, and ammonia. If spring inorganic nitrogen levels are below 0.3 mg/l, summer algae blooms are less likely (Shaw, et al., 1994). The average organic concentration in a study of 61 southeastern Wisconsin lakes was 0.94 mg/l while the average total nitrogen concentration for these lakes was 1.43 mg/l (Lillie and Mason, 1983).

Nitrogen levels were measured for ammonia-nitrogen, nitrate, nitrite, and total organic nitrogen seasonally and at various depths in the 1978 study by Environmental Resource Assessments. DNR staff has also periodically collected samples for total organic nitrogen. Generally, the nitrogen levels are below the average total organic nitrogen levels measured for southeastern Wisconsin lakes. A summary of historical water quality data collected on the Lake is included as Table 1. The water quality sampling completed as part of this study in 2002/2003 did not measure for nitrogen species.

5.3.3 Nitrogen/Phosphorous Ratio

When the ratio of total nitrogen to total phosphorus is greater than 15 to 1, plant and algal growth in a lake is controlled by the amount of phosphorus available and is considered "phosphorus-limited." When the ratio is below 10 to 1, nitrogen is the limiting nutrient for plant and algae growth; values between 10 to 1 and 15 to 1 are considered transitional (Shaw, et al., 1994). Most Wisconsin lakes are phosphorus-limited.

Available total nitrogen to total phosphorus ratios of Little Elkhart Lake indicate that the lake is phosphorus limited. As such, ample nitrogen is present to fuel growth of aquatic plants, and additional phosphorus loading will fuel additional aquatic plant growth and potential algae blooms.

5.4 Chlorophyll *a*

Chlorophyll *a* concentrations correspond to the abundance of algae in lake water. Chlorophyll *a* concentrations respond to seasonal light changes, lake water nutrient content and transparency, aquatic macrophyte growth, temperature, and zooplankton abundance. High chlorophyll *a* concentrations relate to algal blooms. Algal blooms most often occur after spring and fall turnovers in lakes with anoxic hypolimnia when nutrients are released from the sediments. The release of nutrients into the hypolimnia and subsequent mixing of water with the epilimnion during spring turnover causes these nutrients to be readily available to initiate algal blooms. Algal blooms can also occur when other events liberate nutrients into the lake system or otherwise upset nutrient equilibrium. Examples of events that could cause an algal bloom are:

- Severe thunderstorms washing nutrient-laden water or sediment into a lake
- Mid-season circulation of the hypolimnion caused by storms, flood flows, etc.
- Decrease in zooplankton abundance
- Anoxic water conditions destabilizing phosphorus bound in bottom sediments
- Significant manipulation of the macrophyte community

If aquatic macrophytes are destroyed and are not removed from the water, the demand for limiting nutrients is decreased and nutrients are returned to the water from decomposing aquatic plants. This chain of events can cause algal blooms.

Chlorophyll *a* levels were seasonally in surface water samples during the 1978 study by Environmental Resource Assessments. Throughout 1997, chlorophyll *a* levels ranged from 0.47 to 2.65 ug/l. Southeastern Wisconsin lakes mean chlorophyll *a* concentration is 9.9 µg/l. Values of 10 µg/l or higher are associated with algae blooms. Chlorophyll *a* readings less than 5 µg/l indicate very good water quality, while values less than 1 µg/l are indicative of excellent water quality (Lillie and Mason, 1983). While there were reportedly two algae blooms, one in June and one in August 1977, these chlorophyll *a* concentrations are below the average levels measured for southeastern Wisconsin lakes and (as indicators by themselves) are indicative of very good water quality. A summary of historical water quality data collected on the Lake is included as Table 2.

Chlorophyll *a* was measured during the summer and fall 2002. A July chlorophyll *a* sample was not run due to a lab accident. Chlorophyll *a* ranged from 1.26 to 4.42 ug/l, again exhibiting lower than average chlorophyll *a* concentrations and good water quality. A summary of water quality data collected as part of this study is included as Table 1. Copies of laboratory analytical reports are included in Appendix A.

5.5 Alkalinity and pH

Lake water alkalinity is largely attributable to bicarbonate and carbonate that are typically released from dissolution of calcite and dolomite. Dissolution of calcite and dolomite also releases calcium and magnesium, producing hard water. Median alkalinity concentration in 61 southeastern Wisconsin lakes is 160 mg/l. Alkalinity buffers the effects of acidic rainfall by neutralizing low pH rainfall.

Lakes with abundant plant growth and high alkalinity water often have marl deposits. Marl is composed primarily of calcium carbonate but also includes phosphorus. Plant growth fosters marl formation by removing carbon dioxide from the water which subsequently increases pH and converts most alkalinity to carbonate. Marl in often visible on the leaves of certain aquatic macrophytes. Marl formations also contribute to phosphorus precipitating out of the water column and subsequently reducing algae growth.

Lake water samples have been collected and analyzed for total alkalinity and/or total hardness during the 1978 study by Environmental Resource Assessments and water quality sampling completed by WDNR in the 1970s through the 1990s. Review of these data indicated that the lake's water is hard to very hard (Shaw et. al., 1994). Alkalinity levels indicate that the lake is not susceptible to the problems associated with acid rain. A summary of historical water quality data collected on the Lake is included as Table 2.

pH is an exponential index of hydrogen ion concentration used to measure acidity. pH is represented on a logarithmic scale from 1 to 14, 7 being neutral. Readings above 7 have less hydrogen ions and are basic (alkaline); readings below 7 have more hydrogen ions and are considered acidic.

Lake water samples have been collected and analyzed for pH during the 1978 study by Environmental Resource Assessments and water quality sampling completed by DNR in the 1970s through the 1990s. The pH readings ranged from 7.2 to 8.1, which is reasonable given the high alkalinity of the water and abundant aquatic plant growth. The median pH of 61 southeastern Wisconsin lakes is 8.0. Lower pH may be a result of abundant rainfall. Rainfall in southeastern Wisconsin is acidic, having a pH of about 4.4.

5.6 Transparency

Transparency is a function of water color and turbidity and is usually measured with a secchi disk. A secchi disk is an 8-inch circular plate with alternating black and white quadrants fixed to a length of graduated cord. During the middle of the day, the disk is lowered on the shaded side of the boat until an observer can no longer see the secchi disk. The depth is noted, the disk is then raised until it just again is visible, and the depth again is noted. The two measurements are averaged to give a reading. The deeper the secchi disk reading, the clearer the water. High concentrations of algae or suspended sediment usually account for shallow secchi disk readings. In some instances, colored water can also account for low secchi readings.

Water clarity has been measured during the 1978 study by Environmental Resource Assessments and during water quality sampling events completed by DNR in the 1970s through the 1990s. The secchi depth measurements ranged from less than 2 feet to over 15 feet (Table 1). The historical secchi depth measurements are included in Table 2. Secchi depth measurements were also taken during our 2002 study. These depths ranged from 7.2 feet in July to 14.2 feet in October.

Water clarity of 10 feet or greater is considered "good" while 20 feet or greater is considered "very good" (Shaw, et al., 1994). Water clarity of the Lake is typically greater than the median of 4½ feet for southeastern Wisconsin lakes. This likely relates to low planktonic algae concentrations and little surface water/suspended sediment entering the Lake. Secchi depth measurements were highly variable between 1975 and 2002, potentially due to small algae blooms and a multitude of other factors. However, given the available data and looking at seasonal trends, there is no considerable trend toward better or worse water clarity in the last 25 years.

Weekly secchi depth readings collected over a number of years during open water periods would provide an excellent, low-cost method to evaluate changes in lake clarity that may relate to other changes in the Lakes' conditions.

5.7 Trophic Status

Total phosphorus, chlorophyll *a*, and secchi disk depths are used to classify the trophic state of a lake. A trophic state is an indicator of water quality. Using the average summer 2002 data for Little Elkhart Lake (total phosphorus concentration of 18 µg/l, chlorophyll *a* concentration of 2.6 µg/l, and a secchi depth of 9.2 feet) Little Elkhart Lake is classified as mesotrophic with an average Carlson trophic state index of 43. Mesotrophic lakes typically have moderately clear water, can develop anoxic hypolinia during the summer, may have excessive aquatic macrophytes, and will normally only support warm-water fisheries.

Reviewing the trophic state parameters individually, total phosphorus concentration is the most eutrophic parameter. The chlorophyll *a* concentration is lower than predicted for the corresponding summer phosphorus content and secchi depth measurements. This may be attributable to the profuse growth of aquatic macrophytes and epiphytes (attached algae) outcompeting phytoplankton for plant-available phosphorus. The relative abundance of plant nutrients would likely be increased by removing aquatic macrophytes. Consequently, removing excessive amounts of aquatic plants has the possibility of decreasing water clarity by increasing planktonic algal growth.

6.0 AQUATIC PLANTS

Aquatic plants are vital to the health of a water body. Unfortunately, much too often, people refer to all rooted aquatic plants as weeds and their ultimate goal is to eradicate them. This line of thinking must be avoided when trying to manage the entire lake ecosystem. Rooted macrophytes are extremely important for the well being of the lake community and posses many positive attributes. These attributes are what make the littoral zone the most important and productive aquatic habitat in freshwater lakes. However, aquatic macrophytes can become a nuisance when exotics plant species occupy large portions of a lake. Excessive aquatic plant growth can negatively affect recreational activities. When "managing" aquatic plants, it is important to maintain a well-balanced, stable, and diverse aquatic plant community that contain high percentages of desirable native vegetation.

6.1 The Ecological Role of Aquatic Plants

Aquatic plants can be divided into two major groups: microphytes (phytoplankton and epiphytes) composed mostly of single-celled algae, and macrophytes that include macroalgae, flowering vascular plants, and aquatic mosses and ferns. Wide varieties of microphytes co-inhabit all hospitable areas of a lake. Their abundance depends solely on light, nutrient availability, and other environmental factors. In contrast, macrophytes are predominantly found in distinct habitats in the littoral (shallow near shore) zone where sufficient light can penetrate to the lake bottom. The littoral zone is subdivided into four distinct transitional zones: the eulittoral, upper littoral, middle littoral, and lower littoral (Wetzel, 1983).

Eulittoral Zone: Includes the area between the highest and lowest seasonal water levels, and often contains many wetland plants.

Upper Littoral Zone: Dominated by emergent macrophytes and extends from the water edge to water depths between 3 and 6 feet.

Middle Littoral Zone: Occupies water depths of 3 to 9 feet, extending lakeward from the upper littoral zone. The middle littoral zone is dominated by floating-leaf plants.

Lower Littoral Zone: Extends to a depth equivalent to the limit of the photic zone, which is defined as percent of surface light intensity.

The relationship of phytoplankton and macrophyte communities is illustrated in Figure 9.

The abundance and distribution of aquatic macrophytes are controlled by other factors than dissolved nutrient availability. These factors include light availability, lake trophic status as it relates to nutrients and water chemistry, sediment characteristics, and wind energy. Lake morphology and watershed characteristics relate to these factors independently and in combination (NALMS, 1997).

In many instances aquatic plants serve as indicators of water quality due to the sensitive nature of plants to water quality parameters such as water clarity and nutrient levels. To grow, aquatic plants must have adequate supplies of nutrients. Microphytes and free-floating macrophytes (e.g., duckweed) derive all their nutrients directly from the water. Rooted macrophytes can absorb nutrients from water and/or sediment. Therefore, the growth of phytoplankton and free-floating aquatic plants is regulated by the supply of critical available nutrients in the water column. In contrast, rooted aquatic plants can normally continue to grow in nutrient-poor water if lake sediment contains adequate nutrient concentrations. Nutrients removed by rooted macrophytes from the lake bottom may be returned to the water column when the plants die. Consequently, killing aquatic macrophytes may increase nutrients available for algal growth.

In general, an inverse relationship exists between water clarity and macrophyte growth. That is, water clarity is usually improved with increasing abundance of aquatic macrophytes. Two possible explanations are postulated. The first is that the macrophytes and epiphytes out-compete phytoplankton for available nutrients. Epiphytes derive essentially all of their nutrient needs from the water column. The other explanation is that aquatic macrophytes stabilize bottom sediment and limit water circulation, preventing resuspension of solids and nutrients (NALMS, 1997).

If aquatic macrophytes are reduced in abundance, water clarity can suffer. Water clarity reductions can further reduce the vigor of macrophytes by restricting light penetration, reducing the size of the littoral zone, and further reducing water clarity. Studies have shown that if 30 percent or less of the area of a lake occupied by aquatic plants is controlled, water clarity will generally not be affected. However, lake water clarity will likely be reduced if 50 percent or more of the macrophytes are controlled (NALMS, 1997).

Aquatic plants also play a key role in the ecology of a lake system. Aquatic plants provide food and shelter for fish, wildlife and invertebrates. Plants also improve water quality by protecting shorelines and the lake bottom, improving water quality, adding to the aesthetic quality of the lake and impacting recreational activities.

6.2 Aquatic Plant Survey

6.2.1 1977 Aquatic Plant Survey

An aquatic plant survey was completed in 1977 using a point intercept method by Environmental Resource Assessments. A review of this 1977 survey identified *Myriophyllum spicatum* (Eurasian watermilfoil) as the most dominant plant species with a 60 percent frequency of occurrence. The 1977 survey identified 30 aquatic plant species present in the Lake, including emergent species.

6.2.2 2002 Aquatic Plant Survey

Aquatic macrophytes on Little Elkhart Lake were surveyed during June and August in 2002. These two surveys were conducted when aquatic plant growth would be optimal during different periods of the year that would be conclusive to observing the greatest number of species present. 2002 aquatic plant survey transect and sample point locations are illustrated in Figure 5. Information gathered during the surveys concluded that Little Elkhart Lake has moderate species diversity and a moderate amount of biomass. Twenty-one species of floating leaved and submerged aquatic vascular plants were identified during the surveys. Aquatic macrophyte species identified in the Lake are summarized in Table 4. June and August Distribution of aquatic plant species is illustrated in Figures 10A and B and Figures 11A and B, respectively.

During the June and August survey, the most abundant species found in the Lake in both the June and August survey was *Myriophyllum sibiricum* (Northern watermilfoil) with a 75 percent frequency of occurrence (percent of sample points containing that species) in June and 70 percent in August (Tables 5 and 6). Northern watermilfoil had a 17 percent relative frequency (the frequency of occurrence compared to the occurrence of all species) in June and 15 percent in August. *Myriophyllum spicatum* (Eurasian watermilfoil) was the second most abundant species during both surveys with a 75 percent frequency of occurrence June and 59 percent in August. Eurasian watermilfoil had a 17 percent relative frequency in June and 13 percent in August. *Potamogeton zosteriformes* (Flat-stem pondweed) was the third most abundant species in the June survey with a 61 percent frequency of occurrence and a 13 percent relative frequency. In the August survey the third most abundant species present in Little Elkhart Lake was *Najas flexilis* (Slender naid or bushy pondweed) with a 41 percent frequency of occurrence and a 9 percent relative frequency of 9 percent.

The species with the highest mean density rating (the average density rating for all sample points where a species was present) for the June survey was *Potamogeton natans* (Floating-leaf pondweed) and *Nyumphaea odorata* (White water lily). The second highest mean density rating for the June survey was *Utricalaria vulgaris* (Common bladderwort), *Bidens beckii* (Water marigold), *Lemna trisulca* (Forked duckweed) and *Chara sp*. (muskgrass). The August survey saw a shift in relative mean densities for plant species. The aquatic macrophyte with the highest mean density rating in August was *Brasenia schreberi* (Watershield) although it was only detected at one sampling station. The second highest mean density rating was *Myriophyllum sibiricum* (Northern watermilfoil) and *Nuphar variegata* (Spatterdock). Frequency of occurrence, relative frequency and mean density ratings is summarized on Tables 5 and 6.

The littoral zone, the depth to which light penetrates permitting photosynthesis and colonization of aquatic macrophytes for Lake Elkhart Lake is between zero and fifteen feet. Even though the littoral zone can fluctuate based on water quality and the amount of turbidity seen in the water, historically the photic zone has been around 15 feet. You will also tend to see areas of the littoral zone that are more conducive to supporting certain species of aquatic plants. Little Elkhart Lake is mostly composed of soft sediments that are able to support higher numbers of aquatic macrophyte populations due to rich mineral content. Most aquatic macrophytes are found growing in an area in which they are able to maximize their ability to absorb varying levels of light intensity. These areas are generally composed of a substrate that is also for June and August 2002 conducive to supporting aquatic macrophytes as well. Aquatic plant distribution is summarized on Table 7 and Table 8, respectively. June aquatic plant distribution is illustrated in Figures 10a and 10b. August aquatic plant distribution is illustrated in Figures 11a and 11b.

It is interesting to note that *Myriophyllum sibiricum* (northern watermilfoil) was not identified in the 1977 aquatic plant survey and was the most dominant aquatic plant in 2002. This may be attributed to the possible mis-identification as *Myriophyllum spicatum* (Eurasian watermilfoil) in 1977. Also, during the 2002 survey, at many points it was difficult to distinguish between the two watermilfoil species. This may be attributed to hybridization between the two watermilfoil species.

6.3 Management History

Harvesting has reportedly occurred on Little Elkhart Lake in 1977. It is unknown if harvesting has historically occurred in other years or elsewhere. Reportedly, prior to 1998, the aquatic plants have been chemically treated. Since 1998, aquatic vegetation has not been managed and subsequently plant populations have spread rapidly. Little Elkhart Lake has seen a steady decline in the amount of useable area of the lake by both recreational boaters and fisherman.

7.0 CONCLUSIONS AND POSSIBLE MANAGEMENT OPTIONS

7.1 Conclusions

Water quality data collectively indicate that Little Elkhart Lake is a mesotrophic lake with good to fair water quality. The Lake mixes in the spring and fall distributing phosphorus to the water column. The Lake's inherent chemical properties result in a net flux of phosphorus to the sediments. Additionally, storm water runoff from agricultural and rural residential land uses contribute phosphorus to the lake. Dissolved oxygen levels have been adequate to support fish through the winter in recent years. Adequate levels of nutrients and good water clarity contribute to abundant aquatic plant (macrophyte) growth which causes interference with recreational access, boating, and swimming.

Myriophyllum sibiricum (Northern watermilfoil) and *Myriophyllum spicatum* (Eurasian watermilfoil) were the most abundant plant species throughout summer 2002. In spite of the widespread nuisance levels of these two aquatic plants, the Lake exhibits good aquatic plant diversity of some high value species. Additionally, the WDNR designated much of the plant communities as "sensitive areas" (Figure 12) in 1992. The WDNR is scheduled to complete an assessment and update the Lake's sensitive area map in summer 2003. The District wishes to implement an APM plan to manage the nuisance growth of aquatic plants. The APM Plan must recognize and consider the value of some aquatic plant species and WDNR sensitive areas. In other words, not all nuisance aquatic plants will be able to be removed by certain management activities.

7.2 Possible Management Options

Based on the presence of high value species and WDNR designated sensitive areas on Little Elkhart Lake, approximately 12 acres of the Lake could be managed for nuisance levels of aquatic plants. The proposed aquatic plant management area is illustrated in Figure 12. This area is highly monotypic with Eurasian watermilfoil and northern watermilfoil. Coontail is also present. Certain shoreline areas contain high value species, such as *Brasenia schreberi* (watershield) and *Potamogeton amplifolius* (large-leaf pondweed), therefore aquatic plant management will be limited in those areas regardless of what management activity is used.

Existing management techniques and current available research were reviewed in detail. A comprehensive comparision of APM techniques and methods is included in Appendix C. Detailed description of each of these potential management methods, describing the technology, benefits, drawbacks, and costs are included in Appendix C. Based on these comparisons and the specific aquatic plant problems on Little Elkhart Lake, the following potential management strategies were considered. The following management alternatives are included in Table 8.

7.2.1 Harvesting

Harvesting was considered as a potential management option. This technology allows easy treatment of large areas of nuisance aquatic plant stands. Advantages of this technology include immediate results, removal of plant material and nutrients, and the flexibility to move to problem areas and at multiple times of the year "as needed". Disadvantages of this method include the limited depth of operation in shallow areas, high initial equipment costs, disposal site requirements, creation of plant fragments that may move to other parts of the lake and re-colonize (although milfoil is so widespread across Little Elkhart Lake, it would probably have little effect on distribution), and a need for trained staff to operate the harvester. An operator may also be tempted to harvest in areas where plant management is not allowed. A used harvester can also be purchased to reduce costs. A full discussion about harvesting is included in Appendix C.

A smaller harvester would be suitable for Little Elkhart Lake. A harvester will typically last 10 years, potentially longer with proper use and maintenance. This equipment, a shore conveyor, and trailer for transporting the harvester would cost approximately $104,000. Approximately ½ of this cost can possibly by paid by the Wisconsin Waterway Commission. Operating costs would be approximately $1,600 per year to harvest the 12-acre management area three times. A five-year loan can be obtained for the equipment and would cost approximately $11,600 per year. The total on the equipment, loan, permit, and operating costs distributed over a 10-year period is approximately $7,400 per year or approximately $210 per acre if harvested three times per year. Advantages, disadvantages, and costs of these aquatic plant management alternatives are summarized in Table 8.

7.2.2 Contract Harvesting

Contract harvesting was also considered as a potential management option. Of course, this option has the same advantages and disadvantages of the harvesting option listed above, however is more costly. If harvesting appears to be a desirable management alternative but the lake management group does not wish to arrange for insurance, payroll, etc associated with their own harvester and operator, this may be an attractive alternative. Contract harvesting the 12-acre management area on Little Elkhart Lake three times per year would cost approximately $10,400 per year or approximately $290 per acre. If the aquatic plant management area was only harvested twice, contract harvesting would cost approximately $7,100 per year. Advantages, disadvantages, and costs of these aquatic plant management alternatives are summarized in Table 8.

7.2.3 Chemical Treatment – 2,4-D

Use of an aquatic herbicide was considered as a potential management option. Chemical treatments are discussed at length in Appendix C. Treatment of aquatic plants chemically can offer more maneuverability for aquatic plant management in confined quarters and around docks that a harvester cannot. The systemic herbicide 2,4 D was selected as an option because of the potential for a longer effect and potential selectivity. 2, 4-D results can be seen in 10 to 14 days. A suitable herbicide applied at a suitable dose by an experienced licensed pesticide applicator can target exotic plant species but leave native species relatively unaffected. Navigate, a granular 2,4-D product, has demonstrated watermilfoil control while not affecting white water lilies, yellow water lilies, or watershield, or other high value aquatic plant species found in Little Elkhart Lake. Disadvantages include: while 2,4-D lasts only a short time in water, it can be detected in sediments for months after application. After application, water use restrictions may be necessary and enforced.

Applications of 2,4 D-based herbicides (i.e. trade name Navigate) by a licensed applicator would cost approximately $540 per acre. One major treatment per season would be needed, however one potential follow up "spot treatment" may also be needed. Including the permit, a cost estimate for treating the 12-acre management area would be approximately $6,800.00 annually. Table 8 summarizes advantages, disadvantages, and costs of the aquatic plant management alternatives.

7.2.4 Chemical Treatment - Fluridone

A newer chemical, fluridone (i.e. Sonar or Avast) has been used recently in treatments for Eurasian watermilfoil. Studies have demonstrated multi-year watermilfoil control if inputs due to boats, geese, etc. are eliminated. The use of fluridone is generally associated with whole lake treatments. Multiple treatments may be needed to maintain adequate concentration long enough to be effective. Concentrations of 10 to 20 parts per million for a period of 60 days must be maintained. Advantages of fluridone are selectivity of the chemical, low toxicity to aquatic fauna, and three to five years of control. Disadvantages include higher chemical costs for initial treatment, slow action, and the need to treat an entire water body or isolate a bay using a water barrier.

The Lake would require a whole lake treatment followed by a few years of spot treatments using 2,4-D or tryclopyr. Another disadvantage of using fluridone on Little Elkhart Lake would be that it would also target Northern watermilfoil lake-wide, therefore the potential for this option would have to be discussed with WDNR. A preliminary cost estimate for a whole lake treatment using fluridone is approximately **$20,000.** Follow up 2,4-D or tryclopyr spot treatments may also be necessary. Advantages, disadvantages, and costs of these aquatic plant management alternatives are summarized in Table 8.

8.0 RECOMMENDED ACTION PLAN

8.1 Watershed Management

While water quality is good to fair in the Lake, there is potential for improvement. An evaluation of land uses within the Little Elkhart Lake watershed indicate that runoff from agriculture and rural residences are the largest external sources of phosphorus to Little Elkhart Lake. Agricultural best management practices (BMPs) can help prevent erosion and nutrient runoff. Shoreline land-use standards help minimize the flow of nutrients to the lake while maximizing the amount and diversity of nutrient absorbing littoral vegetation. Components of this element include severely limiting the use of fertilizers, timing lawn treatments for minimal impact to the ponds, and establishing shoreline with a high percentage of natural vegetation. Such concepts could be applied to the Lake's watershed. To continue improvement of water quality in Little Elkhart Lake, the District may want to consider the following recommendations:

- Ensure that agricultural BMPs such as minimal tillage and proper nutrient management are being used within the watershed. The county land conservation department has information on BMPs.

- Ensure that land application of dairy wastewater within the watershed is completed in accordance with the landspreading permit issued by WDNR.

- Maintain natural vegetation on shorelines or establish shoreline buffers. This can be promoted and implemented voluntarily or local shoreline ordinances can be developed.

- Use only low or preferably no phosphorus fertilizers on lawns and landscaping (phosphorus is the middle number on a fertilizer rating).

8.2 Water Quality

Internal phosphorus cycling is likely most active within deeper anoxic basins of Little Elkhart Lake. Marl formation likely removes some phosphorus from the water column, however, summer anoxia has developed and can release phosphorus into the water column during fall mixing. A similar flux may occur in the spring if winter anoxia occurs and the water reach 39° F. In addition to the above watershed management recommendations, Little Elkhart Lake has the potential to remove higher levels of phosphorus within the lake by modifying its water level outlet structure to remove water from the deepest basin of the lake. Little Elkhart Lake may want to consider this as a potential way to remove phosphorus from the lake. A detailed nutrient budget would need to be completed. A lake management planning or protection grant may be secured to study and potentially implement a phosphorus removal project. A similar project and study is on-going at Devils Lake in Sauk County, Wisconsin. An article about the Devils Lake study and contact information is included in Appendix D

8.3 Aquatic Plant Management

The aquatic plant community inhabiting Little Elkhart Lake is diverse. The aquatic plant management plan recognizes that the emergent and floating leaf aquatic plant community in Little Elkhart Lake is valuable to the lake ecosystem and should be protected. The submersed Eurasian watermilfoil and Northern watermilfoil have grown to nuisance levels across Little Elkhart Lake. These plants cause recreation and navigational problems and are most dense in the proposed aquatic plant management area.

The recommended APM alternative for Little Elkhart Lake is yearly chemical treatments with 2, 4-D targeting Eurasian watermilfoil and Northern watermilfoil in the mangement area (Figure 12). This method is proposed based on the advantages, disadvantages and costs discussed in Section 7.0 and Table 9. Chemical treatment offers more flexibility in applying in shallow water and/or near obstacles such as piers or rafts. Chemical treatment using 2,4-D is more flexible and viable for spot treatments, while using fluridone would require a lake wide treatment and higher initial costs.

The proposed 2,4-D treatments must be applied by a licensed, qualified aquatic pesticide applicator at application rates that will not affect *potamogeton spp*.(pondweeds), waterlilies, spatterdock, or watershield. The applicator must follow the requirements of Chapter NR 107, Wisconsin Administrative Code. The applicator shall post signs at areas treated in compliance with NR 107. If you need a list of qualified licensed applicators, please contact Northern Environmental. The District must obtain an aquatic nuisance control report from the applicator and submit it to WDNR within 30 days of treatment.

Northern Environmental recommends that the District review the atlernatives (Section 7.0 and Table 9) in detail and consider the options before voting on the issue. Once the district has selected an alternative, be it the recommended alternative or another option, the District will need to prepare a permit application for APM on the Lake. A permit application is included in Appendix E. This report contains all the necessary documentation required to submit a permit application. Simply make a copy of appropriate portions of this report to include in the permit application. The District should contact Northern Environmental if it needs assistance with preparing the permit application.

Northern Environmental recommends completing an aquatic plant survey in the aquatic plant management area after 3 to 5 years to evaluate the effectiveness of the selected APM strategy. Also at this time, we recommend that the District re-evaluate the feasibility of a whole lake fluridone treatment. If the existing nuisance plant control is marginal, the costs of fluridone have decreased and if the WDNR would allow a whole lake fluridone treatment, it may be a more attractive alternative at that time.

9.0 GLOSSARY

The following section is largely adapted from a University of Wisconsin Extension Publication entitled *Understanding Lake Data* (Shaw, et al., 1994).

Algae: One-celled (phytoplankton) or multi-cellular plants either suspended in water (plankton) or attached to rocks, rooted aquatic plants, and other substrates (epiphytes). Their abundance, as measured by the amount of chlorophyll a (green pigment) in an open water sample, is commonly used to help classify the trophic status of a lake. Algae are essential to the lake ecosystems and provide the food base for most lake organisms, including fish. Phytoplankton abundance and specie distribution vary widely from day to day, as life cycles are short.

Alkalinity: A measure of the amount of carbonates, bicarbonates, and hydroxide present in water. Low alkalinity is the main indicator of susceptibility to acid rain. Increasing alkalinity is often related to increased algae productivity. Expressed as mg/l of calcium carbonate ($CaCO_3$) or as microequivalents per liter (µeq/l). 20 µeq/l = 1 mg/l of $CaCO_3$.

Ammonia: A form of nitrogen found in organic materials and many fertilizers. It is the first form of nitrogen released when organic matter decays, can be used by most aquatic plants, and is, therefore, an important nutrient. Ammonia converts rapidly to nitrate (NO_3^-) if oxygen is present. The conversion rate is related to water temperature. Ammonia is toxic fish at relatively low concentrations in pH-neutral or alkaline water. Under acidic conditions, non-toxic ammonium ions (NH_4^+) form, but at high pH values, the toxic ammonium hydroxide (NH_4OH) occurs. The water quality standard for fish and aquatic life is 0.02 mg/l of NH_4OH. At a pH of 7 and a temperature of 68˚F (20˚C), the ratio of ammonium ions to ammonium hydroxide is 250:1; at pH of 8, the ratio is 26:1.

Anion: Refers to the chemical ions present that carry a negative charge in contrast to cations, which carry a positive charge. There must be equal amounts of positive and negative charged ions in any water sample. Following are the common anions in decreasing order of concentration for most lakes: bicarbonate (HCO_3^-), sulfate $SO_4^=$), chloride (Cl^-), carbonate ($CO_3^=$), nitrate (NO_3^-), nitrate (NO_2^-), and phosphates ($H_2PO_4^-$, $HPO_4^=$, and $PO_4^=$).

Aquatic invertebrates: Aquatic animals without an internal skeletal structure, such as insects, mollusks, and crayfish.

Blue-green algae: Algae that are often associated with problem blooms in lakes. Some produce chemicals toxic to other organisms, including humans. They often form floating scum as the die. Many can fix atmospheric nitrogen (N_2) to provide their own nutrient source.

Calcium: The most abundant cation found in Wisconsin lakes. Its abundance is related to the presence of calcium-baring minerals in the lake watershed, and reported in mg/l as calcium carbonate ($CaCO_3$) or mg/l as calcium ion (Ca^{++}).

Cation: Refers to chemical ions present that carry a positive charge. The common cations present in lakes in normal order of decreasing concentrations follow: calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^+), sodium (Na^+), ammonium (NH_4^+), ferric iron (Fe^{+++}) or ferrous iron (Fe^{++}), manganese (Mn^{++}), and hydrogen (H^+).

Chloride: Chlorine in the chloride ion (Cl^-) form has very different properties from chlorine gas (Cl_2), which is used for disinfecting. The chloride ion (Cl^-) in lake water is commonly considered an indicator of human activity. Agricultural chemicals, human and animal wastes, and road salt are the major sources of chloride in lake water.

Chlorophyll *a*: Green pigment present in all plant life and necessary for photosynthesis. The amount present in lake water depends on the amount of algae and is, therefore, commonly used as a water-quality indicator.

Color: Measured in color units that relate to a standard. A yellow-brown natural color is associated with lakes or rivers receiving wetland drainage. The average color value for Wisconsin lakes is 39 units, with the color of state lakes raging from zero to 320 units. Color also affects light penetration, and therefore, the depth at which plants can grow.

Concentration units: Express the amount of a chemical dissolved in water. The most common ways chemical data are expressed is in mg/l and micrograms per liter (µg/l). One mg/l is equal to one part per million (ppm). To convert µg/l to mg/l, divide by 1000 (e.g., 30 µg/l = 0.03 mg/l). To convert mg/l to µg/l, multiply by 1000 (e.g., 0.5 mg/l = 500 µg/l). Microequivalents per liter (µeq/l) is also sometimes used, especially for alkalinity; it is calculated by dividing the weight of the compound by 1000 and then dividing that number into the mg/l.

Conductivity (specific conductance): Measures the ability of water to conduct an electric current. Conductivity is reported in micromhos per centimeter (µmhos/cm) or an equivalent in microsiemens (µs), and is directly related to the total dissolved inorganic chemicals in the water. Values are commonly two times the water hardness unless the water is receiving high concentrations of contaminants introduced by humans.

Drainage basin: The total land area that drains toward the lake.

Drainage lakes: Lakes fed primarily by streams and with outlets into streams or rivers. They are more subject to surface runoff problems but generally have shorter residence times than seepage lakes. Watershed protection is usually needed to manage lake water quality.

Epiphyte: See "Algae"

Filamentous algae: Algae that forms filaments or mats attached to sediment, weeds, piers, etc.

Food chain: The sequence of algae being eaten by small aquatic animals (zooplankton) that in turn are eaten by small fish that are then eaten by larger fish, and eventually by people or predators. Certain chemicals, such as polychlorinated biphenyls (PCBs), mercury, and some pesticides, can be concentrated from very low levels in the water to toxic levels in animals through this process.

Ground-Water discharge lake: Often referred to as a spring-fed lake; has large amounts of ground water as its source, and a source outlet. Areas of high ground-water inflow may be visible as springs or sand boils. Ground-water drainage lakes often have intermediate retention times with water quality dependent on ground-water quality.

Hardness: The quantity of multivalent cations, primarily calcium (Ca^{++}) and magnesium (Mg^{++}) in the water, expressed as mg/l of $CaCO_3$. Amount of hardness relates to the presence of soluble minerals, especially limestone and dolomite, in the lake watershed.

Hypolimnion: see "Stratification"

Ion: A charged atom or group of atoms that have separated from an ion of the opposite charge. In water, some chemical molecules separate into cations (positive charge) and anions (negative charge). Thus, the number of cations equals the number of anions.

Insoluble: Incapable of dissolving in water.

Kjeldahl nitrogen: The most common analysis run to determine the amount of organic nitrogen in water. The test includes ammonium and organic nitrogen.

Limiting factor: The nutrient or condition in shortest supply relative to plant growth requirements. Plants will grow until stopped by this limitation; for example, phosphorous in summer, temperature or light in fall or winter.

Macrophytes: see "Rooted aquatic plants."

Marl: White to gray accumulation on lake bottoms caused by precipitation of calcium carbonate ($CaCO_3$) in hard water lakes. Marl may contain many snail and clamshells, which also are $CaCO_3$. While it gradually fills in lakes, marl also precipitates phosphorous, resulting in low algae populations and good water clarity. In the past, marl was recovered and used to lime agricultural fields.

Metalimnion: see "Stratification."

Nitrate: An inorganic form of nitrogen important for plant growth. Nitrogen is in this stable form when oxygen is present. Nitrate (NO_3^-) often contaminates ground water when water originates from manure pits, fertilized fields, lawns, or septic systems. High levels of nitrate-nitrogen (over 10 mg/l) are dangerous to infants and expectant mothers. A concentration of nitrate-nitrogen (NO_3^-N) plus ammonium-nitrogen (NH_4^-N) of 0.3 mg/l in spring will support summer algae blooms if enough phosphorous is present.

Nitrite: A form of nitrogen that rapidly converts to nitrate (NO_3^-) and is usually included in the NO_3^- analysis.

Overturn: Fall cooling and spring warming of surface water increases density and gradually makes temperature and density uniform from top to bottom. This allows wind and wave action to mix the entire lake. Mixing allows bottom waters to contact the atmosphere, raising the oxygen content of the water. However, warming may occur too rapidly in the spring for mixing to be effective, especially in small sheltered kettle lakes.

Phosphorus: Key nutrient influencing plant growth in more than 80% of Wisconsin lakes. Soluble reactive phosphorus is the amount of phosphorus in solution that is available to plants. Total phosphorus includes the amount of phosphorus in solution (reactive) and in particulate form.

Photosynthesis: Process by which green plants convert carbon dioxide (CO_2) dissolved in water to sugar and oxygen using sunlight for energy. Photosynthesis is essential in producing a food base for a lake and is an important source of oxygen for many lakes.

Phyloplankton: see "Algae."

Precipitate: A solid material that forms and settles out of water as a result of certain negative ions (anions) combining with positive ions (cations).

Retention time: The average length of time water resides in a lake, ranging from several days in small impoundments to many years in large seepage lakes. Retention time (turnover rate or flushing rate) is important in determining the impact of nutrient inputs. Long retention times result in recycling and greater nutrient retention in most lakes. Calculate retention time by dividing the volume of water passing through the lake per year by the lake volume.

Respiration: The process by which aquatic organisms convert organic material to energy. It is the reverse of photosynthesis. Respiration consumes oxygen (O_2) and releases carbon dioxide (CO_2). It also takes place as organic matter decays.

Rooted aquatic plants Refers to higher (multi-celled) plants growing in or near water. Macrophytes are beneficial to lakes because they produce oxygen and provide substrate for fish habitat and aquatic insects. Overabundance of such plants, especially problem species, is related to shallow water depth and high nutrient levels.

Secchi disc: An 8-inch diameter plate with alternating quadrants painted black and white that is used to measure water clarity (light penetration). The disc is lowered into water until it disappears from view. It is then raised until just visible. An average of the two depths, taken from the shaded side of the boat, is recorded as the Secchi disc reading. For best results, the readings should be taken on sunny, calm days.

Sedimentation: Accumulated organic and inorganic matter on the lake bottom. Sediment includes decaying algae and weeds, marl, and soil and organic matter eroded from the watershed of the lake.

Seepage lakes: Lakes without a significant inlet or outlet, fed by rainfall and ground water. Seepage lakes lose water through evaporation and ground water moving on a downgradient. Lakes with little ground-water inflow tend to be naturally acidic and most susceptible to the effects of acid rain. Seepage lakes often have long residence times, and lake levels fluctuate with local ground-water levels. Water quality is affected by ground-water quality and the use of land on the shoreline.

Soluble: Capable of being dissolved.

Stratification: The layering of water due to differences in density. The greatest density of water occurs at 39˚F (4˚C). As water warms during the summer, cool water remains near the bottom. Wind mixing determines the thickness of the warm surface water layer (epilimnion), which usually extends to a depth of about 20 feet. The narrow transition zone between the epilimnion and cold bottom water (hypolimnion) is called the metalimnion or thermocline.

Suspended solids: A measure of the particulate matter in a water sample expressed in milligrams per liter. When measured on inflowing streams, it can be used to estimate the sedimentation rate of lakes or impoundments.

Thermocline: see “Stratification.”

Transparency: see “Secchi disc.”

Trophic state: The degree to which a lake is enriched with nutrients, increasing the production of rooted aquatic plants and algae. The extent to which this process has occurred is reflected in a lake’s trophic classification: oligotrohic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).

Watershed: see “Drainage basin.”

Zooplankton: Microscopic or barely visible animals that often eat algae. These suspended plankton are an important component of the lake food chain and ecosystem. For many fish, they are the primary source of food.

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APPENDIX A

LABORATORY REPORTS

APPENDIX B

WiLMS® MODEL RESULTS

APPENDIX C

SUMMARY OF AQUATIC PLANT MANAGEMENT ALTERNATIVES

Aquatic Plant Management

Aquatic plants are a critical component in an aquatic ecosystem. Any management of an ecosystem can have negative or even detrimental effects on the whole ecosystem. Therefore, the practice of managing aquatic plants should not be taken lightly. The concept of Aquatic Plant Management (APM) is highly variable since different aquatic resource users want different things. Ideal management to one individual may mean providing prime fish habitat, for another it may be to remove surface vegetation for boating. The practice of APM is also highly variable. There are numerous APM strategies designed to achieve different plant management goals. Some are effective on a small scale, but ineffective in larger situations. Others can only be used for specific plants or during certain times of the growing season. Of course, the types of plants that are to be managed will also help determine which APM alternatives are feasible. The following paragraphs discuss the APM methods used today. The discussion is largely adopted from *Managing Lakes and Rivers, North American Lake Management Society, 2001*, supplemented with other applicable current resources and references. The methods summarized here are largely for management of rooted aquatic plants, not algae. While some methods may also have effects on nuisance algae blooms, the focus is submergent rooted aquatic macrophytes. This information is provided to allow the user to gain a basic understanding of the APM method, it is not designed to an all-inclusive APM decision-making matrix. APM alternatives can be divided into the following categories: Physical Controls, Chemical Controls, and Biological Controls.

Physical Controls

Physical APM controls include various methods to prevent growth or remove part or all of the aquatic plant. Both manual and mechanical techniques are employed. Physical APM methods include:

- Hand pulling
- Hand cutting
- Bottom barriers
- Light limitation (dyes, covers)
- Mechanical harvesting
- Hydroraking/rototilling
- Suction Dredging
- Dredging
- Drawdown

Each of these methods is described below. The costs, benefits, and drawbacks of each APM strategy are provided.

Hand Pulling: This method involves digging out or hand removing the entire unwanted plant including stems and roots with a hand tool such as a spade. This method is highly selective and suitable for shallow areas for removing invasive species that have not become well established. This technique is obviously not for use on large dense beds of nuisance aquatic plants. It is best used in areas less than 3 feet deep, but can be used in deeper areas with divers using scuba and snorkeling equipment. It can also be used in combination with the suction dredge method. In Wisconsin, hand pulling may be completed outside a designated sensitive area without a permit but is limited to 30 feet of shoreline frontage. Removal of exotic species is not limited to 30 feet.

Advantages: This technique results in immediate clearing of the water column of nuisance plants. When a selective technique is desired in a shallow, small area, hand pulling is a good choice. It is also useful in sensitive areas where disruption must be minimized.

Disadvantages: This method is labor intensive. Disturbing the substrate may affect fish habitat, increase turbidity, and may promote phosphorus re-suspension and subsequent algae blooms.

Costs: The costs are highly variable. There is practically no cost using volunteers or lakeshore landowners to remove unwanted plants, however using divers to remove plants can get relatively expensive. Hand pulling labor can range from \$100 to \$400 per hour.

Hand Cutting: This is another manual method where the plants are cut below the water surface. Generally the roots are not removed. Tools such as rakes, scythes or other specialized tools are pulled through the plant beds by boat or several people. This method is not as selective as hand pulling. This method is well suited for small areas near docks and piers. Plant material must be removed from the water. In Wisconsin, hand cutting may be completed outside a designated sensitive area without a permit but is limited to 30 feet of shoreline frontage. Removal of exotic species is not limited to 30 feet.

Advantages: This technique results in immediate clearing of the water column of nuisance plants. Costs are minimal.

Disadvantages: This is also a fairly time consuming and labor intensive option. Since the technique does not remove the entire plant (leaves root system and part of plant), it may not result in long-term reductions in growth.

Costs: The costs range from minimal for volunteers using hand equipment up to over \$1,000 for a hand-held mechanized cutting implement. Hand pulling labor can range from \$100 to \$400 per hour.

Bottom Barriers: A barrier material is applied over the lake bottom to prevent rooted aquatics from growing. Natural barriers such as clay, silt, and gravel can be used although eventually plants may root in these areas again. Artificial materials can also be used for bottom barriers and anchored to the substrate. Barrier materials include burlap, nylon, rubber, polyethylene, polypropylene, and fiberglass. Barriers include both solid and porous forms. A permit is required to place any fill or barrier structure on the substrate of a waterbody. This method is well suited for areas near docks, piers, and beaches. Periodic maintenance may be required to remove accumulated silt or rooting fragments from the barrier.

Advantages: This technique does not result in production of plant fragments. Properly installed, it can provide immediate and multiple year relief.

Disadvantages: This is a non-selective option, all plants beneath the barrier will be affected. Some materials are costly and installation is labor intensive. Other disadvantages include limited material durability, gas accumulation beneath the cover, or possible re-growth of plants from above or below the cover. Fish and invertebrate habitat is disrupted with this technique. Anchored barriers can be difficult to remove.

Costs: A 20 foot x 60 foot panel cost \$265, while a 30 foot x 50 foot panel cost \$375 (this does not include installation costs). Costs for materials vary from \$0.15 per square foot (ft^2) to over \$0.35/ ft^2. The costs for installation range from \$0.25 to \$0.50/ ft^2. Barriers can cost \$20,000 to \$50,000 per acre.

Light Limitation: Limiting the available light in the water column can prevent photosynthesis and plant growth. Dark colored dyes and surface covers have been used to accomplish light limitation. Dyes are effective in shallow water bodies where their concentration can be kept at a desired concentration and loss through dilution is less. This method is well suited for small, shallow water bodies with no outlets such as private ponds.

Surface covers can be a useful tool in small areas such as docks and beaches. While they can interfere with aquatic recreation, they can be timed to produce results and not affect summer recreation uses.

Advantages: Dyes are non-toxic to humans and aquatic organisms. No special equipment is required for application. Light limitation with dyes or covers method may be selective to shade tolerant species. In addition to submerged macrophyte control, it can also control the algae growth.

Disadvantages: The application of water column dyes is limited to shallow water bodies with no outlets. Repeated dye treatments may be necessary. The dyes may not control peripheral or shallow-water rooted plants. This technique must be initiated before aquatic plants start to grow. Covers inhibit gas exchange with the atmosphere.

Costs: Costs for a commercial dye and application range from $100 to $500 per acre.

Mechanical Harvesting: Mechanical harvesters are essentially cutters mounted on barges that cut aquatic plants at a desired depth. Maximum cutting depths range from 5 to 8 feet with a cutting width of 6.5 to 12 feet. Cut plant materials require collection and removal from the water. Conventional harvesters combine cutting, collecting, storing, and transporting cut vegetation into one piece of equipment. Transport barges and shoreline conveyors are also available to remove the cut vegetation. The cut plants must be removed from the water body. The equipment needs are dictated by severity of the aquatic plant problem. Contract harvesting services are available in lieu of purchasing used or new equipment. Trained staff will be necessary to operate a mechanical harvester. To achieve maximum removal of plant material, harvesting is usually completed during the summer months while submergent vegetation is growing to the surface. The duration of control is variable and re-growth of aquatic plants is common. Factors such as timing of harvest, water depth, depth of cut, and timing can influence the effectiveness of a harvesting operation. Harvesting is suited for large open areas with dense stands of exotic or nuisance plant species. Permits are now required in Wisconsin to use a mechanical harvester.

Advantages: Harvesting provides immediate visible results. Harvesting allows plant removal on a larger scale than other options. Harvesting provides flexible area control. In other words, the harvester can be moved to where it is needed and used to target problem areas. This technique has the added benefit of removing the plant material from the water body and therefore also eliminates a possible source of nutrients often released during fall decay of aquatic plants. While removal of nutrients through plant harvesting has not been quantified, it can be important in aquatic ecosystem with low nutrient inputs.

Disadvantages: Drawbacks of harvesting include: limited depth of operation, not selective within the application area and expensive equipment costs. Harvesting also creates plant fragments, which can be a concern since certain plants have the ability to reproduce whole plants from a plant fragment (e.g. Eurasian watermilfoil). Plant fragments may re-root and spread a problem plant to other areas. Harvesting can have negative effects on non-target plants, young of year fish, and invertebrates. The harvesting will require trained operators and maintenance of equipment. Also, a disposal site or landspreading program will be needed for harvested plants.

Costs: Costs for a harvesting operation are highly variable dependant on program scale. New harvesters range from $40,000 for small machines to over $100,000 for large, deluxe models. Costs vary considerably, depending on the model, size, and options chosen. Specially designed units are available, but may cost more. The equipment can last 10 to 15 years. A grant for ½ the equipment cost can be obtained from the Wisconsin Waterways Commission and a loan can be obtained for the remaining capital investment. Operation costs include insurance, fuel, spare parts, and payroll. Historical harvesting values have been reported at $200 up to $1,500 per acre. A survey of recent Wisconsin harvesting operations reported costs to be between $100/acre and $200/acre.

A used harvester can be purchased for $10,000 to $20,000. Maintenance costs are typically higher.

Contract harvesting costs approximately $125/per hour plus mobilization to the water body. Contractors can typically harvest ¼ to ½ acre per hour for an estimated cost of $250 to $500/per acre.

Hydroraking/rototilling: Hydroraking is the use of a boat or barge mounted machine with a rake that is lowered to the bottom and dragged. The tines of the rake rip out roots of aquatic plants. Rototilling, or rotovation, also rips out root masses but uses a mechanical rotating head with tines instead of a rake. Harvesting may need to be completed in conjunction with these methods to gather floating plant fragments. This application would best be used where nuisance populations are well established and prevention of stem fragments is not critical. A permit would be required for this type of aquatic plant management and would only be issued in limited cases of extreme infestations of nuisance vegetation. In Wisconsin, this method is not permitted by the WDNR.

Advantages: These methods have the potential for significant reductions in aquatic plant growth. These methods can remove the plant stems and roots, resulting in thorough plant disruption. Hydroraking/rototilling can be completed in "off season" months avoiding interference with summer recreation activities.

Disadvantages: Hydroraking/rototilling are not selective and may destroy substrate habitat important to fish and invertebrates. Suspension of sediments will increase turbidity and can possibly cause algae blooms. These methods can cause floating plant and root fragments, which may re-root and spread the problem. Hydroraking/rototilling are expensive and not likely to be permitted by regulatory agencies.

Costs: Bottom tillage costs vary according to equipment, treatment scale, and plant density. For soft vegetation costs can range from $2,000 to $4,000 per acre. For dense, rooted masses, costs can be up to $10,000 per acre. Contract bottom tillage reportedly ranges from $1,200 to $1,700 per acre (Washington Department of Ecology, 1994).

Suction Dredging: Suction dredging uses a small boat or barge with portable dredges and suction heads. Scuba divers operate the suction dredge and can target removal of whole plants, seeds, and roots. This method may be applied in conjunction with hand cutting where divers dislodge the plants. The plant/sediment slurry is hydraulically pumped to the barge through hoses carried by the diver. Its effectiveness is dependent on sediment composition, density of aquatic plants, and underwater visibility. Suction dredging may be best suited for localized infestations of low plant density where fragmentation must be controlled. A permit will be required for this activity.

Advantages: Diver suction dredging is species –selective. Disruption of sediments can be minimized. These methods can remove the plant stems and roots, resulting in thorough plant disruption and potential longer term control. Fragmentation of plants is minimized. This activity can be completed near and around obstacles such as piers or marinas where a harvester could not operate.

Disadvantages: Diver suction dredging is labor intensive and costly. Upland disposal of dredged slurry can require additional equipment and costs. Increased turbidity in the area of treatment can be a problem. Release of nutrients and other pollutants can also be a problem.

Costs: Suction dredging costs can be variable depending on equipment and transport requirements for slurry. Costs range from $5,000 per acre to $10,000 per acre.

Dredging: Sediment removal through dredging can work as a plant control technique by limiting light through increased water depth or removing soft sediments that are a preferred habitat to nuisance rooted plants. Soft sediment removal is accomplished with drag lines, bucket dredges, long reach backhoes, or other specialized dredging equipment. Dredging has had mixed results in controlling aquatic plant, however it can be highly effective in appropriate situations. Dredging is most often applied in a major restructuring of a severely degraded system. Generally, dredging is an activity associated with other restoration efforts. Comprehensive pre-planning will be necessary for these techniques and a dredging permit would be required.

Advantages: Dredging can remove nutrient reserves which result in nuisance rooted aquatic plant growth. Dredging, when completed, can also actually improve substrate and habitat for more desirable species of aquatic plants, fish, and invertebrates. It allows the complete renovation of an aquatic ecosystem. This method has the potential for significant reductions in aquatic plant growth. These methods can be completed in "off season" months avoiding interference with summer recreation activities.

Disadvantages: Dredging can temporarily destroy important fish and invertebrate habitat. Suspension of sediments usually increases turbidity significantly and can possibly releases nutrients causing algae blooms. Dredging is extremely expensive and requires significant planning. Dredged materials may contain toxic materials (metals, PCBs). Dredged material transportation and disposal of toxic materials are additional management considerations and are potentially expensive. It could be difficult and costly to secure regulatory permits and approvals.

Costs: Dredging costs depend upon the scale of the project and many other factors. It is generally an extremely expensive option.

Drawdown: Water level drawdown exposes the plants and root systems to prolonged freezing and drying to kill the plants. It can be completed any time of the year, however is generally more effective in winter, exposing the lake bed to freezing temperatures. If there is a water level control structure capable of drawdown, it can be an in-expensive way to control some aquatic plants. Aquatic plants vary in their susceptibility to drawdown, therefore, accurate identification of problem species is important. Drawdown is often used for other purposes of improving waterfowl habitat or fishery management, but sometimes has the added benefit of nuisance rooted aquatic plant control. This method can be used in conjunction with a dredging project to excavate nutrient-rich sediments. This method is best suited for use on reservoirs or shallow man-made lakes. A drawdown would require regulatory permits and approvals.

Advantages: A drawdown can result in compaction of certain types of sediments and can be used to facilitate other lake management activities such as dam repair, bottom barrier, or dredging projects. Drawdowns can significantly impact populations of aquatic plants that propagate vegetatively. It is inexpensive.

Disadvantages: This method is limited to situations with a water level control structure. Pumps can be used to de-water further if ground water seepage is not significant. This technique may also result in the removal of beneficial plant species. Drawdowns can decrease bottom dwelling invertebrates and overwintering reptiles and amphibians. Drawdowns can affect adjacent wetlands, alter downstream flows, and potentially impair well production. Drawdowns and any water level manipulation are often highly controversial since shoreline landowners access and public recreation are limited during the drawdown. Fish populations are vulnerable during a drawdown due to over-harvesting by fisherman in decreased water volumes.

Costs: If a suitable outlet structure is available then costs should be minimal. If dewatering pumps would be required or additional management projects such as dredging are completed, additional costs would be incurred. Other costs would include recreational losses and perhaps loss in tourism revenue.

Chemical Controls

Using chemical herbicides to kill nuisance aquatic plants is the oldest APM method. However, past pesticides uses being linked to environmental or human health problems have led to public wariness of chemicals in the environment. Current pesticide registration procedures are more stringent than in the past. While no chemical pesticide can be considered 100 percent safe, federal pesticide regulations are based on the premise that if a chemical is used according to its label instructions it will not cause adverse environmental or human health effects.

Chemical herbicides for aquatic plants can be divided into two categories, systemic and contact herbicides. Systemic herbicides are absorbed by the plant, translocated throughout the plant, and are capable of killing the entire plant, including the roots and shoots. Contact herbicides kill the plant surface in which in comes in contact, leaving roots capable of re-growth. Aquatic herbicides exist under various trade names, causing some confusion. Aquatic herbicides include the following:

- Endothall Based Herbicide
- Diquat Based Herbicide
- Fluridone Based Herbicide
- 2-4 D Based Herbicide

- Glyophosate Based Herbicide
- Triclopyr Based Herbicide
- Phosphorus Precipitation

Each of these methods are described below. The costs, benefits, and drawbacks of each chemical APM alternative are provided.

Endothall Based Herbicide: Endothall is a contact herbicide, attacking a wide range of plants at the point of contact. The chemical is not readily transferred to other plant tissue, therefore regrowth can be expected and repeated treatments may be needed. It is sold in liquid and granular forms under the trade names of Aquathol K, Aquathol, or Hydrothol. Hydrothol is also an algaecide. Most endothall products break down easily and do not remain in the aquatic environment. Endothall products can result in plant reductions for a few weeks to several months. Multi-season effectiveness is not typical. A permit is required for use of this herbicide.

Advantages: Endothall products work quickly and exhibit moderate to highly effective control of floating and submersed species. This herbicide has limited toxicity to fish at recommended doses.

Disadvantages: The entire plant is not killed when using endothall. Endothall is non-selective in the treatment area. High concentrations can kill fish easily. Water use restrictions (time delays) are necessary for recreation, irrigation, and fish consumption after application.

Costs: Costs vary with treatment area and dosage. Average costs for chemical application range between $400 and $700 per acre.

Diquat Based Herbicide: Diquat is a fast-acting contact herbicide effective on a broad spectrum of aquatic plants. It is sold under the trade name of Reward. Diluted forms of this product are also sold as private label products. Since Diquat binds to sediments readily, its effectiveness is reduced by sediment suspended waters. Multi-season effectiveness is not typical. A permit is required for use of this herbicide.

Advantages: Diquat works quickly and exhibit moderate to highly effective control of floating and submersed species. This herbicide has limited toxicity to fish at recommended doses.

Disadvantages: The entire plant is not killed when using diquat. Diquat is non-selective in the treatment area. Diquat can be inactivated by suspended sediments. Diquat is sometimes toxic to zooplankton at the recommended dose. Limited water used restrictions (water supply, agriculture, and contact recreation) are required after application.

Costs: Costs vary with treatment area and dosage. A general cost estimate for treatment is between $200 and $500 per acre.

Fluridone Based Herbicide: Fluridone is a slow-acting systemic herbicide, which is effectively absorbed and translocated by both plant roots and stems. Sonar or Avast are the trade names and are sold in liquid or granular form. Fluridone requires a longer contact time and demonstrates delayed toxicity to target plants. Watermilfoil is more susceptible to fluridone than other aquatic plants. This allows a semi-selective approach when low enough doses are used. Since the roots are also killed, multi-season effectiveness can be achieved. It is best applied during the early growth phase of the plants. A permit is required for use of this herbicide.

Advantages: Fluridone is capable of killing roots, therefore producing a longer lasting effect than other herbicides. A variety of emergent and submersed aquatics are susceptible to this herbicide. Fluridone can be used selectively, based on concentration. A gradual killing of target plants limits severe oxygen depletion from dead plant material. It has demonstrated low toxicity to aquatic fauna such as fish and invertebrates. 3 to 5 year control has been demonstrated. Extensive testing has shown that, when used according to label instructions, it does not pose negative health affects.

Disadvantages: Fluridone is a slow-acting herbicide sometimes taking up to several months for visible effects. It requires a long contact time. Fluridone is extremely soluble and mixable, therefore, not effective in flowing water situations or for treating a select area in a large open lake. Impacts on non-target plants are possible at higher doses. Time delays are necessary on use of the water (water supply, irrigation, and contact recreation) after application.

Costs: Costs vary with treatment area and dosage. Treatment costs range from $500 to $2,000 per acre.

2,4-D Based Herbicide: 2,4-D-based herbicides are sold in liquid or granular forms under various trade names. It is a systemic herbicide that affects broad leaf plants. It has been demonstrated effective against Eurasian watermilfoil, but it may not work on many aquatic plants. Since the roots are also killed, multi-season effectiveness may be achieved. It is best applied during the early growth phase of the plants. Visible results are evident within 10 to 14 days. A permit is required for use of this herbicide.

Advantages: 2,4-D is capable of killing roots, therefore producing a longer lasting effect than some other herbicides. It is fairly fast and somewhat selective, based on application timing and concentration. 2,4-D containing products are moderately to highly effective on a few emergent, floating, or submersed plants.

Disadvantages: 2,4-D can have variable toxicity effects to aquatic fauna, depending on formulation and water chemistry. 2,4-D lasts only a short time in water, but can be detected in sediments for months after application. Time delays are necessary on use of the water (agriculture and contact recreation) after application. The label does not permit use of this product in water used for drinking, irrigation, or livestock watering.

Costs: Costs vary with treatment area and dosage. Treatment costs range from $300 to $800 per acre.

Glyophosate Based Herbicide: Glyophosate has been categorized as both a contact and a systemic herbicide. It is applied as a liquid spray and is sold under the trade name Rodeo or Pondmaster. It is a non-selective, broad based herbicide effective against emergent or floating leaved plants, but not submergents. It's effectiveness can be reduced by rain. A permit is required for use of this herbicide.

Advantages: Glyophoshate is moderately to highly effective against emergent and floating-leaf plants resulting in rapid plant destruction. Since it is applied by spraying plants above the surface, the applicator can apply it selectively to target plants. Glyophosate dissipates quickly from natural waters, has a low toxicity to aquatic fauna, and carries no restrictions or time delays for swimming, fishing, or irrigation.

Disadvantages: Glyophoshate is non-selective in the treatment area. Wind can dissipate the product during the application reducing it's effectiveness and cause damage to non-target organisms. Therefore, spray application should only be completed when wind drift is not a problem. This compound is highly corrosive, therefore storage precautions are necessary.

Costs: Costs average $500 to $1,000 per acre depending on the scale of treatment.

Triclopyr Based Herbicide: Triclopyr is a systemic herbicide. It is registered for experimental aquatic use in selected areas only. It is applied as a liquid spray or injected into the subsurface as a liquid. Triclopyr has shown to be an effective control to many floating and submersed plants. It has been demonstrated to be highly effective against Eurasian watermilfoil, having little effect on valued native plants such as pondweeds. Triclopyr is most effective when applied during the active growth period of younger plants.

Advantages: This herbicide is fast acting. Triclopyr can be used selectively since it appears more effective against dicot plant species, including several difficult nuisance plants. Testing has demonstrated low toxicity to aquatic fauna.

Disadvantages: At higher doses, there are possible impacts to non-target species. There is a time delay of 30 days for fish consumption from treated areas. This herbicide is experimental for aquatic use and restrictions on use of the treated water are not yet certain.

Biological Controls

There has been recent interest in using biological technologies to control aquatic plants. This concept stems from a desire to use a "natural" control and reduce expenses related to equipment and/or chemicals. While use of biological controls is in its infancy, potentially useful technologies have been identified and show promise for integration with physical and chemical APM strategies. Several biological controls that are in use or are under experimentation include the following:

- Herbivorous Fish
- Herbivorous Insects
- Plant Pathogens
- Native Plants

Each of these methods are described below. The costs, benefits, and drawbacks of each biologic APM method are provided.

Herbivorous Fish: A herbivorous fish such as the non-native grass carp can consume large quantities of aquatic plants. These fish have high growth rates and a wide range of plant food preferences. Stocking rates and effectiveness will depend on many factors including climate, water temperature, type and extent of aquatic plants, and other site-specific issues. Sterile (triploid) fish have been developed resulting in no reproduction of the grass carp and population control. This technology has demonstrated mixed results and is most appropriately used for lake-wide, low intensity control of submersed plants. Some states do not allow stocking of herbivorous fish. In Wisconsin, stocking of grass carp is prohibited.

<u>Advantages:</u> This technology can provide multiple years of aquatic plant control from a single stocking. Compared to other long-term aquatic plant control techniques such as bottom tillage or bottom barriers, costs may be relatively low.

<u>Disadvantages:</u> Sterile grass carp exhibit distinct food preferences, limiting their applicability. Grass carp may feed selectively on the preferred plants, while less preferred plants, including milfoil, may increase. The effects of using grass carp may not be immediate. Overstocking may result in an impact on non-target plants or eradication of beneficial plants, altering lake habitat. Using grass carp may result in algae blooms and increased turbidity. If precautions are not taken (i.e. inlet and outlet control structures to prevent fish migration) the fish may migrate and have adverse effects on non-target vegetation.

<u>Costs:</u> Costs can range from $50/acre to over $2,000/acre, at stocking rates of 5 fish/acre to 200 fish/acre.

Herbivorous Insects: Non-native and native insect species have been used to control rooted plants. Using herbivorous insects is intended to selectively control target species. These aquatic larvae of moths, beetles, and thrips use specific host aquatic plants. Several non-native species have been imported under USDA approval and used in integrated pest management programs, a combination of biological, chemical, and mechanical controls.

These non-native insects are being used in southern states to control nuisance plant species and appear climate-limited, their northern range being Georgia and North Carolina. While successes have been demonstrated, non-native species have not established themselves for solving biological problems, sometimes creating as many problems as they solve. Therefore, government agencies prefer alternative controls.

Native insects such as the larvae of midgeflies, caddisflies, beetles, and moths may be successful APM controls in northern states. Recently however, the native aquatic weevil *Euhrychiopsis lecontei* has received the most attention. This weevil has been associated with native northern water milfoil. The weevil can switch plant hosts and feed on Eurasian watermilfoil, destroying it’s growth points. While the milfoil weevil is gaining popularity, it is still experimental.

<u>Advantages:</u> Herbivorous insects are expected to have no negative effects on non-target species. The insects have shown promise for long term control when used as part of integrated aquatic plant management programs. The milfoil weevils do not use non-milfoil plants as hosts.

Disadvantages: Natural predator prey cycles indicate that incomplete control is likely. An oscillating cycle of control and re-growth is more likely. Fish predation may complicate controls. Large numbers of milfoil weevils may be required for a dense stand and can be expensive. The weevil leaves the water during the winter, may not return to the water in the spring, and are subject to bird predation in their terrestrial habitat. Application is manual and extremely time consuming. Introducing any species, especially non-native ones, into an aquatic ecosystem may have undesirable effects. Therefore, it is extremely important to understand the life cycles of the insects and the host plants.

Costs: Reported costs of herbivorous insects rang from $300/acre to $3,000/acre.

Specifically, the native milfoil weevils cost approximately $1.00 per weevil. It is generally considered appropriate to use 5 to 7 weevils per stem. Dense stands of milfoil may contain 1 to 2 million stems per acre. Therefore, costs of this new technology are currently prohibitive.

Plant Pathogens: Using a plant pathogen to control nuisance aquatic plants has been studied for many years, however, this practice still remains largely experimental. Fungi are the most common pathogens, while bacteria and viruses have also been used. There is potential for highly specific plant applications.

Advantages: Plant pathogens may be highly species specific. They may provide substantial control of a nuisance species.

Disadvantages: Pathogens are experimental. The effectiveness and longevity of control is not well understood. Possible side effects are also unknown.

Costs: These techniques are experimental therefore a supply of specific products and costs are not established.

Native Plants: This method involves removing the nuisance plant species through chemical or physical means and re-introducing seeds, cuttings, or whole plants of desirable species. Success has been variable. When using seeds, they need to be planted early enough to encourage the full growth and subsequent seed production of those plants. Transplanting mature plants may be a better way to establish seed producing populations of desirable aquatics. Recognizing that a healthy, native, desirable plant community may be resistant to infestations of nuisance species, planting native plants should be encouraged as an APM alternative. Non-native plants can not be translocated.

Advantages: This alternative can restore native plant communities. It can be used to supplement other methods and potentially prevent future needs for costly repeat APM treatments.

Disadvantages: While this appears to be a desirable practice, it is experimental at this time and there are not many well documented successes. Nuisance species may eventually again invade the areas of native plantings. Careful planning is required to ensure that the introduced species do not themselves become nuisances. Hand planting aquatic plants is labor intensive.

Costs: Costs can be highly variable depending on the selected native species, numbers of plants ordered, and the nearest dealer location.

Aquatic Plant Prevention

The phrase "an ounce of prevention is worth a pound of cure" certainly holds true for APM. Prevention is the best way to avoid nuisance aquatic plant growth. Prevention of the spread of invasive aquatic plants must also be achieved. Inspecting boats, trailers, and live wells for live aquatic plant material is the best way to prevent nuisance aquatic plants from entering a new aquatic ecosystem. Protecting the desirable native plant communities is also often important to maintain a healthy aquatic ecosystem and preventing the spread of nuisance aquatics once they are present.

Prolific growth of nuisance aquatic plants can be prevented by limiting nutrient (i.e. phosphorus) inputs to the water body. Aeration or phosphorus precipitation can achieve controls of in-lake cycling of phosphorus, however, if there are additional outside sources of nutrients, these methods will be largely ineffective in controlling algae blooms or intense aquatic macrophyte infestations. Watershed management activities to control nutrient laden storm water runoff are critical to controlling excessive nutrient loading to the water bodies. Nutrient loading can be prevented/minimized by the following:

- Shoreline buffers
- Using non-phosphorus fertilizers on lawns
- Settling basins for storm water effluents

APPENDIX D

SUMMARY OF DEVILS LAKE PHOSPHORUS REMOVAL SUMMARY

APPENDIX E

WDNR AQUATIC PLANT MANAGEMENT PERMIT APPLICATION