Lake Management Plan for Twin Lakes, Green Lake County, Wisconsin

Prepared for:
Twin Lakes Association, Inc.
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Introduction

Two connected glacial pothole lakes, Big Twin Lake and Little Twin Lake, form the waterbody known as Twin Lakes (**Figure 1**). Big Twin Lake has a surface area of 78 acres, a maximum depth of 46 feet and an average depth of 17 feet (DNR, 2005). Little Twin Lake has a surface area of 33 acres, a maximum depth of 10 feet and an average depth of 4 feet (**Figure 2**). Big and Little Twin Lakes are located in the rolling hills of east-central Green Lake County, Wisconsin. The surrounding countryside is primarily agricultural land. One unnamed creek drains into Big Twin Lake. The outlet for Twin Lakes, Little Hills Creek, drains from the northeast end of Little Twin Lake and flows into Big Green Lake. The shores of Big Twin Lake are predominantly upland. The north and southwest shorelines are developed with cottages and year-around homes. The shores of Little Twin Lake are predominantly a cattail bog. A boat ramp is located on the south shore of Big Twin Lake. Public access to Little Twin Lake is through a narrow channel from Big Twin Lake. The wetlands surrounding Twin Lakes provide important habitat for waterfowl and other wildlife. The lakes are also highly prized by local anglers for their quality largemouth bass and bluegill fisheries.

Two exotic plant species, Eurasian watermilfoil (*Myriophyllum spicatum*) and curly leaf pondweed (*Potamogeton crispus*) were found in both lakes in recent years. Faced with increasing threats from invasive exotic plants, the Twin Lakes Association, Inc. began conducting herbicide treatments for invasive aquatic plants on the lakes. Initial control measures were taken for Eurasian watermilfoil. The following outlines the management efforts, prior to the start of this study, for the control of these exotic species:

- In 2002 approximately 13 acres of Eurasian watermilfoil were mapped throughout Twin Lakes (**Figure 3**).

- By 2003 16 acres of Eurasian watermilfoil had been found (**Figure 4**).

- In the spring of 2003 Eurasian watermilfoil was treated in Little Twin with the herbicide Navigate® (granular 2,4-D) at a rate of 100 lbs/acre.

- On July 9, 2003, a line-transect aquatic plant survey was conducted and confirmed the presence of large amounts of both Eurasian watermilfoil and curly leaf pondweed throughout Twin Lakes.

- Efforts made to further reduce the extent of exotic species were made in 2004 and 2005. Results of these efforts are presented later in this report.

In recent years, Twin Lakes has also experienced very poor water quality. The lakes have suffered from severe summer algae blooms, poor water clarity, and low dissolved oxygen levels. High levels of nutrients have contributed to the poor water quality found in Twin Lakes. In order to better understand the role and movement of nutrients throughout Twin Lakes, water chemistry analyses were performed from May 2004 to January 2006.

Figure 1. Twin Lakes and the surround area, Green Lake County, Wisconsin.

Figure 2. Twin Lakes (Big Twin Lake and Little Twin Lake) in Green Lake County, Wisconsin

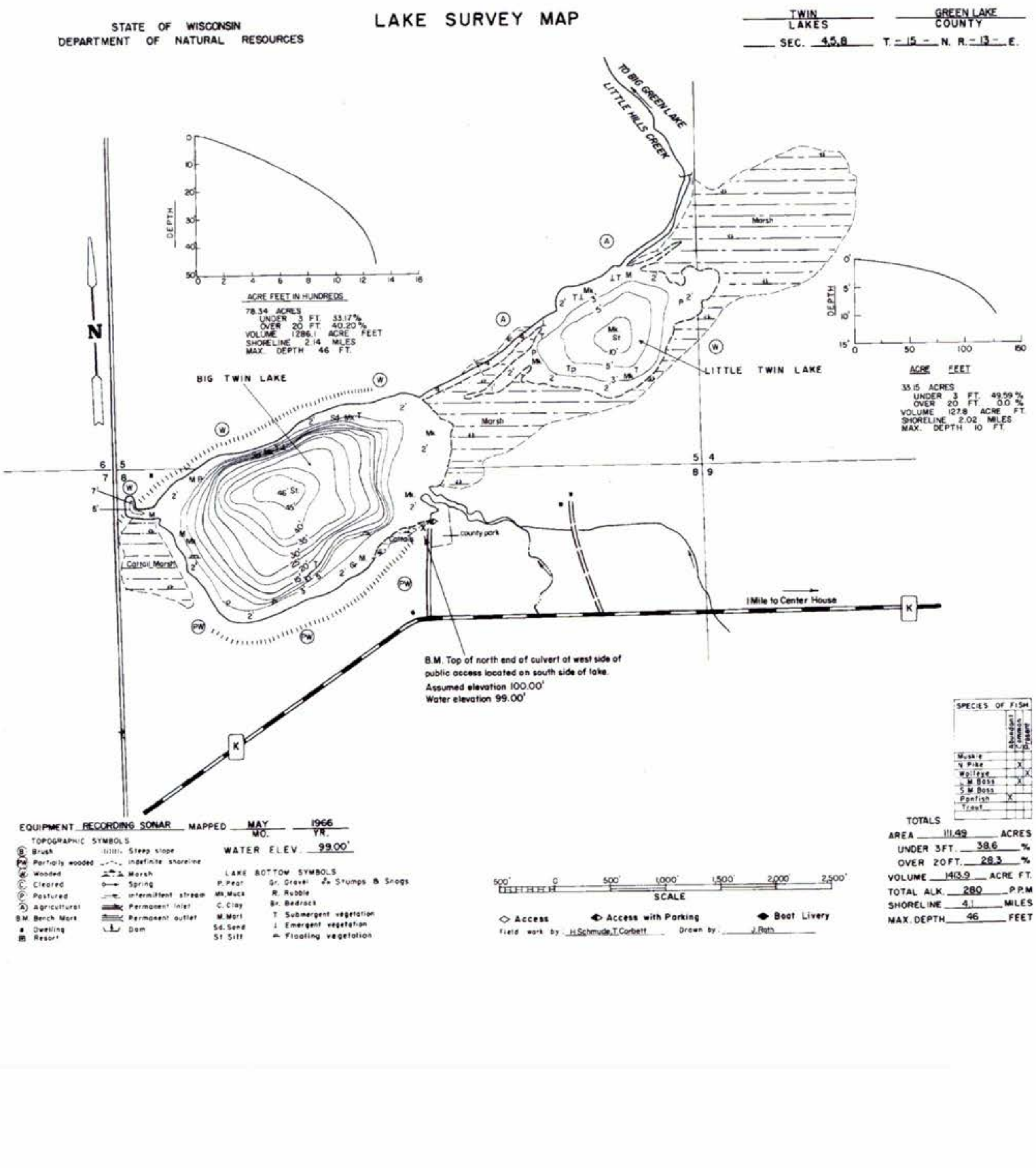

Figure 3. Distribution of Eurasian watermilfoil (*Myriophyllum spicatum*) on Twin Lakes, Green Lake County, on July 2, 2002.

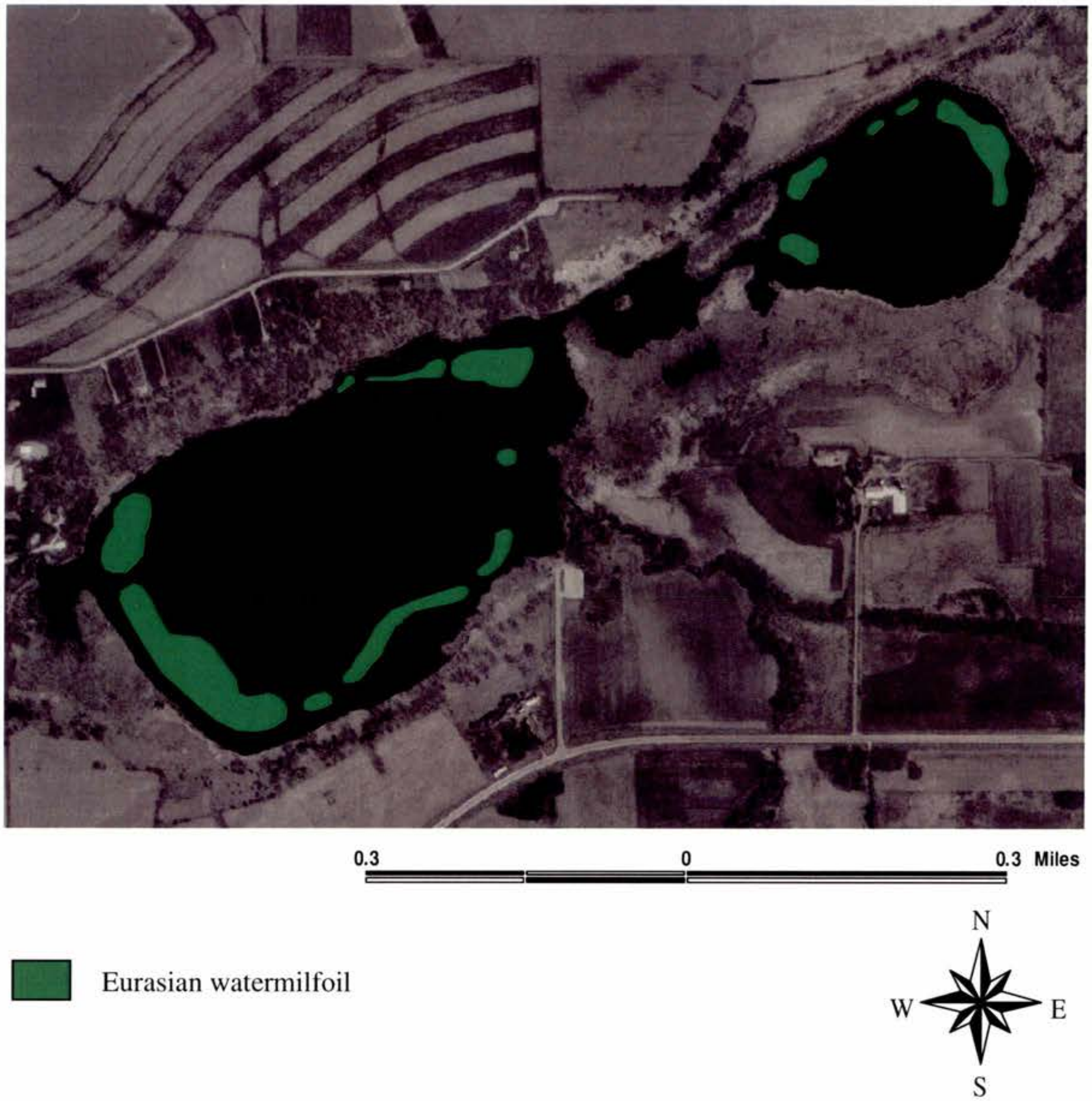

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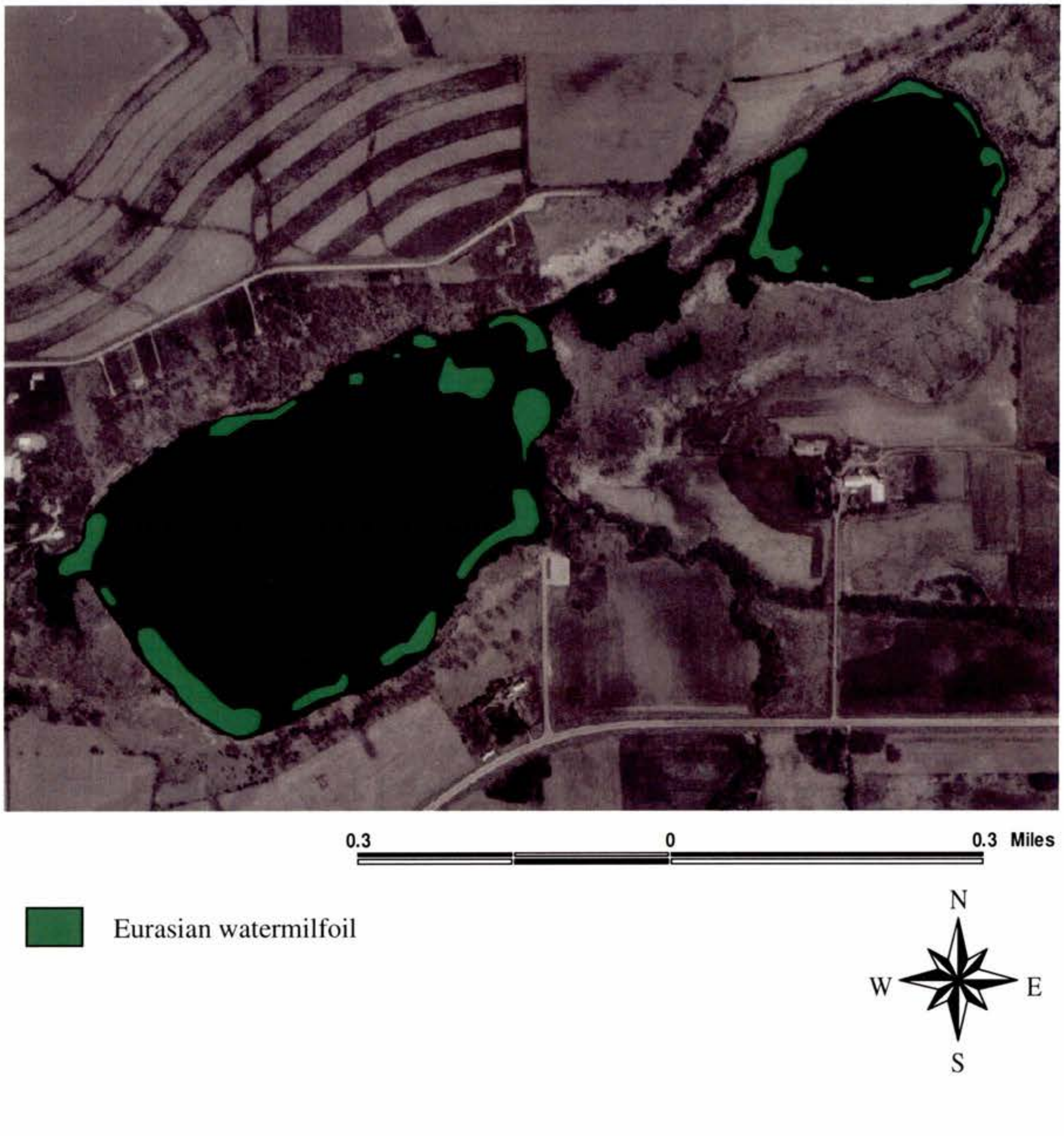
Figure 4. Distribution of Eurasian watermilfoil (*Myriophyllum spicatum*) on Twin Lakes, Green Lake County, 2003. Note: map is a composite of several surveys; not all milfoil beds shown were present at the same time.



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+ more goals for whole lake/long range

The goals of this study were 1) to collect physical, chemical, and biological data from Twin Lakes and their watershed, 2) to identify and prioritize management needs, and 3) to develop a long-range management plan with recommendations for future management of Twin Lakes

Methods

Field studies for this project included 1) conducting submergent and emergent aquatic plant surveys, 2) pre- and post-treatment mapping of the distribution of Eurasian watermilfoil and curly-leaf pondweed, 3) analyzing several water quality parameters, 4) and conducting a survey of the Twin Lakes watershed.

Submergent Aquatic plant survey

The aquatic plant survey involved plotting a series of 16 transects (8 in each lake basin) that radiated at 45-degree angles from a center point in each basin (**Figure 5**). Three plots were sampled along each transect: at 2.5, 5, and 10-foot depths in June 2004. At the time of this study, this design covered the maximum extent of rooted vegetation (the littoral zone). Plots were established by estimating a 10-foot diameter circle around the anchored boat. The circular plot was then divided into four quarters with each quarter representing a quadrant. Plants were collected in each quadrant by making tows with a tethered short-toothed rake. A total of 192 quadrants were sampled. From each rake tow, all plants collected were identified to *genus* and to *species* whenever possible. Data collected was used to determine species distribution, relative abundance (percent composition) and percent frequency.

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Emergent Aquatic Plant Survey

An emergent aquatic plant survey was also conducted in June 2004. Sixteen transects of equal distance ran parallel to shore, and were located between the starting points of the submergent plant transects (**Figure 5**). All emergent and floating-leaf plants observed were identified to *genus* and to *species* whenever possible, and recorded on a data sheet. The relative abundance of each plant species found along a given transect was ranked. The rankings used were:

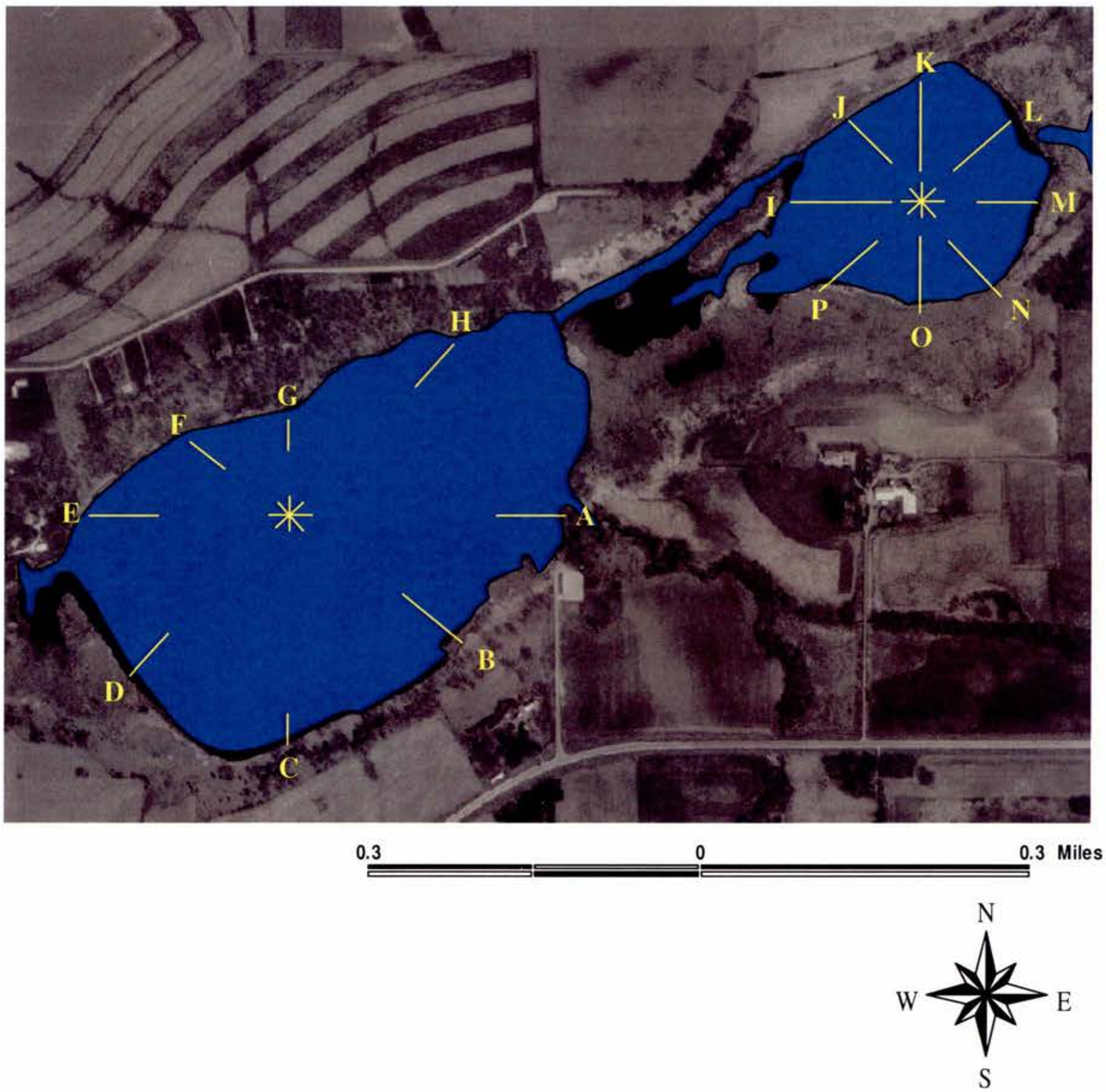
1. Rare – found along less than 5% of transect
2. Present – found along 5-25% of transect
3. Common – found along 25-50% of transect
4. Abundant – found along more than 50% of transect

For each transect, data collected was used to determine species composition, percent frequency and relative abundance.

Exotic plant species mapping

Both prior to and following the 2004 herbicide treatment for Eurasian watermilfoil, the extent and location of milfoil beds were determined from surface observations and rake tows. Minimum and maximum depths of beds were noted, and the locations of the beds were drawn on lake contour maps using shoreline features as references. Modified acreage grid analysis was then used to determine the area of each milfoil bed. Similarly, in June 2004, the distribution of curly-leaf pondweed was also mapped in Little Twin Lake where its distribution was the greatest.

Figure 5. Transect map for the aquatic plant surveys conducted in 2003 and 2004 on Twin Lakes, Green Lake County.



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Water quality monitoring

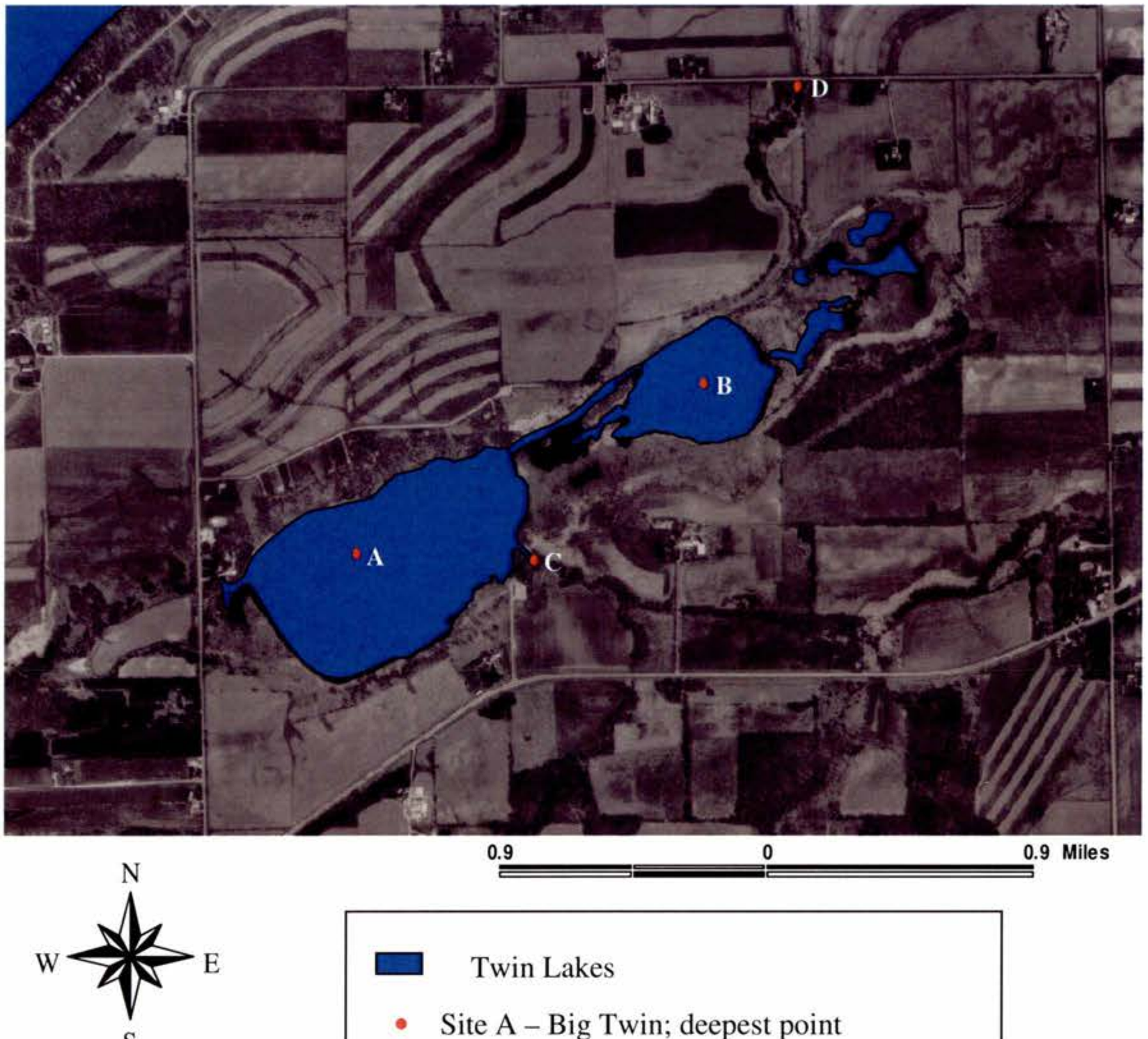
Seasonal water quality testing was conducted from May 2004 to January 2006. Sampling occurred during the winter, spring turnover, three times during the summer, and fall turnover. Samples were collected from the deepest point of each lake basin and from the inlet and outlet streams when possible (**Figure 6**). On April 14, 2005 the water sample was collected from near the spring which feeds the western branch of the inlet creek. This spring is located approximately one mile south of Twin Lakes just off Center Road. The purpose of this sampling was to estimate the nutrient concentration of the groundwater near Twin Lakes. Parameters analyzed on site in both lake basins included pH, dissolved oxygen, temperature, and water transparency (Secchi depth). Measurements of pH were made using a Hach Kit (titration method) in 2004 and with a portable Hach HQ20 Dissolved Oxygen/pH meter in 2005/2006. Dissolved oxygen and temperature profile data were collected with a YSI 55 dissolved oxygen meter in 2004 and with the Hach HQ20 meter in 2005. Oxygen and temperature measurements were taken at 2-foot intervals in Big Twin Lake and 1-foot intervals in Little Twin Lake. Secchi depths were measured using a standard 8-inch, black and white disc. Water samples were collected at all four sampling locations when possible and sent to the State Lab of Hygiene for analysis. Analyses included total phosphorus, and nitrate and nitrite (as nitrogen) for all locations. Additionally, samples for analysis of chlorophyll *a* were also collected in both lake basins and sent for laboratory analysis.

A more thorough or "complete" water chemistry and limnology analysis was conducted in August 2004 and 2005. Analyses performed included:

- pH
- Dissolved (ortho) phosphorus
- Total phosphorus
- Total Kjeldahl nitrogen
- Nitrate + nitrite as N
- Ammonia as N
- Chloride
- Chlorophyll *a*
- Color
- Suspended solids
- Total dissolved solids
- Conductivity
- Alkalinity
- Dissolved oxygen profile
- Temperature profile
- Secchi depth

Samples were collected in the same manner as the seasonal samples. However, total phosphorus, dissolved phosphorus, Kjeldahl nitrogen, nitrate + nitrite and ammonia samples were also collected from one foot above the lake bottom in each basin. This was done in order to compare water quality of the lakes' surface where oxygen levels were highest with conditions at the bottom of the lakes where oxygen levels were depleted.

Figure 6. Sampling locations on Twin Lakes, Green Lake County, 2004-2006.



Twin Lakes

- Site A – Big Twin; deepest point
- Site B – Little Twin; deepest point
- Site C - Inlet stream (unnamed)
- Site D – Outlet stream (Little Hills Creek)

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Hydrologic and Nutrient Budgets

During the second phase of this study, a hydrologic or water budget was developed to estimate the relationship between input and output sources of water through the Twin Lakes system. Similarly a nutrient budget was developed and compared phosphorus content from all input and output sources. In the development of the hydrologic budget sources such as precipitation, surface water flow, evaporation, and groundwater were identified and estimated. Precipitation values were obtained from the National Weather Service. During each of the six water-sampling periods, water flow rates were calculated with a flow meter at the inlet and outlet creeks. Because it is difficult to estimate rates of evaporation, the loss of water via evaporation was considered equal to the total amount of precipitation. Groundwater flow and direct runoff were not computed independently, but was rather computed as residuals in the equation used to determine the hydrologic budget. Data collected were used to develop a picture of seasonal water flow and its relationship to water quality. The basic water balance equation used for this study considers the following terms:

Inflow + precipitation = outflow + evaporation + change in storage

Phosphorus data collected throughout the lakes were used in conjunction with the hydrological data collected to estimate internal and external loading. The main sources of phosphorus, which were quantified, included precipitation, inflowing surface water, - septic systems, and groundwater. Phosphorus concentrations in precipitation were estimated from data available for Wisconsin. Surface water samples were collected at the inlet and outlet streams. Septic system inputs were calculated based on standard export and soil retention coefficients and estimated capita years for residents. Groundwater contributions were measured by sampling spring water at the source of the inlet stream. This assumes that the concentration of phosphorus entering Twin Lakes through groundwater is the same concentration of phosphorus in the spring water. Once the data was collected, changes in nutrient loading and concentrations in Twin Lakes were quantified.

Watershed Analysis

The boundary of the Twin Lakes' watershed was delineated and its physical characteristics described by using topographic maps, and land-use planning maps. Land use patterns, vegetative cover, potential nutrient loading sources, and environmentally sensitive areas were further assessed by ground surveys. Management strategies for watershed features, which are potential pollution sources, are incorporated later in this report.

Results and Discussion

Aquatic plant community characteristics

A total of 25 species of aquatic plants were recorded during the June 10, 2004 submergent and emergent plant surveys of Twin Lakes (**Tables 1 and 2, Figures 7 and 8**). Ten of these were rooted submergent plants, including two exotic species: Eurasian watermilfoil and curly-leaf pondweed, ten were emergent species, three were free-floating plants (duckweeds), and two were colonial or mat-forming algae. Raw data for both surveys including GPS coordinates for each transect can be found in Appendix A.

The most abundant species in the submergent plant survey was flatstem pondweed (*Potamogeton zosteriformis*) at 55.2% frequency. The next most abundant species were curly-leaf pondweed, coontail (*Ceratophyllum demersum*) and filamentous algae (*Cladophora, Pithophora, etc.)* The two exotic species, curly-leaf pondweed and Eurasian watermilfoil, were widely distributed around the lakes, having been found at 52.1% and 8.9% of the sample points, respectively. Collectively these two species made up 21% of the aquatic plant community.

Data from 2003 and 2004 were compiled and analyzed to determine whether differences between the surveys were statistically significant. Paired t-tests were run on the data using 95% confidence intervals. This comparison of each plant species is given in **Appendix A**. A total of 20 submergent species were found between 2003 and 2004. Of these, three species decreased in distribution. These were sago pondweed (*Stuckenia pectinata*), Eurasian watermilfoil, and coontail. The survey on June 23, 2004 confirmed the decrease in Eurasian watermilfoil was due directly to the herbicide treatment. When 2,4-D is applied at the rates used during the 2004 treatment, it is highly selective for Eurasian watermilfoil. Some species, including coontail, northern watermilfoil (*Myriophyllum sibiricum*), and the water lilies can be somewhat susceptible to 2,4-D. Their populations may decrease after treatment, but should not be impacted in the long-term at the rates of application recommended for control of Eurasian watermilfoil. Often the distribution of plant species will naturally fluctuate. As a result, there may be significant declines from one year to the next. Another likely cause for these declines is the low water clarity that existed in Twin Lakes at the time of the 2004 survey. The turbid water blocked sunlight and inhibited plant growth.

Three native plant species showed significant increases in frequency. They include large duckweed (*Spirodela polyrhiza*), lesser duckweed (*Lemna minor*), and northern milfoil. Duckweeds as well as algae typically thrive in stagnant, nutrient-rich waters, and are thus indicators of poor water quality in lakes. Their presence in Twin Lakes suggests excessive nutrient levels. The increase in northern watermilfoil may be due to a number of reasons. However, this plant species, in particular, exhibits wide fluctuations in growth from year to year. The increase in frequency over the past year is likely due to a natural cycle of growth. Although curly leaf pondweed, another invasive exotic species, was found at high levels, it did not appear to have a significant increase in frequency from 2003 to 2004.

Table 1. Results of the submergent aquatic plant survey conducted on Twin Lakes, Green Lake County, June 10, 2004

Species common name	scientific name	Frequency	Percent Frequency	Percent Composition
Flatstem Pondweed	*Potamogeton zosteriformis*	*106*	55.2	18.0
Curly Leaf Pondweed	*Potamogeton crispus*	*100*	52.1	16.9
Coontail	*Ceratophyllum demersum*	*76*	39.6	12.9
Filamentous Green Algae	*Cladophora, Pithophora, etc.*	*75*	39.1	12.7
Lesser Duckweed	*Lemna minor*	*53*	27.6	9.0
Northern Water Milfoil	*Myriophyllum sibiricum*	*39*	20.3	6.6
Large Duckweed	*Spirodela polyrhiza*	*36*	18.8	6.1
Sago Pondweed	*Stuckenia pectinata*	*30*	15.6	5.1
Clasping Leaf Pondweed	*Potamogeton richardsonii*	*24*	12.5	4.1
Eurasian Watermilfoil	*Myriophyllum spicatum*	*17*	8.9	2.9
Musk Grass	*Chara* spp.	*12*	6.3	2.0
Cattails	*Typha* spp.	*9*	4.7	1.5
Star Duckweed	*Lemna trisulca*	*6*	3.1	1.0
Elodea	*Elodea canadensis*	*5*	2.6	0.8
Common Bur-reed	*Sparganium eurycarpum*	*1*	0.5	0.2
White Water Crowfoot	*Ranunculus longirostris*	*1*	0.5	0.2
No Plants Found		*21*	10.9	
	Total	*611*		

Table 2. Results of the emergent aquatic plant survey conducted on Twin Lakes, Green Lake County, June 10, 2004.

Species common name	scientific name	Frequency	Percent Frequency	Percent Composition
Cattail	*Typha* spp.	59	92.2	46.8
Common Bur-reed	*Sparganium eurycarpum*	25	39.1	19.8
Spatterdock	*Nuphar variegata*	10	15.6	7.9
Broad-leaf Arrowhead	*Sagittaria latifolia*	7	10.9	5.6
Hardstem Bulrush	*Scripus acutus*	6	9.4	4.8
Reed Canary Grass	*Phalaris arundinacea*	6	9.4	4.8
Bottlebrush Sedge	*Carex comosa*	4	6.3	3.2
Sweetflag	*Acorus calamus*	4	6.3	3.2
Blue Flag Iris	*Iris versicolor*	2	3.1	1.6
Softstem Bulrush	*Scirpus validus*	2	3.1	1.6
Water Plantain	*Alisma* spp.	1	1.6	0.8
	Total	*126*		*100.0*

Figure 7. Submergent aquatic plant community composition for Twin Lakes, Green Lake County, June 2004

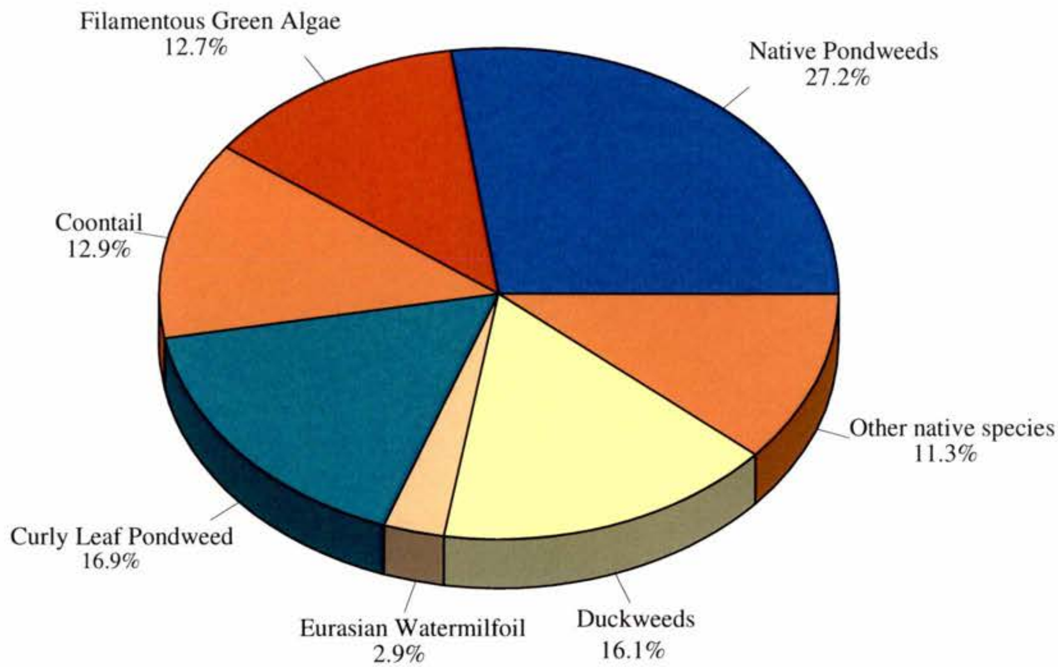
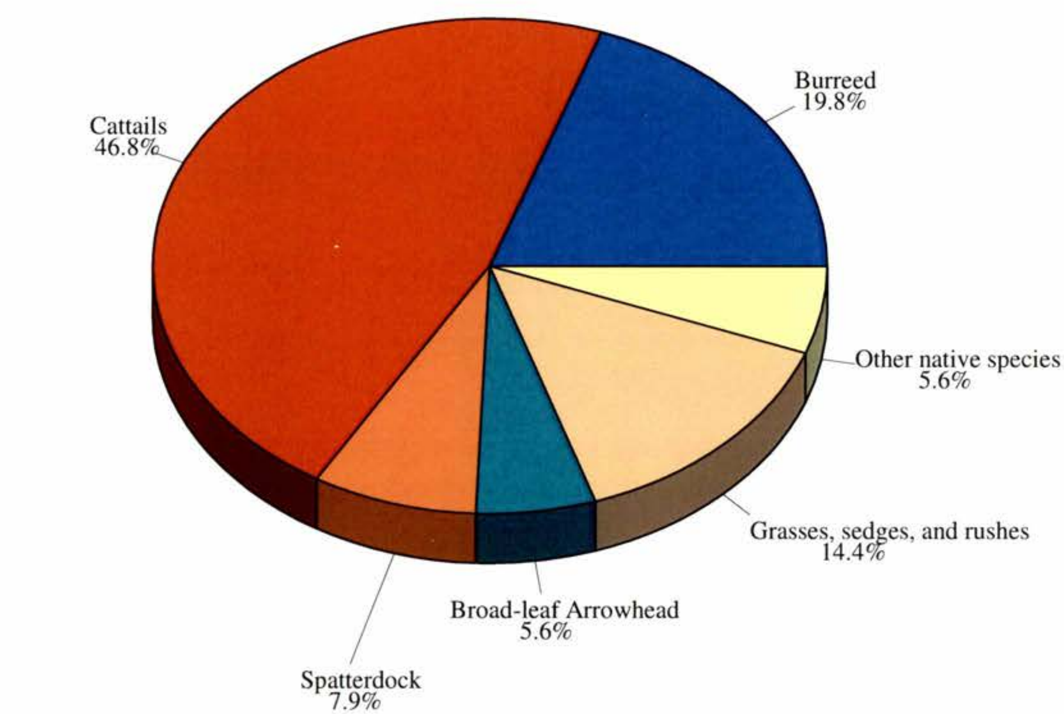


Figure 8. Emergent aquatic plant community composition for Twin Lakes, Green Lake County, June 2004



The most abundant species in the emergent plant survey were the cattails (*Typha* spp.) at 92.2% frequency. The next most abundant species were common bur-reed (*Sparganium eurycarpum*), spatterdock (*Nuphar variegata*) and broad-leaf arrowhead (*Sagittaria latifolia).*

Exotic plant species

On June 6, 2004, 7.4 acres of Eurasian watermilfoil were found in Big Twin Lake and treated with Navigate® at a rate of 100 lbs/acre (**Figure 9**). Although milfoil was present in Little Twin, treatment was not performed.

The post-treatment survey conducted on July 12, 2004 found excellent treatment success. Eurasian watermilfoil had noticeably declined to only scattered plants in the east end of the lake (Figure 10). At the same time, curly-leaf pondweed was found primarily in Little Twin Lake where it covered 20.9 acres; nearly the entire lake basin (Figure 11). No treatments for curly-leaf pondweed were performed in 2004. The Twin Lakes Association elected not to perform follow-up treatments in 2005.

On August 23, 2005, both lakes were surveyed for exotics. Eurasian watermilfoil was found throughout much of the lakes' littoral zones. Both planktonic and filamentous algae were abundant at this time, making it difficult to locate plants in deeper waters. In total 18.5 acres of Eurasian watermilfoil were found in Big Twin Lake and 8.7 acres were found in Little Twin Lake (**Figure 12**). The plants which were found were fairly sparse and immature. They had not yet dominated the plant community. However, if left untreated Eurasian watermilfoil will likely become very dense and problematic.
At the time of the survey, no curly-leaf pondweed was found in either lake. Since curly-leaf pondweed is a cold-water species it had died back by this time. However, turions were found extensively in Little Twin Lake in areas of previous curly-leaf pondweed infestation. There was no evidence of curly-leaf pondweed in Big Twin.

Figure 9. Distribution of Eurasian watermilfoil (*Myriophyllum spicatum*) on Twin Lakes, Green Lake County, June 2004.

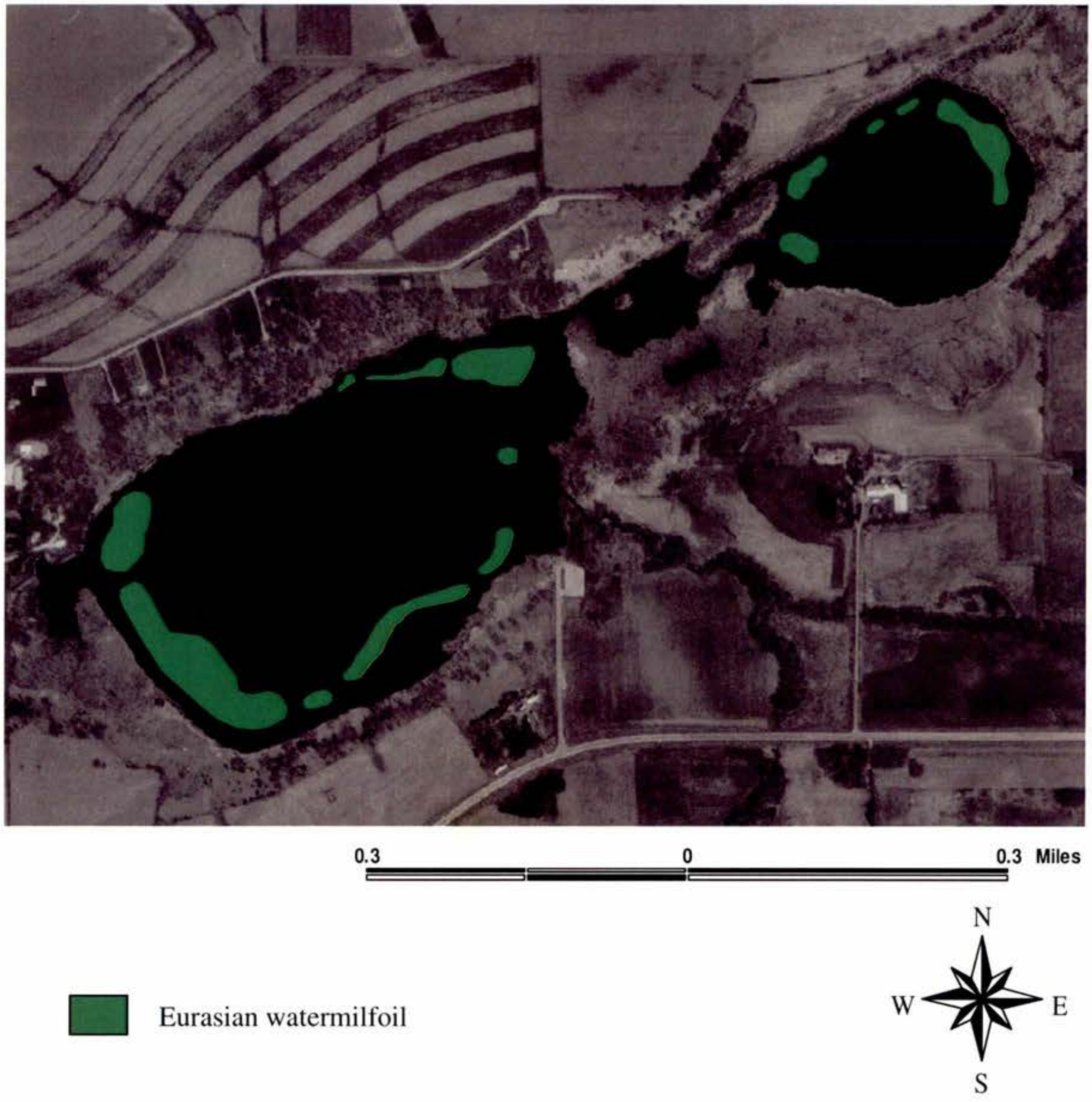


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Figure 10. Distribution of Eurasian watermilfoil (*Myriophyllum spicatum*) on Big Twin Lake, Green Lake County, July 2004.

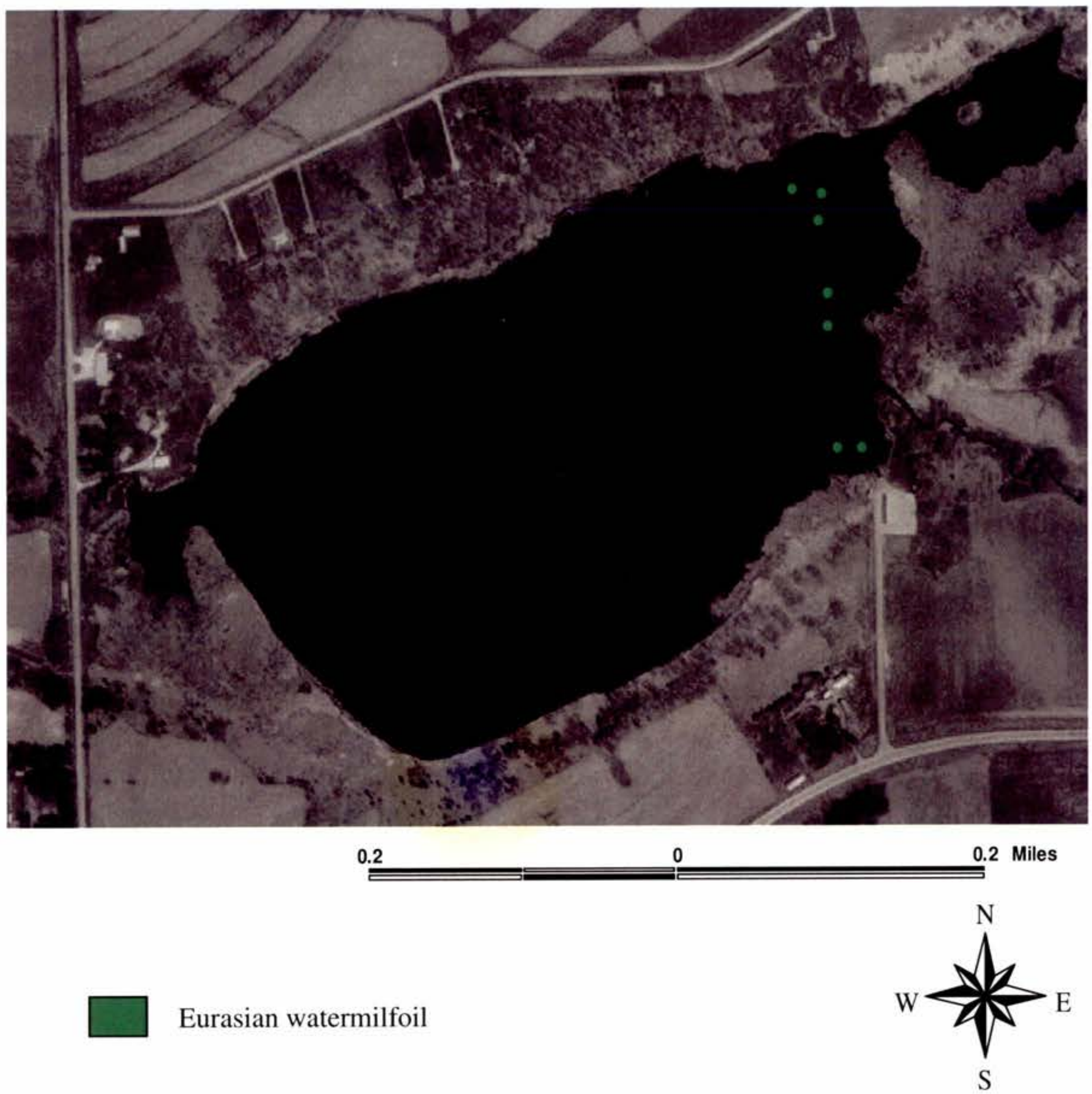

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Figure 11. Distribution of curly-leaf pondweed (*Potamogeton crispus*) on Little Twin Lake, Green Lake County, June 2004.

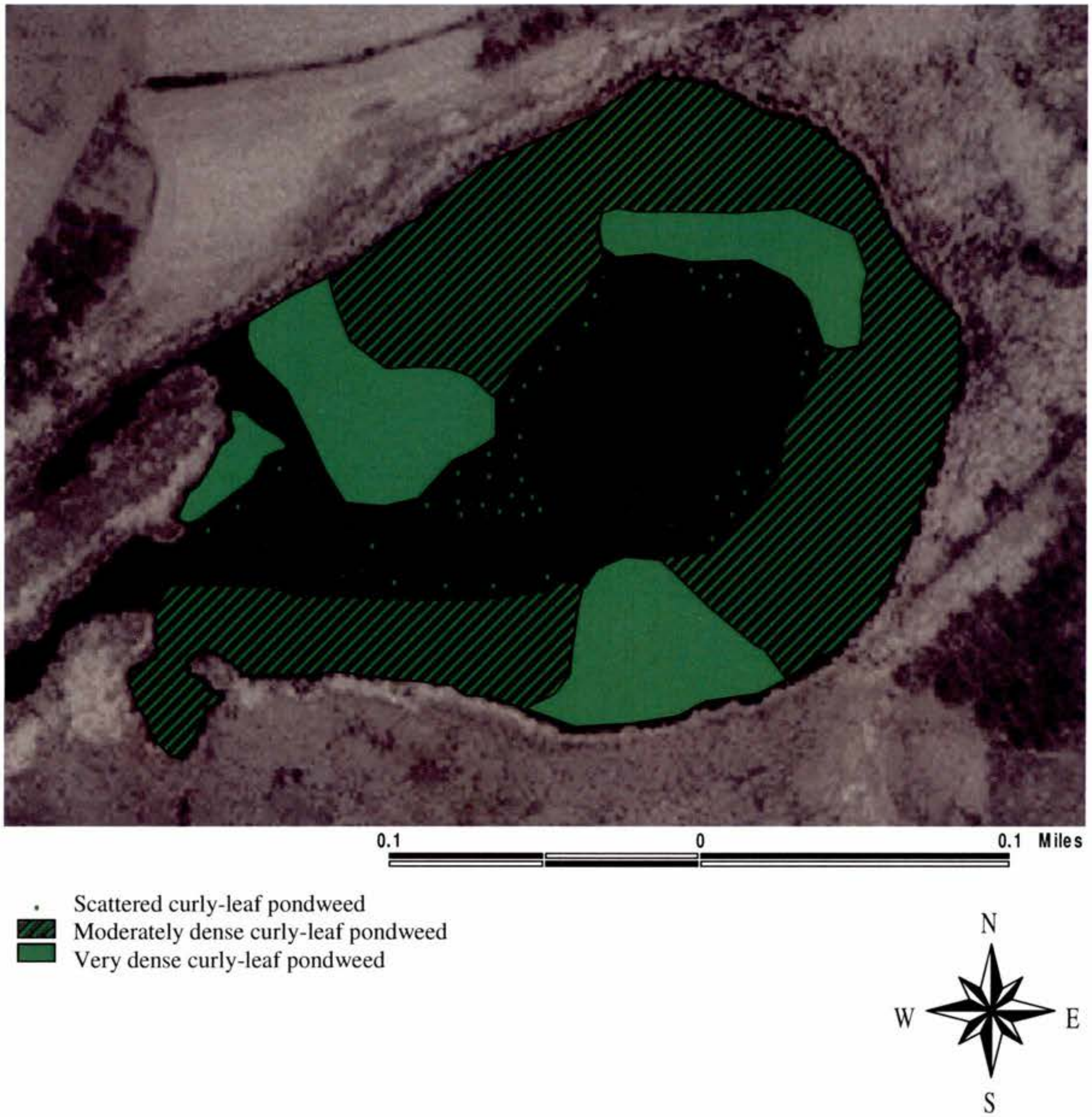

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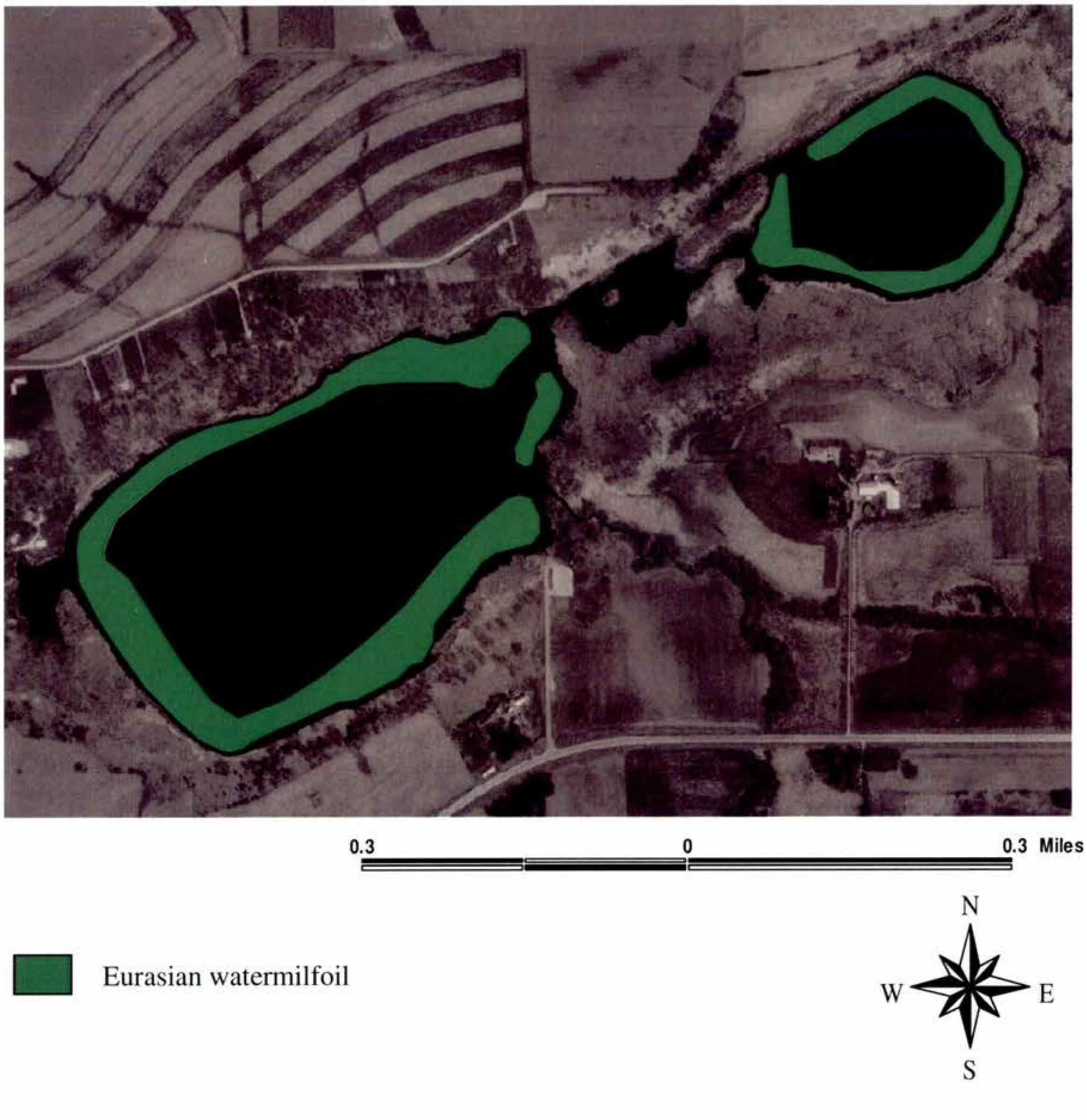
Figure 12. Distribution of Eurasian watermilfoil (*Myriophyllum spicatum*) on Twin Lakes, Green Lake County, August 23, 2005.



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The Importance of Aquatic Plants

Aquatic plants serve an important purpose in the aquatic environment. They play an instrumental role in maintaining ecological balance in ponds, lakes, wetlands, rivers, and streams. Native aquatic plants have many values. They serve as important buffers against nutrient loading and toxic chemicals, they act as filters that capture runoff-borne sediments, they stabilize lakebed sediments, they protect shorelines from erosion, and they provide critical fish and wildlife habitat. Therefore, it is essential that the native aquatic plant community in Twin Lakes be protected. The following is a list of common native aquatic plants that were found in Twin Lakes. Ecological values and a description are given for each plant. Plant information was gathered from Borman et al. (1997), Eggers and Reed (1997), Fasset (1940), Fink (1994), Nichols and Vennie (1991), and Whitley et al. (1999). Images obtained from Schmidt and Kannenberg (1998) and Borman et al. (1997).

Submersed Plants - Plants that tend to grow with their leaves under water.

Bushy pondweed (*Najas flexilis*) also known as **slender naiad** has a finely branched stem that grows from a rootstock. Leaves are short (1-4 cm), pointed and grow in pairs. Slender naiad is an annual and must grow from seed each year. It tends to establish well in disturbed areas. Slender naiad is a one of waterfowl's favorite foods and considered very important. Waterfowl, marsh birds, and muskrats relish seeds, leaves and stems. Slender naiad stabilizes bottom sediment and offers cover for fish.

Coontail *(Ceratophyllum demersum)* produces whorls of narrow, toothed leaves on a long trailing stem that often resembles the tail of a raccoon. The leaves tend to be more crowded toward the tip. Coontail blankets the bottom, which helps to stabilize bottom sediments. Tolerant to nutrient rich environments, coontail filters a high amount of phosphorus out of the water column. Coontail provides a home for invertebrates and juvenile fish. Seeds are consumed by waterfowl, but are not of high preference.

Elodea (*Elodea canadensis*) or **common waterweed** is made up of slender stems with small, lance-shaped leaves that attach directly to the stem. Leaves are found in whorls of two or three and are more crowded toward the stem tip. The branching stems of elodea provide valuable cover for fish and are home for many insects that fish feed upon. Elodea also provides food for muskrats and waterfowl.

Musk grass (*Chara* spp.) is a complex form of algae that resemble higher plants. It is identified by its pungent, skunk-like odor and whorls of toothed branched leaves. Ecologically, this plant provides shelter for juvenile fish and is associated with black crappie spawning sites. Waterfowl love to feast on musk grass when the plant bears its seed-like oogonia. This species serves an important role in stabilizing bottom sediments, tying up nutrients in the water column, and maintaining water clarity.

Although **native pondweeds** (*Potamogeton spp.*) may vary in appearance, there are a number of key features members of this genus have in common. Pondweed leaves are alternate with a noticeable midvein. The nutlets, leaves, and stipules of a particular species can often be used to reliably identify it. The pondweeds grow in a wide range of aquatic habitats. They all emerge from rhizomes, which help the plants overwinter. The pondweeds are a valuable food source for waterfowl and a number of mammals. They also provide a home for fish and invertebrates.

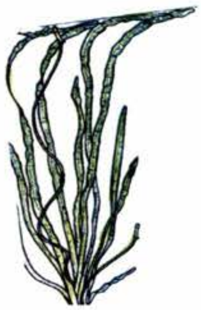
Northern Watermilfoil (*Myriophyllum sibiricum*) produces whorls of feather-like leaflets from a fairly stout stem. Northern watermilfoil is identified by its 5 to 12 pairs of leaflets that become progressively longer near the base of the leaf – giving the leaf a candelabra-like appearance. The leaves and fruit of this plant are eaten by a variety of waterfowl. Its finely divided leaves are habitat for numerous invertebrates that fish feed upon. Northern watermilfoil is an indicator of good water quality, as the plant seldom survives in more eutrophic environments.

Sago Pondweed (*Potamogeton pectinatus*) is a perennial herb that emerges from a slender rhizome that contains many starchy tubers. Leaves are sharp, thin, and resemble a pine needle. Reddish nutlets (seeds) that resemble beads on a string rise to the water surface in mid-summer. Sago pondweed produces a large crop of seeds and tubers that are valued by waterfowl. Juvenile fish and invertebrates utilize sago pondweed for cover.

Water Stargrass (*Heteranthera dubia*) resembles some of the narrow-leaved pondweeds. It is dark green to brown with thread-like leaves scattered on flexible stems. A close examination of the leaves will show that they have several veins but no obvious midvein. It reproduces from plant fragments. Water stargrass usually becomes abundant in late summer. It settles to the bottom in late autumn where it forms a decaying mat in the winter that provides habitat to many small aquatic animals. Water stargrass provides valuable habitat for fish and serves as a source of macroinvertebrates for fish.

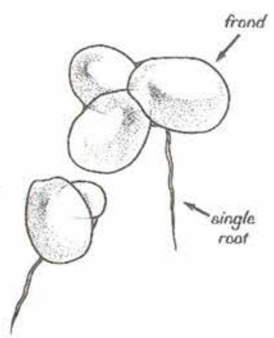
White Water Crowfoot (*Ranunculus longirostris*) produces white flowers with 5 petals that emerge above the water's surface. Leaves are finely cut into thread-like divisions and are in an alternate arrangement along the stem. White water crowfoot is not tolerant to pollution and considered an indicator of good water quality. Waterfowl graze on both fruit and plant foliage. Crowfoot provides habitat for invertebrates, which in turn are fed upon by fish.

Wild Celery (*Vallisneria americana*) also known as **eelgrass** has long ribbon-like leaves that emerge in clusters. Leaves have a prominent central stripe and leaf tips tend to float gracefully at the water's surface. In the fall, a vegetative portion of the rhizome will break free and float to other locations. Wild celery is considered one of the best all natural waterfowl foods. The entire plant is relished by waterfowl, especially canvasbacks. Eelgrass beds serve as an important food source for sea ducks, marsh birds, and shore birds. Fish also find wild celery to be a popular hiding spot.



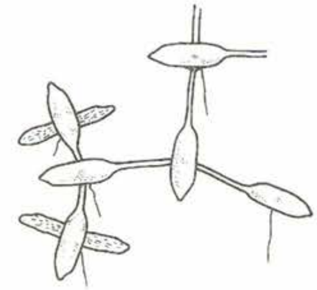
Floating Leaf Plants - Plants that have leaves that float at the water's surface.

Common Duckweed (*Lemna minor*) and **Large Duckweed** (*Spirodela polyrhiza*) are among the world's smallest vascular plants. Individual plants are tiny, round, and bright green, each with a single or multiple roots. Fronds are nearly circular to oval. They occur as single plants or up to five plants may be connected. In lakes, they are found scattered among emergent plants or massed together in floating mats. Duckweeds are also commonly found in stagnant waters. They provide food for fish and waterfowl and habitat for aquatic invertebrates.



Spatterdock (*Nuphar variegata*) is a perennial herb that produces yellow, rounded flowers. Large (4-10 inches) long, heart-shaped leaves float at the waters surface. Leaf stalks have flattened wings and emerge from a buried spongy rhizome. With large buried rhizomes, spatterdock helps stabilize bottom sediment. The large leaves also help buffer the impact of wave action on the shoreline. Like lilies, spatterdock offers excellent fish habitat. Seeds are eaten by waterfowl; leaves, rhizomes, and flowers are relished by muskrats, beaver, and deer.

Star Duckweed (*Lemna trisulca*) individuals are called fronds. Each frond consists of a small, green, floating body with a single root that extends into the water from the undersurface, but is not rooted to the soil. Star duckweed can grow rapidly, reproducing not by seeds, but by simple division of a frond to produce new "daughter" fronds. The developing daughter fronds remain attached to the "mother" frond for a short time as shown above, but eventually break apart. Star duckweed is a good food sources for waterfowl. Large amounts of star duckweed can provide cover and habitat for fish and invertebrates.



Exotic Species

The invasive exotic plants identified in Twin Lakes are Eurasian watermilfoil and curly-leaf pondweed. The following descriptions are given to promote awareness of these plants.

Eurasian Watermilfoil (*Myriophyllum spicatum*) produces long spaghetti-like stems that often grow up to the water's surface. Leaves are feather-like and resemble bones on a fish. 3-5 leaves are arranged in whorls around the stem, and each leaf contains 12-21 pairs of leaflets. At mid-summer small reddish flower spikes may emerge above the water's surface. Perhaps the most distinguishing characteristic though, is the plant's ability to form dense, impenetrable beds that inhibit boating, swimming, fishing, and hunting.

Of the eight milfoil (*Myriophyllum*) species found in Wisconsin, Eurasian watermilfoil is the only exotic. It is native to Europe, Asia and Northern Africa. The plant was first introduced into U.S. waters in 1940. By 1960, it had reached Wisconsin's lakes. Since then, its expansion has been exponential (Brakken, 2000).

Eurasian watermilfoil begins growing earlier than native plants, giving it a competitive advantage. The dense surface mats formed by the plant block sunlight and have been found to displace nearly all native submergent plants. Over 200 studies link declines in native plants with increases in Eurasian watermilfoil (Madsen, 2001). The resultant loss of plant diversity degrades fishery habitat (Pullman, 1993), and reduces foraging opportunities for waterfowl and aquatic mammals. Eurasian watermilfoil has been found to reduce predatory success of fish such as largemouth bass (Engel, 1985), and spawning success for trout (*Salmonidae spp.*) (Newroth, 1985).

The continued spread of Eurasian watermilfoil can produce significant economic consequences. In the Truckee River Watershed below Lake Tahoe, located in western

Nevada and northeastern California, economic damages caused by Eurasian watermilfoil to the recreation industry have been projected at $30 to $45 million annually (Eiswerth et al., 2003). In Tennessee Valley Authority Reservoirs, Eurasian watermilfoil was found to depress real estate values, stop recreational activities, clog municipal and industrial water intakes and increase mosquito breeding (Smith, 1971).

Eurasian watermilfoil has been found to reduce water quality in lakes by several means. Dense mats of Eurasian watermilfoil have been found to alter temperature and oxygen profiles – producing anoxic conditions in bottom water layers (Unmuth et al., 2000). These anoxic conditions can cause localized die-offs of mollusks and other invertebrates. Eurasian watermilfoil has also been found to increase phosphorus concentration in lakes through accelerated internal nutrient cycling (Smith and Adams, 1986). Increased phosphorus concentrations released by dead and dying Eurasian watermilfoil have been linked to algae blooms and reduced water clarity.

Curly Leaf Pondweed (*Potamogeton crispus*) has oblong leaves that are 2-4 inches long and attach to a slightly flattened stem in an alternate pattern. The most distinguishing characteristics are the curled appearance of the leaves, and the serrated leaf edges. Curly-leaf pondweed produces a seed-like turion, which resembles a miniature pinecone. This exotic pondweed is a cold-water specialist. Curly-leaf pondweed can begin growing under the ice, giving it a competitive advantage over native plants, which are still lying dormant. By mid-summer when water temperatures reach the upper 70° F, it begins to die off.

Curly-leaf pondweed has been found in the U.S. since at least 1910. A native of Europe, Asia, Africa and Australia, this plant is now found throughout much of U.S. (Baumann et al., 2000).

As with Eurasian watermilfoil, curly-leaf pondweeds aggressive early season growth allows it to out compete native species and grow to nuisance levels. Because the plant dies back during the peak of the growing season for other plants though, it is better able to coexist with native species than Eurasian watermilfoil. Perhaps the most significant problem associated with curly-leaf pondweed involves internal nutrient cycling. The die-off and decomposition of the plant during the warmest time of year lead to a sudden nutrient release in the water. This in turn, leads to nuisance algae blooms and poor water quality.

Eurasian Watermilfoil Management Options

Historically, management of Eurasian watermilfoil has included mechanical, biological, and chemical means. It is important to consider each of these control measures before continuing with management efforts in Twin Lakes. After weighing the pros and cons of each option, the wisest course of action should be chosen and control efforts continue.

Hand pulling
Hand pulling of Eurasian watermilfoil is a useful tool when the extent of milfoil occurs at very low frequencies. For this method to be successful care must be taken to remove the entire root mass along with the plant or it will quickly regenerate. Given the current distribution of Eurasian watermilfoil in Twin Lakes, this method is impractical as a lake-wide control option at this time. However, if other management options are successful in reducing Eurasian watermilfoil to a sparse distribution, this option could be reconsidered. This is still a viable option for riparian property owners. Without obtaining a permit, individuals can hand pull aquatic plants in a 30-foot strip along their property extending out as far as necessary. If *exotic* plants are singled out for hand removal, there are no restrictions on the extent of hand-pulling. If large amounts of milfoil are present, it will be labor intensive. If individuals choose to hand pull, care should be taken to properly identify Eurasian watermilfoil and minimize its fragmentation.

Mechanical harvesting
Mechanical control methods include hand cutters and boat-mounted mechanical weed harvesters (Nichols, 1974). While these methods provide temporary nuisance relief, they are rarely recommended as control methods for Eurasian watermilfoil. Eurasian watermilfoil can reproduce effectively through fragmentation (Borman et al. 1997). Free-floating plant matter left from cutting operations can spread quickly and encourage additional infestations within the lake or in neighboring lakes. Although harvesting does remove plant matter, a source of nutrients to the lake, it is unlikely that harvesting will induce a shift back to a native plant-dominated community.

Milfoil weevils
There has been considerable research on biological vectors, such as insects, and their ability to affect a decline in Eurasian watermilfoil populations. Of these, the milfoil weevil (*Euhrychiopsis lecontei*) has received the most attention. Native milfoil weevil populations have been associated with declines in Eurasian watermilfoil in natural lakes in Vermont (Creed and Sheldon, 1995), New York (Johnson et al., 2000) and Wisconsin (Lilie, 2000). While numerous lakes have attempted stocking milfoil weevils in hopes of controlling milfoil in a more natural manner, this method has not proven successful in Wisconsin. A twelve-lake study called "The Wisconsin Milfoil Weevil Project" (Jester et al. 1999) conducted by the University of Wisconsin, Stevens Point in conjunction with the Wisconsin DNR researched the efficacy of weevil stocking. This report concluded that milfoil weevil densities were not elevated, and that Eurasian watermilfoil was unaffected by weevil stocking in any of the study lakes. Until more evidence that suggests weevil stocking is an effective control agent for Eurasian watermilfoil, this method should be discouraged as a control option for Twin Lakes.

Herbicides

Herbicides have been the most widely used and often most successful tools for controlling Eurasian watermilfoil. The two herbicide groups most commonly employed are fluridone (Avast®, Sonar®) and 2,4-D (Aquacide®, Aquakleen®, Navigate®, and Weedar 64®).

Whole-lake fluridone treatments have been conducted on several Wisconsin Lakes. While initial results were encouraging (species selectivity, 95-100% initial control), continued monitoring found that desired long-term control was not achieved (Cason, 2002). In addition, for fluridone to be most effective, a relatively long contact time is needed. It is a more viable option for lakes with little surface inflow and outflow. Since water regularly flows into and out of Twin Lakes, the dilution of the fluridone would result in a loss of efficacy.

2,4-D herbicides have been very effective at controlling Eurasian watermilfoil in hundreds of Wisconsin lakes. 2,4-D is a herbicide which rapidly biodegrades and does not persist in the environment. When applied at labeled rates, it has been widely used as a selective herbicide with little or no impact to the native plant community. Twin Lakes would continue to benefit from the use of 2,4-D as a management tool for Eurasian watermilfoil

Curly-leaf Pondweed Management Options

Curly-leaf pondweed has primarily been managed through mechanical and chemical means. The following control options should be considered to determine the best course of action for curly-leaf pondweed control.

Hand pulling

As with Eurasian watermilfoil, this method may be appropriate for riparian property owners on Twin Lakes. Hand pulling is most effective when curly-leaf pondweed is discovered in its pioneering stage. If it has existed long enough to produce turions, the vegetative reproductive structure, hand pulling may become a long-term, labor-intensive process. To be most effective, as with other curly-leaf pondweed control options, early response is recommended. Turion production begins when water temperatures reach into the 70's.

Mechanical harvesting and cutting

Both mechanical harvesting and hand cutting are commonly used to control curly-leaf pondweed. Cutting the plant provides temporary nuisance relief and may increase recreational opportunities on the lake. And although harvesting may not encourage dispersal of the plant, as it does with Eurasian watermilfoil, it is unlikely to provide any long-term control, especially if harvesting is conducted after the production of turions. Curly-leaf pondweed is primarily found in Little Twin Lake. Due to the narrow shallow channel connecting the two lakes, it will be difficult if not impossible to get harvesting equipment to Little Twin Lake. Therefore this method is currently not a good choice for Twin Lakes.

Herbicides

The herbicide most often used to control curly-leaf pondweed is endothall (Aquathol®). . Aquathol® is an endothall salt-based herbicide which also rapidly biodegrades and does not persist in the environment. While endothall herbicides are effective on a broad range of aquatic monocots, early season applications made at low rates are highly species-selective for curly-leaf pondweed. While herbicides effectively kill the parent plant, the turions are resistant to herbicides, allowing curly-leaf pondweed to regenerate annually.

Studies conducted by the Army Corps of Engineers have found that conducting treatments of curly-leaf pondweed using Aquathol® when water temperatures are in the 50-60° F range will kill plants before turions form, thus providing long-term control. Researchers found that conducting two or more treatments over consecutive seasons for established curly-leaf pondweed populations will target both the standing crop of the pondweed as well as the resulting regrowth from the turions (Skogerboe and Poovey, 2002). These findings make Aquathol® the tool of choice for controlling curly-leaf pondweed in Twin Lakes.

Herbicide treatments

Before any treatment plan is adopted for a lake, the following concerns should be addressed:

Are these herbicides safe for humans? The Environmental Protection Agency (EPA) lists 2,4-D and endothall as Class D herbicides. This classification means that there are insufficient data to suggest that either compound causes cancer or is harmful to humans. The EPA product label lists no water use restrictions for swimming or fish consumption following treatment with 2,4-D. The product label for endothall however lists a three-day fish consumption waiting period. The University of Michigan School of Public Health recently concluded a review of more than 160 toxicological and epidemiological studies on 2,4-D and concluded that there was not adequate evidence to link 2,4-D exposure to any forms of cancer. Nor does 2,4-D from treated lakes appear to be able to contaminate well water. The Michigan Department of Environmental Quality recently released results of a 4-year study of drinking water wells surrounding twelve lakes heavily treated with 2,4-D. To date, no traces of 2,4-D have been found in any of the test wells (Bondra, 2002). While it is not possible to guarantee that any herbicide is 100% safe, the overwhelming body of evidence suggests that both 2,4-D and endothall pose minimal risks to humans.

Are these herbicides safe for the environment? 2,4-D and endothall are both organic herbicides that biodegrade quickly in aquatic environments and do not bioaccumulate. Even if fish consume 2,4-D pellets, the chemical is quickly excreted without entering muscle tissues. For these reasons, there are no label restrictions on fish consumption. Generally, fish species are tolerant of the Aquathol® formulation of endothall at concentrations of approximately 100 ppm or more. However, concentrations of only 0.5 to 5.0 ppm are generally required for aquatic weed control. Endothall also has a low toxicity to crustaceans and a medium toxicity to aquatic insects.

Will these herbicides affect desirable plants? Applied correctly at prescribed rates (100-150 lbs/acre), 2,4-D is highly selective to Eurasian watermilfoil. According to the product label, the following plants found in Twin Lakes are susceptible or slightly to moderately resistant to 2,4-D at higher rates (150+ lbs/acre): coontail, northern watermilfoil, and spatterdock. At lower rates these and other native plants typically respond positively to treatments and the resulting decreases in Eurasian watermilfoil occurrences.

When applied at low rates (0.5-1.5 ppm), endothall can be used as an effective control option for curly-leaf pondweed. At rates above 1.0 ppm, other native pondweeds as well as coontail, slender naiad, water stargrass and milfoils can also be affected. As a result endothall treatments are timed early in the season and at low rates to target curly-leaf pondweed while native plant species have not begun to actively grow.

Are they effective? 2,4-D and endothall have been used on thousands of lakes throughout North America. To date 2,4-D treatments have been the single most effective

Eurasian watermilfoil control method. In fact, the number of lakes in Michigan having Eurasian watermilfoil problems has actually declined as a result of 2,4-D use (Pullman, 1993). The success of endothall in the control of curly-leaf pondweed depends heavily on timing as well as application rates. As previously stated, early season, low-dose applications have been the most successful control measure for curly-leaf pondweed.

Are they economical? While no control method could be considered cheap, herbicide treatments are among the least costly of methods. This is in part due to the relatively low labor costs in comparison to measures such as hand-pulling, mechanical harvesting, etc. Perhaps the greatest consideration is that these herbicides typically produce long-term control of exotics. This means that lake management units seldom need to spend as much in the long-term as they do for the initial treatments. Once the target species are brought under control, the costs of annual maintenance treatments, if needed, are minimal.

What are the disadvantages? The greatest disadvantage of herbicide treatments is that they rarely produce 100% control. In most cases, herbicides tend to work only where applied. This is more so the case with granular formulations. Unnoticed and untreated plants may eventually grow to dense beds if left unchecked. Factors such as pH and plant maturity may also reduce treatment efficacy. Several follow-up treatments, whether in-season or in subsequent years, may be needed to reduce exotic species to target levels.

Water Quality Analysis

Dissolved Oxygen and Temperature
Dissolved oxygen and temperature data collected for Twin Lakes is included in **Appendix B**. These data were used to develop profile graphs from May 2004 to January 2005 (**Figures 12 and 13**) and from April 2005 to January 2006. (**Figures 14 and 15**). The profiles shown for Twin Lakes are typical of low water quality lakes. Levels of dissolved oxygen at the surface for both lakes remained relatively high throughout the season. However, the depths at which oxygen levels dropped off, referred to as the oxycline, were rather shallow. Below the oxycline there was insufficient oxygen to support many fish species. The threshold level of oxygen needed for fish such as bass, perch, and sunfish to survive and grow is 5 mg/L. During the summer months when the lakes were not undergoing turnover, oxygen levels dropped off at a depth of 10 to15 feet for Big Twin and between 6 to 8 feet for Little Twin. As a result, large portions of both lakes had little to no oxygen present for extended periods of time. This is most significant in Big Twin which reaches depths of nearly 50 ft. These oxygen conditions are referred to as lake stratification. Although it is common in Wisconsin for lakes to become stratified, Twin Lakes is an extreme case. Big and Little Twin Lakes are both highly productive lakes. They exhibit high rates of biological activity, primarily through bacteria as well as elevated levels of algae and aquatic plant growth. This effect is of particular concern in Little Twin Lake where in August the effects of oxygen depletion are at their worst. Annually large amounts of curly-leaf pondweed die and decompose during the warmest times of the year. Through this decomposition, vast amounts of oxygen are consumed, having a detrimental affect on the lake.

Some anomalies in the data exist though. To better understand these anomalies, it is important to first understand the relationship between dissolved oxygen and temperature. As a rule, colder water can hold more oxygen than warmer water. **Table 3** illustrates this point.

Table 3. Oxygen solubility in water at different temperatures.

Temperature °C	Temperature °F	Oxygen solubility (mg/L)
0	32	15
5	41	13
10	50	11
15	59	10
20	68	9
25	77	8

By utilizing this relationship the percent saturation of oxygen can be calculated at a given temperature. Profiles of percent saturation values were also graphed to better understand oxygen conditions in Twin Lakes. A number of the profiles in **Figures 12 – 15** do not follow the solubility rules for oxygen and temperature. For these profiles the surface dissolved oxygen levels are higher than solubility levels at the corresponding temperatures. This is due to conditions in the lakes which produce elevated levels of oxygen. In lakes with high levels of algae, large amounts of oxygen can be produced through photosynthesis. Under warm sunny conditions in particular, oxygen levels in the lake can rise above the levels of solubility shown in **Table 3**. This is a condition referred to as supersaturation. During the night when photosynthesis ceases and respiration takes over, oxygen levels drop off significantly. Through respiration, oxygen is consumed leaving depleted levels in the lake. These wide fluctuations can be particularly stressful to many fish and invertebrate species. Percent saturation values of 80-120% are considered to be excellent and values less than 60% or over 125% are considered to be poor. So in addition to poor oxygen levels in the deeper portions of the lakes, the high oxygen levels on the surface during the warmest summer months is also having a negative impact on the quality of the water.

Temperature profiles in Little Twin show little change with depth, which is not surprising given its shallowness. Big Twin showed more of a decline in temperature with depth generally dropping to 40-45 ºF at the deepest point and reaching over 80ºF at the surface during the warmest times of the year.

Figure 12. Profiles of dissolved oxygen, temperature and percent saturations for Big Twin Lake, Green Lake County, May 2004 to January 2005

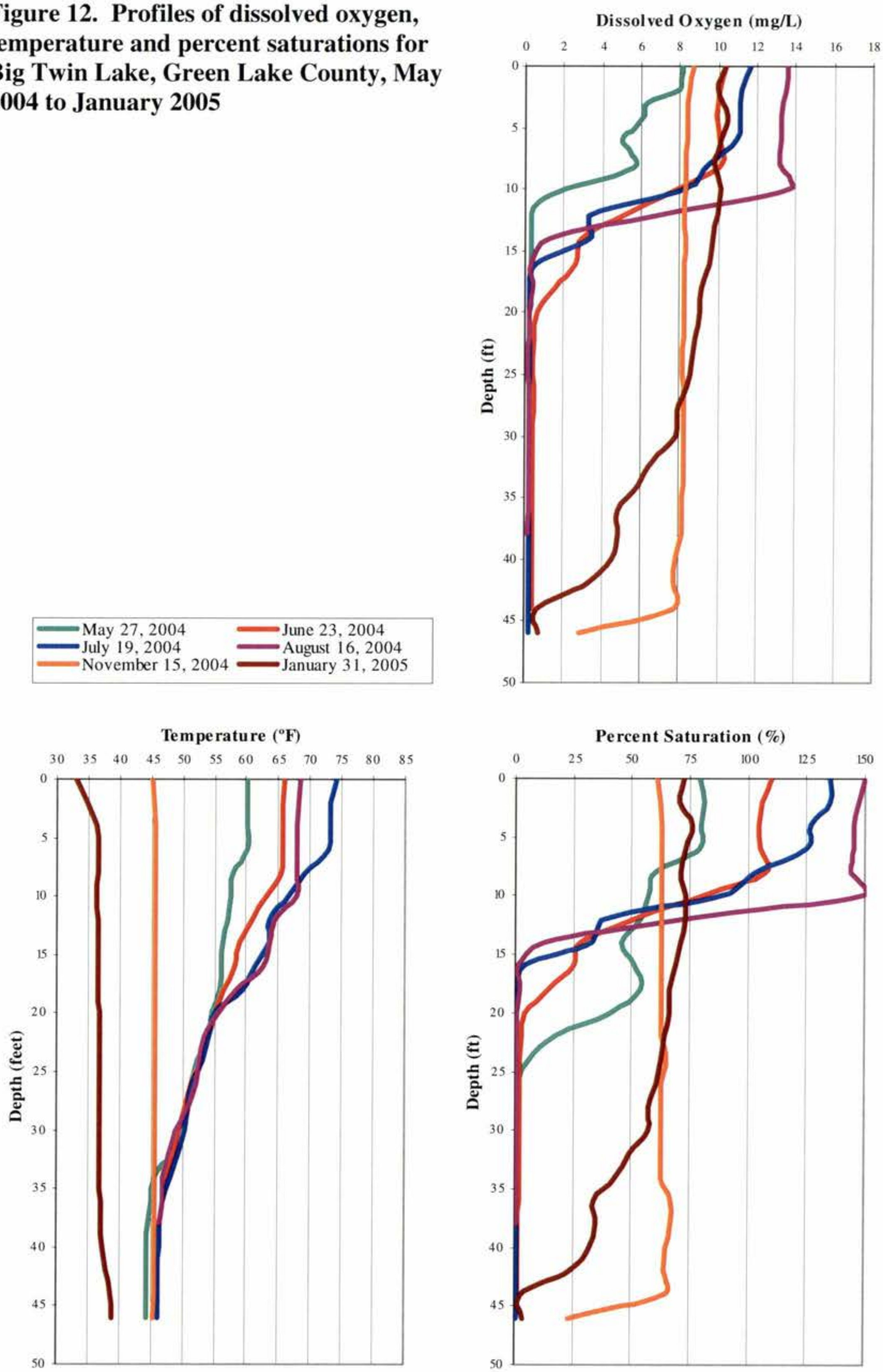
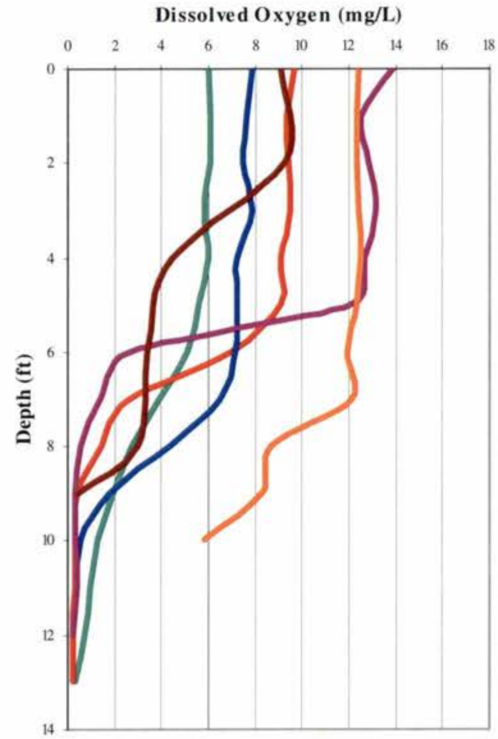
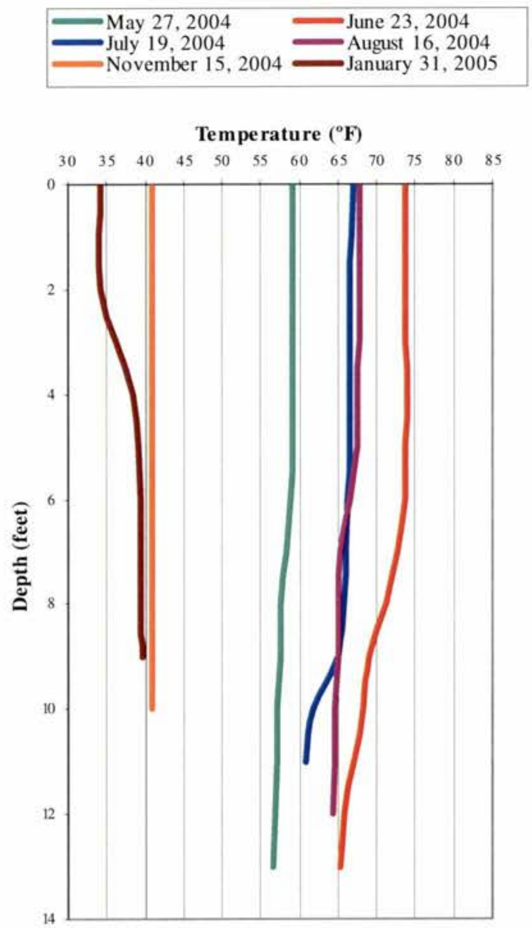


Figure 13. Profiles of dissolved oxygen, temperature and percent saturations for Little Twin Lake, Green Lake County, May 2004 to January 2005





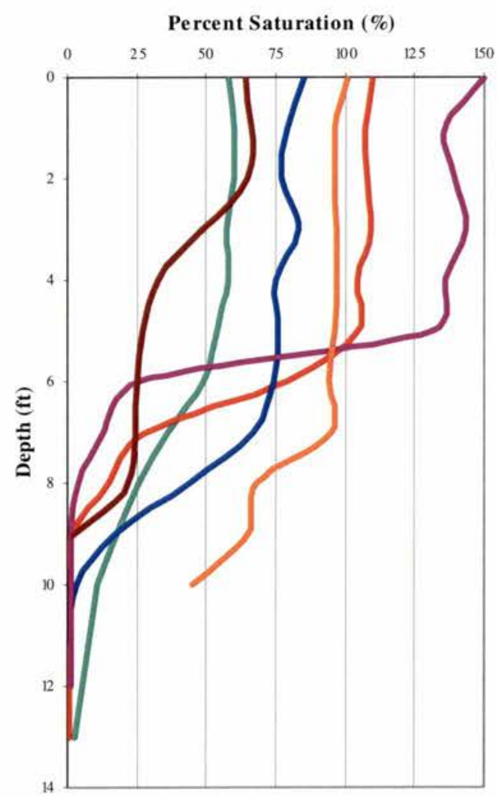
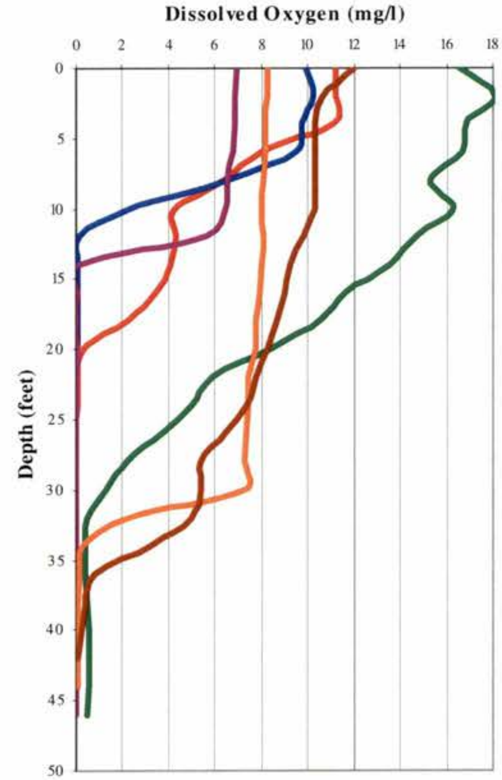
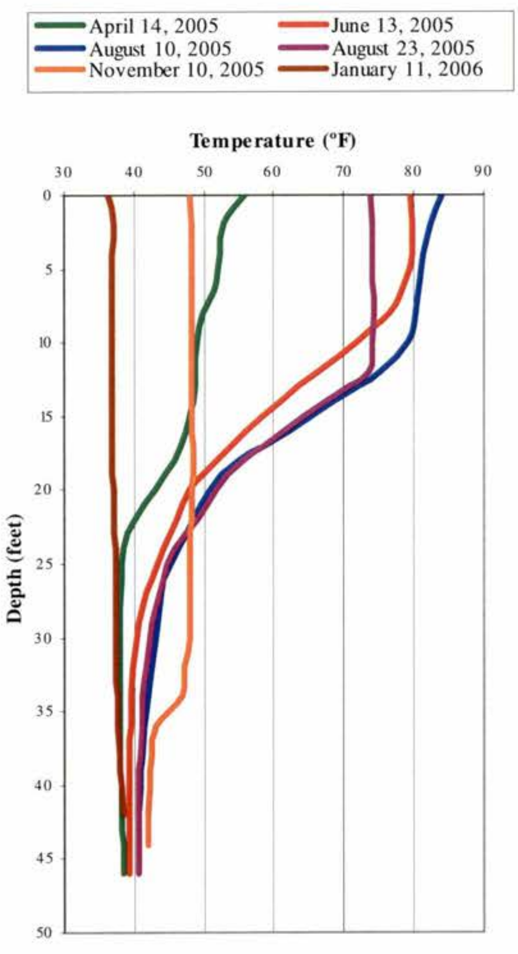


Figure 14. Profiles of dissolved oxygen, temperature and percent saturations for Big Twin Lake, Green Lake County, April 2005 to January 2006





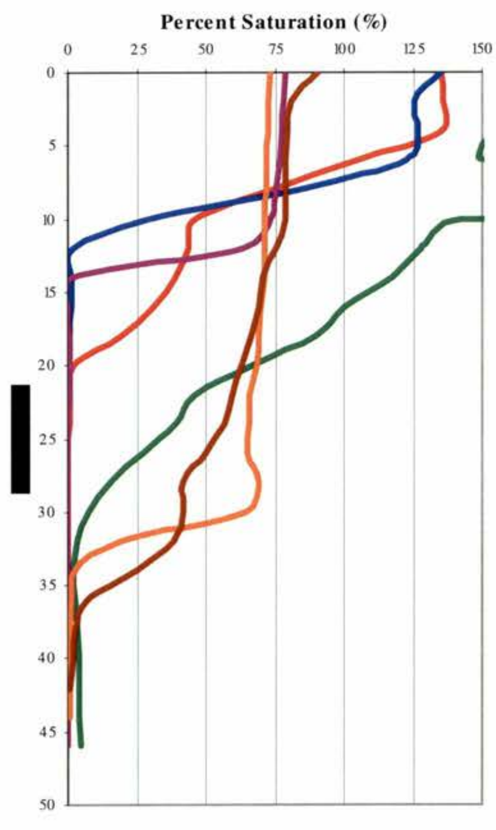
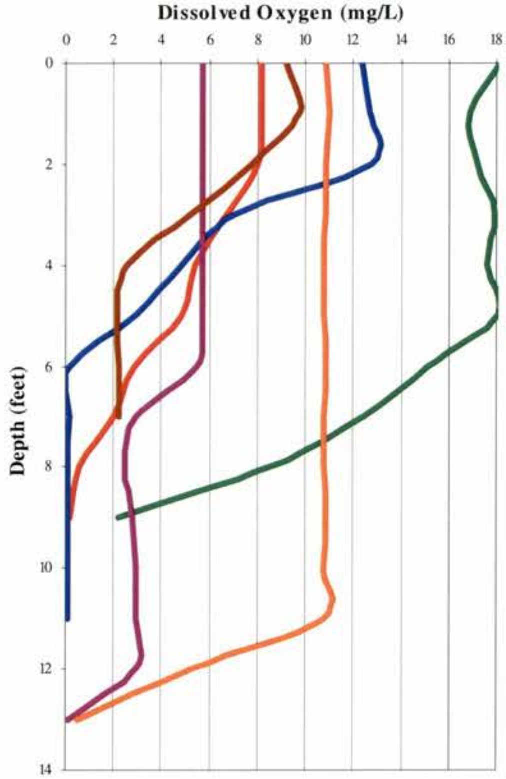
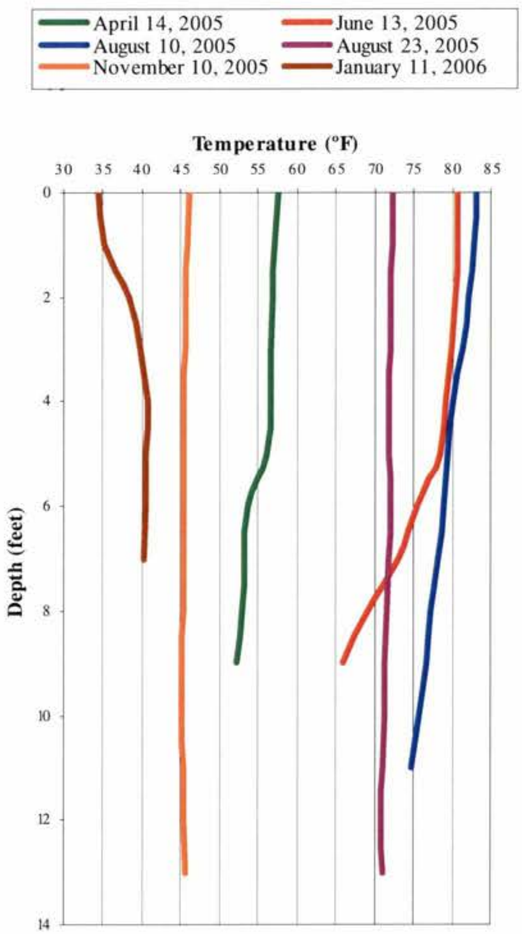
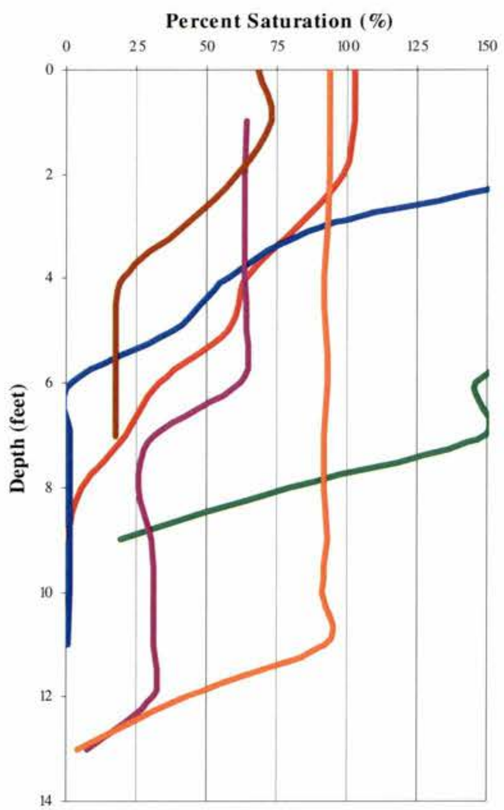


Figure 15. Profiles of dissolved oxygen, temperature and percent saturations for Little Twin Lake, Green Lake County, April 2005 to January 2006







Seasonal trends in a number of water quality parameters for the periods of May 2004 to January 2005 and April 2005 to January 2006 are shown in **Tables 4 and 5**, respectively.

Table 4. Seasonal Water quality data for Twin Lakes, Green Lake County, May 2004 to January 2005

	Parameter				
May 27, 2004	pH	Nitrogen (mg/l)	Phosphorus (mg/l)	Chlorophyll (µg/l)	Secchi (m)
Inlet	--	11.70	0.132	--	--
Big Twin	8.5	2.30	0.135	4.33	1.68
Little Twin	8.0	1.42	0.131	2.34	0.94
Outlet	--	1.26	0.098	--	--
June 23, 2004					
Inlet	--	15.30	0.078	--	--
Big Twin	8.5	5.97	0.076	7.18	2.74
Little Twin	8.25	2.02	0.111	22.1	1.83
Outlet	--	1.31	0.105	--	--
July 19, 2004					
Inlet	--	16.50	0.082	--	--
Big Twin	8.5	6.28	0.03	20.5	2.44
Little Twin	8.5	1.37	0.066	56.5	1.83
Outlet	--	0.579	0.121	--	--
August 16, 2004					
Inlet	--	16.3	0.082	--	--
Big Twin	8.75	5.00	0.039	35	0.94
Little Twin	8.75	nd	0.233	109	0.46
Outlet	--	0.03	0.199	--	--
November 15, 2004					
Inlet	--	na	0.072	--	--
Big Twin	8.0	na	0.116	9.24	2.29
Little Twin	8.5	na	0.052	21.2	2.44
Outlet	--	na	0.140	--	--
January 31, 2005					
Inlet	8.1	na	na	--	--
Big Twin	8.0	2.02	0.054	7.74	2.13
Little Twin	8.0	1.66	0.062	22.2	1.77
Outlet	7.1	na	na	--	--

na – data not available
nd – not detected; below detection limits

Table 5. Seasonal Water quality data for Twin Lakes, Green Lake County, April 2005 to January 2006

	Parameter				
April 14, 2005	pH	Nitrogen (mg/l)	Phosphorus (mg/l)	Chlorophyll (μg/l)	Secchi (m)
Inlet	8.5	7.36	0.109	--	--
Big Twin	8.0	1.51	0.125	70.9	0.76
Little Twin	8.5	nd	0.146	45.8	0.73
Outlet	8.0	0.19	0.288	--	--
June 13, 2005					
Inlet	8.74	6.78	0.182	--	--
Big Twin	9.29	0.36	0.054	41.7	1.68
Little Twin	8.94	nd	0.194	7.69	2.50
Outlet	9.13	0.462	0.586	--	--
August 3, 2005					
Inlet	8.7	5.1	0.181	--	--
Big Twin	9.17	nd	1.08	30.7	1.07
Little Twin	8.84	nd	0.347	131	0.46
Outlet	no flow	no flow	no flow	--	--
August 23, 2005					
Inlet	no flow	no flow	no flow	--	--
Big Twin	9.24	nd	0.049	na	0.94
Little Twin	8.68	nd	0.322	na	0.34
Outlet	no flow	no flow	no flow	--	--
November 10, 2005					
Inlet	8.08	2.28	0.294	--	--
Big Twin	8.44	0.110	0.076	31.7	1.04
Little Twin	9.01	0.054	0.140	16.3	0.88
Outlet	no flow	no flow	no flow	--	--
January 11, 2006					
Inlet	na	6.340	0.046	--	--
Big Twin	8.27	0.197	0.281	13.3	0.73
Little Twin	7.70	0.174	0.095	12.8	1.80
Outlet	no flow	no flow	no flow	--	--

na – data not available
nd – not detected; below detection limits

pH

pH is a measure of a lake's acid level. It is the negative log of the hydrogen ion concentration in the water. Many factors influence pH including geology, productivity, pollution, etc. pH levels between 7.5 and 8.5 are common in lakes of central Wisconsin. Increased photosynthetic activity can increase pH. With a few exceptions, pH data for

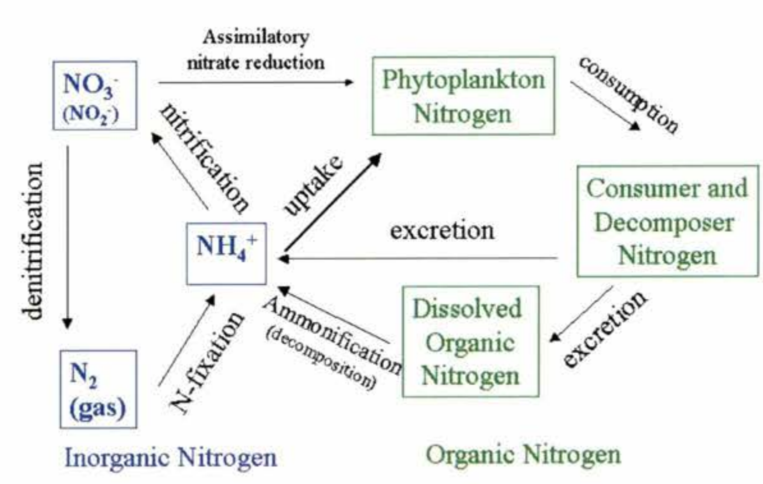
Twin Lakes were often above a value of 8 and reached as high as 9.24. This is again an indication of high productivity and poor water quality.

Nitrogen

Elevated levels of nitrogen (as nitrates and nitrites) enter Big Twin Lake from the inlet creek. In 2004 concentrations were consistently greater than 10 mg/L. In 2005, levels were generally above 5 mg/L with the exception of the November 10 sampling which found concentrations below 2.5 mg/L. Water naturally contains less than 1 mg/L of nitrogen. Levels of as low as 0.3 mg/L are sufficient to support high levels of algae production. Elevated levels indicate that the water has been contaminated. Nitrogen is an important plant fertilizer. But more importantly, it is an indicator that agricultural activities are influencing (polluting) the lake. Common sources of nitrate contamination include fertilizers, animal wastes, septic tanks, municipal sewage treatment systems, and decaying plant debris. Although the inlet water is not used for drinking water, the levels of nitrates are still of concern. State and federal laws set a maximum allowable level of nitrate in public drinking water at 10 mg/L.

As the water flowed through the Twin Lakes system, nitrogen values dropped and the outflow values were consistently less than 1.5 mg/L. Keep in mind, these values are for nitrates (NO_3^-) and nitrites (NO_2^-). The August 2004 nutrient data presented later in this report help shed some light on the fate of the forms of nitrogen in Twin Lakes. It is clear from the data that large amounts of nitrogen are entering the lakes through the inlet. Samples collected in Big Twin Lake had nitrogen concentrations that were consistently lower than the inlet samples. There are a number of processes at work here. Plants and algae take up some of the nitrogen in what is called uptake or assimilation while some is converted to nitrogen gas (N_2) through denitrification by bacteria (**Figure 16**). Under anaerobic conditions bacteria convert organic and inorganic forms of nitrogen to ammonia (NH_4^+). As the water flowed into Little Twin Lake there again was a drop in nitrogen (nitrate and nitrite) concentrations. Results show that in 2004, as the water flowed through the large cattail marsh adjacent to Little Twin and out Little Hills Creek, the value for nitrogen drops again. By August there was a 99.8% drop in nitrate and nitrite levels between the inlet and the outlet. This is due to in part to the ability of the cattail wetland to filter the surface water and remove nutrients. It can also be attributed in part to the conversion of nitrates and nitrites to other forms of nitrogen. Because 2005 was such a dry year, outflow data was only

Figure 16. Nitrogen cycle found in aquatic systems



available for the first two sampling dates. However, these data show again a dramatic decrease in nitrate and nitrite levels between the inlet and outlet creeks.

Phosphorus
Total phosphorus is one of the most important water quality indicators. Phosphorus levels determine the amount of plant and algae growth in a lake. Phosphorus can come from external sources within the watershed (fertilizers, livestock) or to a lesser extent, from groundwater (septic systems). Phosphorus can also come from within the lake. Internal loading occurs when plants and chemical reactions release phosphorus from the lake sediments into the water column.

Phosphorus data in Twin Lakes did not follow the same trends as nitrogen. The average phosphorus concentration for natural lakes in Wisconsin is .025 mg/L. Values over .05 mg/l are indicative of poor water quality. Phosphorus concentrations reached levels throughout the Twin Lakes system were often well above 0.05 mg/L in both 2004 and 2005. In June, July, and August concentrations of phosphorus in the water samples collected from the outlet stream, when available, were higher than the concentrations collected from the inlet. The highest concentration for phosphorus was measured on June 13, 2005. Phosphorus concentration in the outlet at that time was 0.586 mg/L. Clearly, inputs of phosphorus are likely occurring from elsewhere in the watershed and from within the lakes themselves.

In August 2004 and 2005, the phosphorus levels in Little Twin Lake were alarmingly high. This is due in part to the high density of curly-leaf pondweed present. When such a dense bed of curly-leaf pondweed begins to die off in mid to late summer, large amounts of nutrients are released through microbial decomposition. Phosphorus concentrations for these time periods are more than ten time the desired levels.

Wetlands are valued for their ability to remove nutrients and sediments from neighboring lakes. However, the data available for Twin Lakes show that for both nitrogen and phosphorus there were no consistency in the comparison of nutrient data between Little Twin Lake and Little Hills Creek. This would suggest that, although the cattail marsh to the east of Little Twin Lake likely has played a role in removing nutrients in the past, it appears this capability is reaching capacity.

Secchi Transparency
Water clarity is often used as a quick and easy test for a lake's overall water quality, especially in relation to the amount of algae present. As the season progressed, the water quality in both lake basins, as estimated by the Secchi transparency, went from fair to very poor. This is due to high levels of algae and other particulate matter in the water column. Secchi transparency was generally lower in Little Twin than in Big Twin.

Chlorophyll *a*
Chlorophyll is the pigment found in all green plants including algae that give them their green color. Chlorophyll is the site in plants where photosynthesis occurs. Chlorophyll absorbs sunlight to convert carbon dioxide and water to oxygen and sugars. Chlorophyll

data is collected because this green pigment is found in algae and can be used to estimate how much phytoplankton (algae) there is in the lake. Generally speaking, the more nutrients there are in the water and the warmer the water, the higher the production of algae and consequently chlorophyll.

Chlorophyll concentrations below 10 µg/l are most desirable for lakes. Data for Twin Lakes show various concentrations of chlorophyll throughout the year. Because levels can vary due to nutrient availability and weather conditions, obvious trends are not often seen. Interestingly, high chlorophyll *a* concentrations were measured in April 2005 when cold conditions and shorter day lengths would be expected to result in low chlorophyll values. This may be due in part to the large beds of curly-leaf pondweed found in Little Twin. Curly-leaf pondweed grows vigorously much earlier in the season than native plants species. By midsummer curly-leaf pondweed dies back and the decomposing plants release large amounts of nutrients into the water column. The first sign of this nutrient release is typically a dramatic increase in chlorophyll *a* concentrations. The August 2004 data demonstrate this effect when the Little Twin chlorophyll a concentration was almost three times higher than the concentration in Big Twin Lake on the same date.

There is a strong relationship between phosphorus and chlorophyll *a* concentrations and water clarity in lakes. As a response to rising levels of phosphorus, chlorophyll *a* levels increase and transparency values decrease.

Trophic State

Lakes can be categorized by their productivity or trophic state. When productivity is discussed, it is normally a reflection of the amount of plant and animal biomass a lake produces or has the potential to produce. The most significant and often detrimental result is elevated levels of algae and nuisance aquatic plants. Lakes can be categorized into three trophic levels:

- oligotrophic - low productivity, high water quality
- mesotrophic - medium productivity and water quality
- eutrophic - high productivity, low water quality

These trophic levels form a spectrum of water quality conditions. Oligotrophic lakes are typically deep and clear with exposed rock bottoms and limited plant growth. Eutrophic lakes are often shallow and marsh-like, typically having heavy layers of organic silt and abundant plant growth. Mesotrophic lakes are typically deeper than eutrophic lakes with significant plant growth, and areas of exposed sand, gravel or cobble bottom substrates.

Lakes can naturally become more eutrophic with time, however the trophic state of a lake is more influenced by nutrient inputs than by time. When humans negatively influence the trophic state of a lake the process is called *cultural eutrophication*. A sudden influx of available nutrients may cause a rapid change in a lake's ecology. Opportunistic plants such as algae and nuisance plant species are able to out-compete other more desirable species of macrophytes. The resultant appearance is typical of poor water quality.

Total phosphorus, chlorophyll *a* and Secchi depth are often used as trophic state indicators for lakes. Values measured for these parameters can be used to calculate Trophic State Index (TSI) values (Carlson 1977). The formulas for calculating the TSI values for Secchi disk, chlorophyll *a*, and total phosphorus are as follows:

$$TSI = 60 - 14.41 \ln \text{Secchi disk (meters)}$$

$$TSI = 9.81 \ln \text{Chlorophyll } a\ (\mu g/L) + 30.6$$

$$TSI = 14.42 \ln \text{Total phosphorus } (\mu g/L) + 4.15$$

The higher the TSI calculated for a lake, the more eutrophic it is (**Figure 17**). Eutrophic lakes have TSI values starting around 50 to 55. Values calculated from the Twin Lakes water quality data for 2004 and 2005 were consistently at or above this level (**Tables 6 and 7**). Levels would be expected to drop during winter months when chlorophyll concentrations would normally drop and clarity would increase. However, TSI values calculated for January 2005 and 2005 were between 53 and 68.

Figure 17. Relationship between trophic state in lakes and parameters including Secchi transparency, chlorophyll *a*, and total phosphorus.

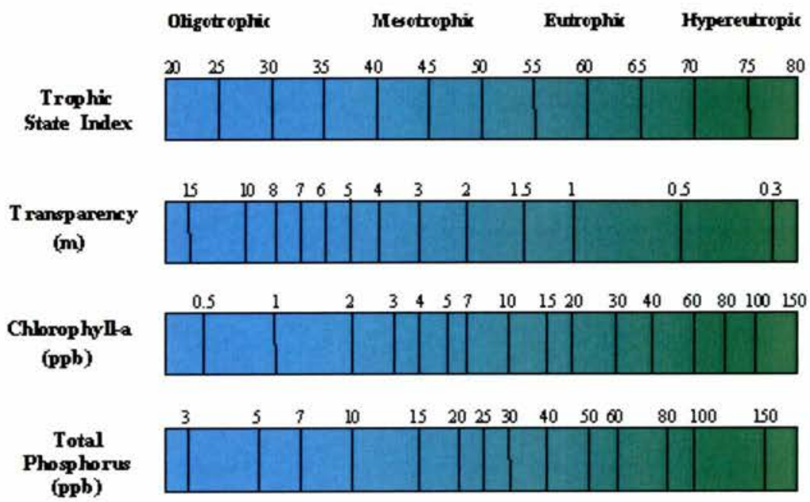


Table 6. Trophic State Index values calculated from data collected on Twin Lakes, Green Lake County, May 2004 to January 2005.

	Parameter			
May 27, 2004	*Phosphorus TSI*	*Chlorophyll TSI*	*Secchi TSI*	*Average TSI*
Big Twin	*74.88*	*44.98*	*52.56*	*57.47*
Little Twin	*74.45*	*38.94*	*60.82*	*58.07*
June 23, 2005				
Big Twin	*66.60*	*49.94*	*45.46*	*54.00*
Little Twin	*72.06*	*60.97*	*51.30*	*61.44*
July 17, 2004				
Big Twin	*53.20*	*60.23*	*47.16*	*53.53*
Little Twin	*64.56*	*70.18*	*51.30*	*62.01*
August 16, 2004				
Big Twin	*56.98*	*65.48*	*60.82*	*61.09*
Little Twin	*82.75*	*76.62*	*71.28*	*76.88*
November 15, 2004				
Big Twin	*72.70*	*52.41*	*48.09*	*57.73*
Little Twin	*61.13*	*60.56*	*47.16*	*56.28*
January 31, 2005				
Big Twin	*61.67*	*50.68*	*49.08*	*53.81*
Little Twin	*63.66*	*61.01*	*51.79*	*58.82*

Table 7. Trophic State Index values calculated from data collected on Twin Lakes, Green Lake County, April 2005 to January 2006.

	Parameter			
April 14, 2005	*Phosphorus TSI*	*Chlorophyll TSI*	*Secchi TSI*	*Average TSI*
Big Twin	*73.77*	*72.40*	*63.92*	*70.03*
Little Twin	*76.01*	*68.12*	*64.51*	*69.54*
June 13, 2005				
Big Twin	*61.67*	*67.20*	*52.56*	*60.47*
Little Twin	*80.11*	*50.61*	*46.80*	*59.17*
August 3, 2005				
Big Twin	*104.87*	*64.19*	*59.07*	*76.04*
Little Twin	*88.50*	*78.43*	*71.28*	*79.40*
August 23, 2005				
Big Twin	*60.27*	--	*60.82*	*60.54*
Little Twin	*87.42*	--	*75.75*	*81.58*
November 10, 2005				
Big Twin	*66.60*	*64.51*	*59.49*	*63.53*
Little Twin	*75.41*	*57.98*	*61.78*	*65.06*
January 11, 2006				
Big Twin	*85.46*	*55.99*	*64.51*	*68.65*
Little Twin	*69.82*	*55.61*	*51.54*	*58.99*

Tables 8 and 9 present the results of the water sampling done in August of 2004 and 2005.

Alkalinity

Alkalinity is a measure of the acid buffering capacity of a lake and is expressed in mg/L of calcium carbonate. A higher alkalinity value means a higher buffering capacity for a given a lake. Alkalinity values above 25 mg/L are indicative of an aquatic system with a very high buffering capacity. pH values above 8 and alkalinity levels well above 25 mg/L in Twin Lakes reflect not only an increase in productivity but are also indicative of a hard water system able to withstand acidic rain conditions.

Chloride

Chloride is not commonly a concern for lakes in Wisconsin. Naturally occurring concentrations of chloride in central Wisconsin range from approximately 3-10 mg/L. Twin Lakes levels in August were between 28 and 32 mg/L. High levels may indicate input from external sources such as septic systems, animal waste, road salt, and fertilizers.

Conductivity

Conductivity is the measure of the ions in a body of water by determining how well an electrical current is carried through the water sample. This has a direct correlation to the amount of salts in the water. The recommended value for conductivity in lake samples is below 300 μMhos/cm. Values in Twin Lakes were well above 300 μMhos/cm and indicate higher than normal levels of salts (as also implied by the chloride levels). Again this indicates high pollutant inputs from external sources.

Color

The color of a lake indicates the type and amount of dissolved organic chemicals present. Measured and reported as standard units, the main significance of lake color is aesthetic. High color values can impair Secchi disc readings and are indicative high levels of decomposing organic (plant) matter. Color values for Twin Lakes were between 10 and 60. Values below 40 are considered low and have little effect on transparency.

Solids

Total suspended solids (TSS) concentrations indicate the amount of solids suspended in the water, whether mineral (e.g., soil particles) or organic (e.g., algae, plankton). More productive lakes and those with soils susceptible to erosion tend to have higher concentrations of suspended solids. High concentrations of solids affect light penetration and habitat quality. Particles also provide attachment places for other pollutants, notably metals and bacteria. Pollution or general human activities usually result in higher TSS concentrations or turbidity. TSS concentrations below 5 mg/L are preferable for lakes. Values for Twin Lakes were between 8 and 23 mg/L.

Dissolved solids are a measure of dissolved organic compounds present in water. The most common source of dissolved solids is decomposing plant matter. Water having high concentrations of dissolved solids limits the depth at which photosynthesis can take place. Thus it is an important parameter that can affect lake ecosystems. The high concentrations of dissolved solids found in Twin Lakes likely limit the aquatic plant community in deeper waters. This was evident during the designing of the aquatic plant surveys conducted in 2003 and 2004. At the time it was decided to limit sampling to areas of the lakes which were shallower than 10 feet because only sparse plant growth was found in deeper water.

Elevated levels of both suspended and dissolved solids in Twin Lakes are again indicative of external and internal sources of pollutants.

Nutrients
As was previously discussed, much of the lower portions of both Big Twin and Little Twin Lakes were without oxygen during the August sampling dates. Under anaerobic conditions nutrients, in particular phosphorus, which are tied up in lake sediments, can be released into the water column through chemical and biological processes. This is clearly evident in the Big Twin data. Concentrations of total phosphorus at the lake bottom were 10 – 20 times higher than the concentration at the surface. In 2005, dissolved (ortho) phosphorus levels were 120 times higher at the bottom than at the surface. Ammonia, which is produced by anaerobic bacteria, was found in relatively low or undetectable concentrations on the lake surface. The samples collected from the bottom of Big Twin, were over 130 times higher.

Table 8. "Complete" water quality data collected on Twin Lakes, August 2004.

Parameter	Units	Big Twin - surface	Big Twin - bottom	Little Twin - surface	Little Twin - Bottom
pH	SU	8.65	--	8.41	--
Alkalinity	mg/L	180	--	199	--
Chloride	mg/L	29.5	--	28.6	--
Conductivity	μMhos/cm	495	--	476	--
Color	SU	10	--	25	--
Suspended solids	mg/L	8	--	16	--
Total dissolved solids	mg/L	300	--	286	--
Total phosphorus	mg/L	0.039	0.38	0.233	0.272
Dissolved (ortho) phosphorus	mg/L	na*	na*	na*	na*
Total Kjeldahl nitrogen	mg/L	5	3.5	2.1	1.44
Nitrate + nitrite as N	mg/L	1.15	1.79	nd*	nd*
Ammonia as N	mg/L	0.019	2.48	0.017	0.114

na = not available - dissolved phosphorus test were not run as hoped
nd = not detected/ below detection limits

Table 9. "Complete" water quality data collected on Twin Lakes, August 2005.

Parameter	Units	Big Twin - surface	Big Twin - bottom	Little Twin - surface	Little Twin - bottom
pH	SU	9.24	7.16	8.68	8.55
Alkalinity	mg/L	167	--	195	--
Chloride	mg/L	32.5	--	31.2	--
Conductivity	μMhos/cm	427	--	446	--
Color	SU	15	--	60	--
Suspended solids	mg/L	10	--	23	--
Total dissolved solids	mg/L	256	--	264	--
Total phosphorus	mg/L	0.049	1.05	0.322	0.323
Dissolved (ortho) phosphorus	mg/L	0.008	0.963	0.01	0.01
Total Kjeldahl nitrogen	mg/L	1.57	5.01	3.48	3.43
Nitrate + nitrite as N	mg/L	nd	nd	nd	nd
Ammonia as N	mg/L	nd	4.3	0.017	nd

na = not available (no flow in inlet or outlet streams; lab error in chlorophyll a sample analysis)
nd = not detected/ below detection limits

Hydrologic and Nutrient Budgets.

Table 10 shows the rates and volume of flow for the inlet and outlet creeks to Twin Lakes. Unfortunately, when this study was designed, the researchers did not expect 2005 to be as a dry year as it was. As a result, only three sampling dates yielded usable data. At the time of the remaining sampling dates, the streams had either imperceptible flow or no water present.

Table 10. Hydrologic data for the inlet and outlet creeks for Twin Lakes, Green Lake County.

Inlet Stream			
	ft^3/sec	gal/day	acre-ft/day
4/14/2005	3.348	2,164,008	6.64
6/13/2005	0.3564	230,362	0.71
8/3/2005*	--	--	--
8/23/2005+	--	--	--
11/10/2005*	--	--	--
1/11/2006	0.1496	96,695	0.30

Outlet Stream			
	ft^3/sec	gal/day	acre-ft/day
4/14/2005	6.7032	4,332,670	13.30
6/13/2005	0.3465	223,963	0.69
8/3/2005+	--	--	--
8/23/2005+	--	--	--
11/10/2005+	--	--	--
1/11/2006+	--	--	--

* imperceptible flow

\+ no water present

The hydrologic budget for Twin Lakes can be viewed in terms of the following equation:

$$PPT + SW_i + DR + GW_i = EVAP + SW_o + GW_o$$

where:

- PPT = precipitation
- SW_i = surface water inflow
- DR = direct runoff
- GW_i = groundwater inflow
- $EVAP$ = evaporation
- SW_o = surface water inflow
- GW_o = groundwater inflow

Table 11 presents the estimations for each of the above variables. Rainfall data available for Green Lake County show that in 2005, the total rainfall was 5 inches below normal. Precipitation for the period from April 14, 2005 to January 11, 2006 was estimated at 23.3 inches. Surface flow rates were calculated directly from flow measurements taken at the inlet and outlet creeks. Direct runoff was estimated at an average rate of 4 inches per year for the entire watershed minus the surface flow from the inlet creek. Pan evaporation rates were obtained from the Campus Climatological Observatory in Saint Paul, MN. The average annual evaporation from 2000-2205 was 35.1 inches. Groundwater rates were not measured directly; values are estimates of net flow in the system.

Table 11. Water budget data for Twin Lakes, Green Lake County.

Water Inputs	Volume (acre-feet/year)
precipitation	215.1
surface flow	306.0
direct runoff	324.4
groundwater	--
Total	845.5
Water outputs	Volume (acre-feet/year)
evaporation	326.1
surface flow	419.7
groundwater	99.7
Total	1170.6

Because it is nearly impossible to account for all variables affecting the lake, and because flow rates frequently fell below detectable limits, certain assumptions and estimations were made as follows:

1) Water flow from the inlet creek was estimated to occur for 120 days.
2) Water flow from the outlet creek was estimated to occur for 60 days.

Mass balance modeling
By utilizing the hydrologic budget and the empirical data collected for phosphorus over the timeframe of this study, a mass balance model can be created. This model can be used to identify the sources and movement of nutrients throughout the Twin Lakes system. The external loading of runoff pollutants, namely phosphorus, into Twin Lakes can be approximated by utilizing the concentrations of phosphorus collected from the inlet creek and general *export coefficients* for total phosphorus. Export coefficients are available for a number of land use types as kilograms of pollutant per hectare per year. Coefficients for total phosphorus are given in **Table 12**.

Table 12. General Export Coefficients for total phosphorus or the Eastern U.S.

	Export Coefficients* (kg/ha/yr)
Land Use	TP
Urban	1.0
Rural/Agriculture	0.5
Forest	0.05

*From Rast and Lee (1978).

Using the water budget estimates for the inlet and outlet creeks with the nutrient data found in **Tables 5, 8 and 9**, the following results were obtained:

Total P load from inlet:	**104 lbs P**
Total P load from direct runoff	**662 lbs P**
Total P load from precipitation	**4.1 lbs P**
Total P load from septic/groundwater (net)	**20 lbs P**
Total P load from internal cycling	**490 lbs P**
Total P load from outlet:	**517 lbs P**

Clearly precipitation and groundwater are not major sources of phosphorus into Twin Lakes. Contributions from precipitation were determined assuming 23.3 inches of rainfall with a total phosphorus concentration of 0.007 mg/L P (Robertson and Rose, 2000). This value is particularly low since 2005 was a relatively dry year. Septic system contributions were estimated at 2 lbs for each year-round household per year.

A small number of residents live on the lakes, therefore, the contribution of phosphorus from septic systems is minimal. Phosphorus concentrations in groundwater were measured from the April 2005 sampling which took place near the spring which feeds the western branch of the inlet creek. Values can also be estimated from the January 2006 inlet data. During winter months, it is safe to assume nutrients in flowing water are from groundwater sources since runoff is not occurring due to frozen conditions. The average phosphorus concentrations from these two dates were 0.078 mg/L. However, since more groundwater is moving out of the lakes than into the lakes, the amount of phosphorus contributed to the lakes through groundwater is negligible.

The nutrient data for August 2004 and August 2005 (**Tables 8 and 9**) show that high concentrations of nutrients have been recorded near the lake bottom. Again it is likely that through anaerobic processes, large amounts of nutrients are annually being released from the sediments. Using the total phosphorus data for August 2004 and August 2005 it was estimated that 1280 lbs of phosphorus exists in Twin Lakes during summer months. After subtracting contributions from the inlet, direct runoff, groundwater and precipitation, the total phosphorus load from internal cycling was estimated.

As is evident, phosphorus imports exceed exports. The data presented above show that Twin Lakes act as a nutrient sink. Nutrients continuously accumulate in the lakes faster than they are removed. The data also show that the primary sources of phosphorus to Twin Lakes are direct runoff, internal cycling, and the inlet creek. In order to reverse this process, nutrients from these sources would have to be reduced significantly. In doing so, the model shows that the response would be a shift toward the removal of more phosphorus from the system at a rate higher than it is imported. However, with the internal accumulation of phosphorus likely occurring for years, there are few short-term solutions which will allow for such a shift to occur.

As will be further explained in the results of the watershed analysis, there have been a number of areas in the immediate vicinity of the lakes which are known sources of runoff; in some cases washing manure applied to local fields directly into the lake. It will be vital to control these two major sources of phosphorus before a significant improvement in the quality of Twin Lakes will be seen.

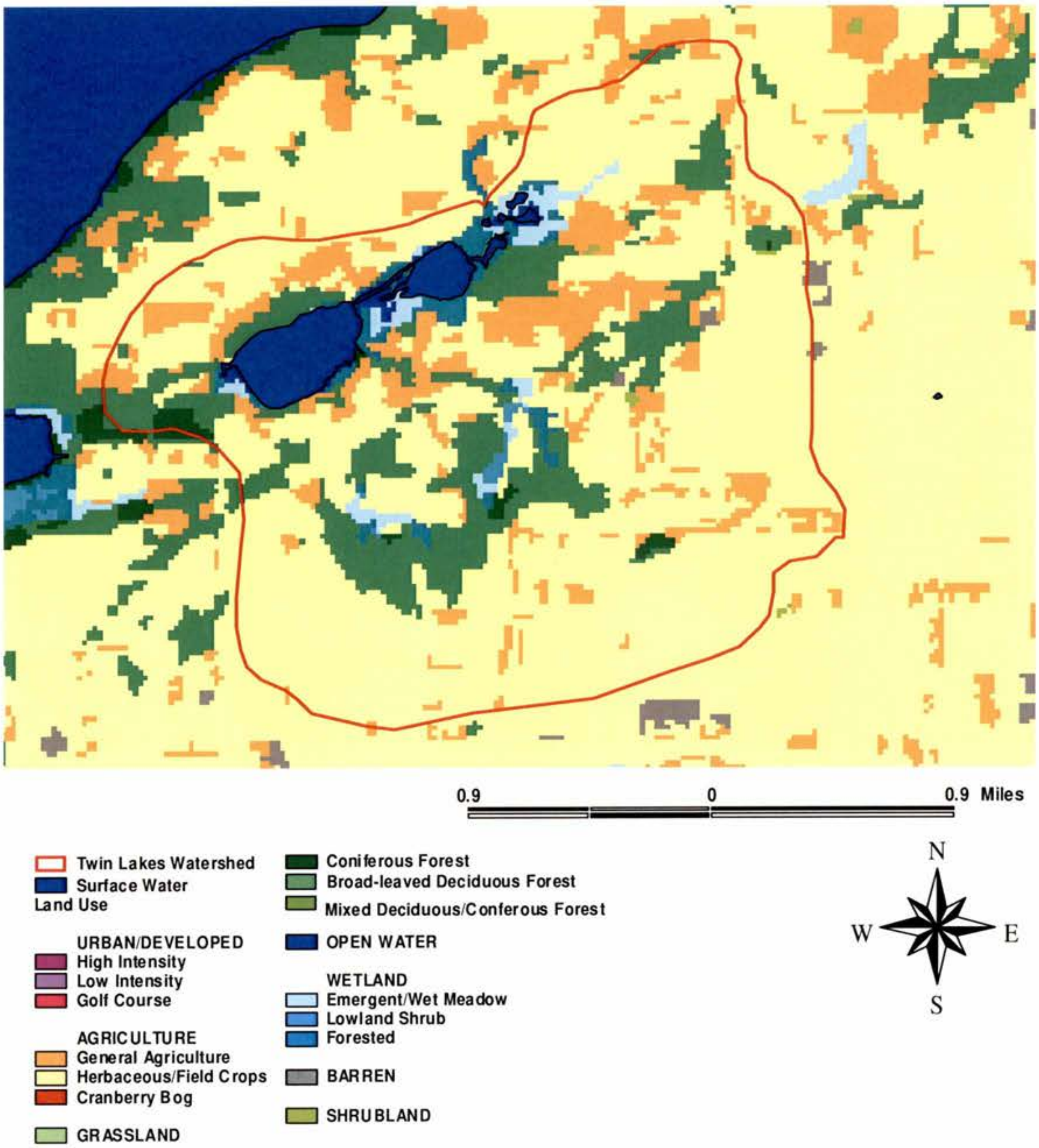
Watershed Analysis

In June 2005, the watershed analysis was conducted. **Figure 18** shows the delineation of the Twin Lakes watershed and the land use types present. The watershed for Twin Lakes is approximately 1.97 square miles. The steepest slopes in the watershed are found in areas closest to the lakes. The area of the watershed that stretches to the southeast of Twin Lakes has much shallower slopes. For this reason, it is those areas closest to the lakes which have the greatest influence on water quality.

The survey and resulting analysis found that the watershed of Twin Lakes is heavily dominated (74%) by agriculture. An additional 18 % is forested and 5% is wetlands. The agricultural areas of the watershed are mostly row crop fields dominated by corn, alfalfa, wheat and soybeans. The agriculture land surrounding Twin Lakes contributes much higher amounts of nutrients to the lakes than other land use types present (see **Table 12**). Reckhow et al. (1980) showed that row crops contribute higher amounts o f nutrients through runoff (4.46 kg P/ha/yr) than other forms of agriculture such as non row crops (1.08 kg P/ha/yr), pasture (1.50 kg P/ha/yr) , and mixed agriculture (1.13 kg P/ha/yr). For this reason it is these areas, in particular those areas closest to the lakes, which should receive the greatest attention in terms of management priorities.

The soils found in the Twin Lakes watershed are dominated (~90%) by silty loam and loam soils (**Appendix C**). Loamy soils are comprised of relatively even amounts of the three main mineral soil components: sand, silt, and clay. Loams are gritty soils, which are pliable when wet and which retain water easily. Where slopes allow, these soils also drain well. In general these soils contain more nutrients than sandy or clay soils. Silty loam soils are less gritty than loam soils and have a higher concentration of organic matter and subsequently are higher in nutrient content. These are also well-drained soils with high available water capacity.

Figure 18. Land use and watershed delineation for Twin Lakes, Green Lake County, Wisconsin.

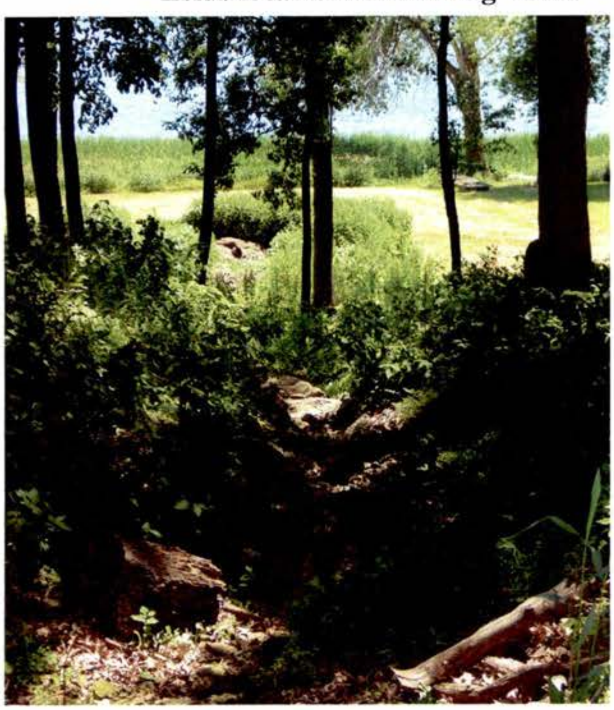


The watershed survey found a number of specific locations which should also be considered areas of high priority.

Figure 19. One of four culverts located under Twin Lakes Road, north of Big Twin Lake.

During certain times of the year, most notably in the spring during the snowmelt and during periods of heavy precipitation, high rates of runoff are likely to transport large amounts of nutrients into the lake system from surrounding farmlands. **Figure 19** shows one of four culverts found under Twin Lakes Road to the north of Big Twin Lake. It was noted at the time of the survey that in the past, in early spring as the snow is melting, a large volume of water passes under the road and flows directly into Big Twin Lake (**Figure 20**). In recent years this has been of particular concern since this melt water transports large amounts of manure which had been applied to the fields north of Twin Lakes Road throughout the winter. Thankfully, this practice has ceased and the owner of this property is in the process of placing this land under the Conservation Reserve Program. This effort should result in a significant decrease of nutrient influx into Twin Lakes.

Figure 20. One of four ravines which transport spring melt water from fields located north of Big Twin.



Just north of Little Twin Lake is another field which is fertilized with manure during certain times of the year. This is of particular concern because of the close proximity of this field to the lake. Only a strip of cattail approximately 20 feet wide separates the field from the lake. The relatively steep slope of this field facilitates the transport of large amounts of nutrients directly into Little Twin Lake.

Another area of concern due to the potential for high runoff and nutrient loading is located just south of Highway K approximately ¼ mile east of Highway N (**Figure 21**). This section of the farm field showed evidence of heavy erosion. This area

Figure 21. Site of heavy erosion located south of Highway K, Green Lake County.

is of particular concern because it constitutes the headwaters of the eastern most branch of the unnamed tributary creek which eventually enters Big Twin Lake near the boat landing. Rainwater can easily flow under the highway and ultimately into Big Twin Lake.

Additional information is available from the Green Lake County Land Conservation Office in regards to recent management practices within the watershed. Most recently has been the improvements made to the Wabiszewski farm to the west of Big Twin Lake. Work on this farm has included two retention ponds, a shallow scrape near the road, three grass waterways, a diversion, and field terracing. At the time of the watershed survey, these ponds had not yet been constructed. Retention ponds of this type are used to capture surface runoff allowing sediments to settle out and keep large amounts of nutrients from entering the lakes.

In addition, improved contour farming practices have been implemented on the Richard Patin farm while the Dickmann property has been placed into the Conservation Reserve Program. Over time, these and similar efforts will benefit Twin Lakes by decreasing the input of nutrients from the watershed.

All the Hickory Shores properties which are located on the north shore of Twin Lakes were subdivided in the 1960s and more recently equipped with septic systems.

Protecting Lake Water Quality

Twin Lakes currently experiences at least four main sources of nutrient loading. Nutrients are entering the lakes through surface water via the inlet creek, direct runoff primarily along the north shore, nutrient cycling from decomposing plant matter, and anaerobic phosphorus release from sediments. Elevated nutrient inputs from human activities around Twin Lakes have adversely affected both water clarity and water quality. The following are options for water quality enhancement which both the Association as a whole and individual lakefront property owners can undertake to improve Twin Lakes. A number of these practices are already underway.

Nutrient Management Options

The first steps taken in managing nutrients in a lake should be to control external sources of nutrients. These can include: encouraging the use of phosphorus free fertilizers; improving agricultural practices, reducing urban run-off; and restoring vegetation buffers around waterways.

Erosion control

Rainfall is one of the most powerful things on earth (Holdren et al., 2001). When a rain event occurs loose sediment can be washed directly into the lake or into inlets that drain into the lake. Precautions in disturbed areas need to be addressed. The use of silt fencing is a popular tool designed to help control erosion on construction sites. Because Twin Lakes are located in a heavily farmed area of the state, erosion control is particularly important. For the benefit of the landowners and health of the lake erosion control practices should be carried out to slow the process as much as possible. It is important that the Association work with the local Soil Conservationist with the Natural Resource Conservation Service (NRCS) and the Green Lake County Land Conservation Office to encourage improved farming practices within the watershed.

Erosion can also be a concern for shoreline property owners. Individuals are encouraged to leave existing vegetation, which is a great shore stabilizer. The placement of logs, brush mats, and rock riprap are also options against erosion. When riprap is used it is recommended that desirable shrubs and aquatic plants be planted within the rocks. The plantings serve as nutrient filters and habitat. Before any shoreline stabilization project is initiated, it is recommended that property owners contact the local DNR office for project approval and to obtain any necessary permits.

Lawn care practices

Mowed grass up to the water's edge is a poor choice for the well being of the lake. Studies show that a mowed lawn can cause 7 times the amount of phosphorus and 18 times the amount of sediment to enter a waterbody (Korth and Dudiak, 2003). Lawn grasses also tend to have shallow root systems that cannot protect the shoreline as well as deeper-rooted native vegetation (Henderson et al., 1998).

Landowners living in close proximity to the water should be discouraged from using lawn fertilizers. Fertilizers contain nutrients, including phosphorus and nitrogen can wash directly into the lake. While elevated levels of phosphorus can cause unsightly algae blooms, nitrogen inputs have been shown to increase weed growth. Landowners are encouraged to perform a soil test before fertilizing. A soil test will help determine if you need to fertilize, and give you direction on fertilizing. For assistance in having your soil tested, contact your county UW-Extension office. If there is a need to fertilize your lawn, use a fertilizer that does not include phosphorus. Most lawns in Wisconsin don't need additional phosphorus. The numbers on a bag of fertilizer are the percentages of available nitrogen, phosphorus and potassium found in the bag. Phosphorus free fertilizers will have a 0 for the middle number (e.g. 10-0-3).

To further reduce nutrient loading, avoid raking twigs, leaves, and grass clippings into the lake. They contain nitrogen and phosphorus. The best disposal for organic matter, like leaves and grass clippings is to compost them. Composted material can then be used for gardening.

Vegetative buffer zones
There are beneficial alternatives to the traditional mowed lawn. The best alternative is to protect the natural shoreline and leave it undisturbed. If clearing is necessary to access and view the lake, consider very selective removal of vegetation. Restoring a vegetative buffer zone is also an important alternative.

A recommended buffer zone consists of native vegetation that may extend from 25 – 100 feet or more from the water's edge onto land, and 25 – 50 feet into the water. A buffer should cover at least 50%, and preferably 75% of the shoreline frontage (Henderson et al., 1998). In most cases this still allows plenty of room for a dock, swimming area, and lawn. Buffer zones are made up of a mixture of native trees, shrubs, and other upland and aquatic plants.

Shoreline vegetation serves as an important filter against nutrient loading and trapping loose sediment. A buffer provides excellent fish and wildlife habitat, including nesting sites for birds, and spawning habitat for fish. Properly vegetated shorelines also play a key role in bank stabilization. A number of resources are available to assist property owners in creating beneficial buffer zones. These include descriptions of native beneficial plant species and where they can be found locally.

Emergent plant restoration

Shoreline vegetation can benefit lake ecology tremendously. A properly vegetated shoreline provides habitat for a variety of birds, furbearers, amphibians, and reptiles. Much of the shoreline and emergent vegetation in Twin Lakes appears to have been destroyed by lakefront development. Benefits to lake water quality, fishery and wildlife could be achieved by restoring shoreline plants in Twin Lakes. Lakefront habitat improvement is often done on a property-by-property basis. In recent years many new techniques have been developed for restoring lakefronts. This type of work often incorporates many attractive flowering plants and adds a great deal of aesthetic appeal to lakefronts as well.

Septic system maintenance

It is the responsibility of lakeshore property owners to ensure that septic systems are properly functioning. A failing septic system can contaminate both surface and ground water. If located in a groundwater discharge area, failing septic systems can be a major cause of nutrient loading in lakes. Systems should be professionally inspected every 3 years, and pumped every 2-5 years depending on operating circumstances (EPA, 2002). Avoid flushing toxic chemicals into the system. This can harm important bacteria that live in your tank and naturally break down wastes. Avoid planting trees in the drain field, compacting soil within the drain field, and directing additional surface runoff on top of the drain field.

Alum treatments

Aluminum compounds such as aluminum sulfate (alum) or aluminum chlorohydrate can be used to significantly reduce the concentration of phosphorus and improve the clarity of lake water. Alum has long been used in wastewater treatment plants for these purposes. When either of these compounds is applied to a body of water, the aluminum binds with phosphorus forming an insoluble precipitate which then settles out. As the settling occurs the precipitate will also capture suspended sediments, and leave the lake noticeably clearer. Once it has settled out, this precipitate forms a barrier which can reduce the rate of future internal nutrient loading. Care must be taken because aluminum compounds can significantly decrease the pH of a lake if applied at too high a rate. Aluminum sulfate has a greater risk of causing changes in pH that aluminum chlorohydrate. Estimates for an aluminum sulfate treatment in Big Twin Lake would currently range between $60,000 and $70,000. Aluminum chlorohydrate would cost considerably more. It is important to note that alum treatments will only target phosphorus which is present at the time of treatment. A treatment will not have an effect on future nutrient inputs. Although, this is a costly option, it has been shown to produce fast results. And if external nutrient sources are effectively managed, the improvements to lake water quality as a result of an alum treatment can last a number of years. Despite the high initial cost, the multi-year benefits that are possible may make alum treatment a management option worth pursuing for Twin Lakes.

Trace Mineral Organic Catalyst

Another option for the reduction of nutrients, that would be more economical, is a product referred to as Trace Mineral Organic Catalyst (TMOC). This product uses a combination of over 80 micronutrients, minerals, and trace elements to breakdown to accelerate the removal of phosphorus and suspended solids. A treatment of this type would also buffer the alkalinity of the lake, decrease excess nitrogen and volatile solids, stimulate biological activity, and replenish trace minerals. Additionally, it would not have the same effect on pH as an alum treatment would. The cost of this treatment would be approximately \$40,000 - \$50,000. As with an alum treatment, the use of TMOC would target the nutrients present at the time of treatment and its effects would persist longer if external nutrients were effectively managed. Although TMOC has been effectively used in wastewater treatment, it has only recently directed at nutrient management in lakes and ponds. Therefore, there is little scientific data for this application. The Twin Lakes Association would be advised to research this method further before implementation.

Aeration

By artificially introducing air into a lake, a number of benefits can be achieved. One of the most common and arguably the most effective way to artificially introduce oxygen into a waterbody is through a diffused-air aeration system. In a system of this type, a compressor stationed on shore pumps air through hoses connected to diffusers placed near the bottom of the lake. These diffusers are manufactured with permeable membranes which emit fine bubbles intended to maximize oxygen transfer. The rising air bubbles not only increase the diffusion of oxygen into the water but also increase the rates of circulation, aerating large amount of water. By evenly spacing the diffusers throughout the system, the entire lake will become aerated within a short time period.

The most common result of aeration is an improvement in dissolved oxygen levels and the resulting benefits to fish and water quality. Under oxygenated conditions, nutrients otherwise available to fuel weed and algae growth are greatly reduced. As these nutrients become tied up in the sediments, nuisance plant growth slows and the general appearance and quality of the water increases.

Stagnant conditions often result in high levels of organic sediments ("muck") associated with foul odors. These odors, similar to the smell of rotten eggs, are a result of the breakdown of organic matter by anaerobic bacteria. Aeration is able to not only eliminate these odors, but also increase the rate of *aerobic* decomposition of organic matter. Diffused aeration systems have been shown to significantly reduce the levels of organic material and prevent further muck accumulation.

In general, the health of a lake's fishery can be improved through aeration. Increase dissolved oxygen levels will allow the not only desirable fish species to thrive but also the numerous organisms upon which fish feed. As often is the case in systems without aeration, low levels of oxygen greatly limit the areas of the waterbody in which fish can survive. This is evident from the dissolved oxygen data available for Twin Lakes. These data show that only the upper layer of the lake (10-15 feet) is able to support most fish species. Aeration can improve fish habitat by allowing fish to live throughout the lake year-round.

Clearly there would be a number of benefits to installing an aeration system on Twin Lakes. However, a system of this type would likely cost over $50,000 to install. In addition, there would also be the annual costs of operation. The greatest of which would be the cost of electricity to run the on-shore compressor(s). Also, in order to supply a sufficient amount of air to the depths of Big Twin Lake, the compressor(s) would need to have high capacity. As a result, there would need to be a decision made regarding the placement of the compressor housing in relation to the placement of the diffusers, individual property owners' wishes and the sound produced by the compressor(s).

Informational resources for property owners
The following list are a number of valuable references that property owners and the Association can utilize to further explore options for water quality and shoreline habitat improvements.

Lakescaping for Wildlife and Water Quality. This 180-page booklet contains numerous color photos and diagrams. Many consider it the bible of shoreline restoration. It is available from the Minnesota Bookstore (651-297-3000) for $19.95.

The Living Shore. This video describes buffer zone construction and gives information on selecting and establishing plants. May be available at local library, or order from the Wisconsin Association of Lakes (800-542-LAKE) for $17.00.

A Fresh Look at Shoreland Restoration. A four-page pamphlet that describes shoreland restorations options. Available from UW Extension (#GWQ027) or WDNR (#DNR-FH-055).

What is a Shoreland Buffer? A pamphlet that discusses both ecological and legal issues pertaining to riparian buffer zones. Available from UW Extension (#GWQ028) or WDNR (#DNR-FH-223).

Life on the Edge…Owning Waterfront Property. A guide to maintaining shorelands for lakefront property owners. Available from UW Extension-Lakes Program, College of Natural Resources, University of Wisconsin, Stevens Point, WI 54481, for $4.50.

The Water's Edge. A guide to improving fish and wildlife habitat on your waterfront property. Available from WDNR (#PUB-FH-428-00).

District Involvement

Improved public awareness is one of the most important aspects of any lake management effort. By becoming knowledgeable about the condition of Twin Lakes, the Association can learn what practices are necessary to restore the plant community and keep the lake healthy. There are a number of activities that Association members can carry out to improve lake users' awareness of the problems facing Twin Lakes.

It is important that the boat landing on Big Twin Lake be posted with exotic species prevention signs available through the DNR. It is recommended that the current signs be maintained and that additional signs be posted to encourage boaters leaving the lakes to remove any plant material from their watercrafts before entering another waterbody.

Several other prevention and educational awareness activities should be planned. This can include public notices regarding exotic species, distribution of WDNR educational literature to public lake users, and conducting watercraft inspections. These volunteer efforts should focus on preventing the spread of Eurasian watermilfoil and other exotic species. Watercraft inspections can also be used as a tool to document potential watercraft infestations that can be communicated to the WDNR.

Clean Boats, Clean Waters

The Wisconsin DNR in cooperation with the EW-Extension Lakes Program have developed a volunteer watercraft inspection program designed to educate motivated lake organizations in preventing the spread of exotic plant and animal species in Wisconsin lakes. Through the Clean Boats, Clean Waters program volunteers are trained to organize and conduct boater education programs.

For more information contact:
Laura Felda-Marquardt
Clean Boats, Clean Waters Program Coordinator
Wisconsin Invasive Species Program
Ph: 715-365-2659 (Rhinelander)
Ph: 715-346-3366 (Stevens Point)

To download a printable brochure regarding the Clean Boats, Clean Waters program go to http://www.uwsp.edu/cnr/uwexlakes/CBCW/Pubs/CBCW_brochure.pdf.

State grant programs

A number of State-funded grants are available to qualified lake organizations for a variety of lake management and improvement projects. Grants which the Twin Lakes Association may benefit from include: Lake Management Protection grants, Aquatic Invasive Species Control grants, and the Recreational Boating Facilities grant.

Lake Management Protection Grants

The Lake Management Protection Grant program awards funds up to 75 percent of project costs with a maximum grant amount of $200,000. Eligible projects include the purchase of land or conservation easements, restoration of wetlands and shorelands, development of local regulations or ordinances to protect lakes, and lake management plan implementation projects.

Aquatic Invasive Species (AIS) Control Grants

This grant program is designed to assist management units in the control of aquatic invasive species. The WDNR awards cost-sharing grants for up to 50% of the costs of projects to control invasive species. These grants are awarded to projects that fall within three major categories:

1. Education, Prevention and Planning
2. Early Detection and Rapid Response
3. Controlling Established Infestations

These funds are currently available only to units of government. If members of the Twin Lakes Association chose to apply, they would need to have the support of a local governmental unit such as the township or land conservation office. This unit would then sponsor the grant on behalf of the Association.

Recreational Boating Facilities Grants

The DNR's Waterways Commission provides grant money for a variety of projects designed to improve recreation on Wisconsin lakes. The DNR provides cost sharing of up to 50 percent for eligible costs. Organizations can apply for funds to provide safe recreational boating facilities, conduct feasibility studies, purchase aquatic weed harvesting equipment, purchase navigation aids, dredge waterways, and chemically treat Eurasian watermilfoil.

For more details on each of these and other grant programs, visit the DNR's grant program website at http://www.dnr.state.wi.us/org/caer/cfa/grants/index.html.

Conclusions and Recommendations

Aquatic plant management

Results of the aquatic plant surveys conducted in 2003 and 2004 show that

Eurasian watermilfoil and curly-leaf pondweed continue to pose serious threats to Twin Lakes. Milfoil is currently the greater of these two evils. If left to spread and mature, milfoil will again have a serious impact on the recreational use of the lakes as well as to the water quality and fishery. Twin Lakes should be monitored annually for regrowth of milfoil and curly-leaf pondweed. Lake residents should undertake an active monitoring program for the purpose of identifying and documenting the extent of exotics.

The Association has expressed interest in focusing management efforts on Big Twin Lake. Initially, annual treatments should be made to control Eurasian watermilfoil and maintain this species below nuisance levels. It is recommended that the full extent of milfoil be targeted for treatment whenever possible. Since treatments have not been performed in over a year, milfoil which survived treatment or was reintroduced has regrown to much of its former range. Although the density of milfoil in Big Twin Lake is low, the recommended treatment approach remains the same (application of granular 2,4-D at a rate of 100 lbs/acre). Initial treatment costs will likely be high. Once control is gained, however, the Twin Lakes Association should be able to manage Eurasian watermilfoil at sub-nuisance levels with a minimal annual cost. The Lake Association should expect to budget funds and obtain permits annually for spot treatment of milfoil. Even if complete control is reached, Big Twin Lake could easily be reinfested with Eurasian watermilfoil either through new plant materials brought in by boat or through the transport of plant material from Little Twin Lake.

Treatment costs for Eurasian watermilfoil are as follows:

- If the full extent of Eurasian watermilfoil in Twin Lakes (27.2 acres) is targeted for treatment, the cost to the Association would be approximately $12,409.
- If milfoil in Big Twin Lake alone is targeted (18.5 acres) the cost would be approximately $8,553.
- The cost to treat Eurasian watermilfoil in Little Twin Lake (8.7 acres) would be an additional $3,856.

Although curly-leaf pondweed is generally not as invasive as Eurasian watermilfoil, it has and will likely continue to be a big problem for Twin Lakes. Curly-leaf pondweed was found in every sample transect in both Big Twin and Little Twin during the 2004 plant survey. The densest concentration of curly-leaf pondweed is currently in Little Twin Lake. However, if further monitoring finds an increase in the abundance of curly-leaf pondweed in Big Twin, it is recommended that the Twin Lakes Association seriously consider a large scale curly-leaf pondweed treatment. Keep in mind, because of the unique life cycle of curly-leaf pondweed, effective management will require approximately three years of annual early-season herbicide treatments. If the Association decided to treat Little Twin only the cost to treat the 20.9 acres present would be approximately $5,877.

Because Eurasian watermilfoil and curly-leaf pondweed are found throughout Twin Lakes, annually large amounts of nutrients are released when these plants die and decompose. Any effort to control of exotics should also result in improvement to water quality as well.

If members of the Association decide to implement an exotic species control program, it is recommended they apply for an Aquatic Invasive Species grant. Again this is a 50% reimbursement grant program that can be written for a three-year time period.

If native aquatic plants continue to impede navigation on the lake, the Lake Association can seek the required DNR permits to either harvest or chemically treat navigation lanes, within the vegetation, designed to improve the access of individual property owners. However, it is best if this step is taken only after management of Eurasian watermilfoil has been successful. Harvesting in areas infested with Eurasian watermilfoil would risk the further spreading of this species. Eliminating native plants by chemical control would allow for the further spread of a more aggressive species such as Eurasian watermilfoil. It should be noted that while these types of programs are designed to increase access to the lake through navigation lanes, they are typically contracted on an individual property owner basis. Usually a Lake Association does not sponsor these efforts because of the benefits to the individuals and not the Association as a whole.

Water quality management

Water quality will continue to be a problem for Twin Lakes. Vast amounts of nutrients are annually introduced externally and recycled internally in the lake. It is vital that efforts to control nutrient inputs be undertaken for the future of Twin Lakes. As was previously discussed, the two options likely to have the greatest short-term impact to the water quality of Twin Lakes, alum treatment and aeration, are both costly projects outside the current financial scope of the Association. However, if additional funding becomes available in the future, the Association should again consider these options.

Other efforts can result in improved water quality for Twin Lakes in the long-term. Improved land use practices within watershed, including not only farming practices, but also improvements to individual lakeshore properties, will contribute to improvements to the lakes as well. Again it is recommended that the Association work with the County Land Conservation Office and the local NRCS Soil Conservationist to further encourage best management practices throughout the watershed.

Management plan development

Results of this study were to the Twin Lakes Association in March 2006. At that time, issues related to water quality, the aquatic plant community, and the Twin Lakes watershed were discussed. Members of the Association expressed greatest concern regarding exotic plants, namely Eurasian watermilfoil, and the persistence of poor water quality in Twin Lakes. The Association identified Big Twin as being a higher priority over Little Twin. There was much discussion regarding options for aquatic plant control and nutrient management in Big Twin Lake. Options discussed for aquatic plant control were primarily continued chemical treatments and mechanical harvesting. Options for large-scale water quality improvement included chemical intervention (alum, etc.) and the use of aeration. In the end many options discussed were deemed too costly for further consideration.

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Appendix A

- Twin Lakes submergent aquatic plant survey data, June 2004.
- Twin Lakes emergent aquatic plant survey data, June 2004.
- Twin Lakes analysis of variance: submergent aquatic plant survey data from 2003 and 2004.

Appendix B

- Little Twin Lake 2004 dissolved oxygen and temperature data.
- Big Twin Lake 2004 dissolved oxygen and temperature data.
- Little Twin Lake 2005 dissolved oxygen and temperature data.
- Big Twin Lake 2005 dissolved oxygen and temperature data.

Appendix C

- Soils types found in the Twin Lakes watershed, Green Lake County, WI

Waterbody:	Twin Lakes		**Collectors:**	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				
TRANSECT:	A1	A2	A3		Total
Depth feet	2.5	5	10		
Substrate					
GPS Coordinates	N43º 47.566' W88º 58.611'	N43º 47.561' W88º 58.632'	N43º 47.560' W88º 58.631'		
Species / Occurrence					
Coontail			1		1
Curly Leaf Pondweed	2	2	1		5
Elodea		1			1
Flatstem Pondweed		2			2
Sago Pondweed	4				4
No Plants Found			3		3
				Total	16
Observations:					

Waterbody:	Twin Lakes		**Collectors:**	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				
TRANSECT:	B1	B2	B3		Total
Depth feet	2.5	5	10		
Substrate					
GPS Coordinates	N43º 47.490' W88º 58.666'	N43º 47.498' W88º 58.710'	N43º 47.498' W88º 58.716'		
Species / Occurrence					
Clasping Leaf Pondweed	1				1
Coontail	1	1	3		5
Curly Leaf Pondweed	3	4	3		10
Eurasian Watermilfoil		1	2		3
Filamentous Green Algae	4				4
Flatstem Pondweed	4	2	1		7
Musk Grass (Chara)		4			4
				Total	34
Observations:					

Waterbody:	Twin Lakes		Collectors:	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				
TRANSECT:	C1	C2	C3		Total
Depth feet	2.5	5	10		
Substrate					
GPS Coordinates	N43º 47.421'	N43º 47.429'	N43º 47.848'		
	W88º 58.765'	W88º 58.774'	W88º 58.782'		
Species / Occurrence					
Clasping Leaf Pondweed	4				4
Coontail		1			1
Curly Leaf Pondweed	2				2
Elodea	1				1
Filamentous Green Algae	2				2
Flatstem Pondweed	4	4	1		9
Musk Grass (Chara)		4	2		6
Sago Pondweed		1			1
No Plants Found			2		2
				Total	28
Observations:					

Waterbody:	Twin Lakes		Collectors:	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				
TRANSECT:	D1	D2	D3		Total
Depth feet	2.5	5	10		
Substrate	muck	muck	muck		
GPS Coordinates	N43º 47.406'	N43º 47.416'	N43º 47.448'		
	W88º 58.975'	W88º 58.954'	W88º 58.938'		
Species / Occurrence					
Common Bur-reed	1				1
Clasping Leaf Pondweed	4		1		5
Coontail	3	4	3		10
Curly Leaf Pondweed		1	4		5
Eurasian Watermilfoil/hybrid?		4	4		8
Filamentous Green Algae	2				2
Flatstem Pondweed	3	4	4		11
Musk Grass (Chara)		1			1
Northern Watermilfoil	2	3	1		6
Sago Pondweed	3		3		6
				Total	54
Observations:					

Waterbody:	Twin Lakes		**Collectors:**	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				
TRANSECT:	E1	E2	E3		Total
Depth feet	2.5	5	10		
Substrate	muck	muck	muck		
GPS Coordinates	N43º 47.543'	N43º 47.527'	N43º 47.526'		
	W88º 59.079'	W88º 59.042'	W88º 59.035'		
Species / Occurrence					
Clasping Leaf Pondweed	4	2			6
Coontail	2	1	2		5
Curly Leaf Pondweed		2			2
Eurasian Watermilfoil/hybrid	1		1		2
Flatstem Pondweed	4	4	4		12
Northern Watermilfoil		2	2		4
Sago Pondweed	4	2			6
No Plants Found				4	4
				Total	41
Observations:					

Waterbody:	Twin Lakes		**Collectors:**	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				
TRANSECT:	F1	F2	F3		Total
Depth feet	2.5	5	10		
Substrate	muck	muck	muck		
GPS Coordinates	N43º 47.620'	N43º 47.605'	N43º 47.605'		
	W88º 58.943	W88º 58.950'	W88º 58.941'		
Species / Occurrence					
Clasping Leaf Pondweed		1			1
Coontail		1	2		3
Curly Leaf Pondweed	4	2	1		7
Filamentous Green Algae	4	2	2		8
Flatstem Pondweed	4	4	3		11
Lesser Duckweed	4				4
Northern Watermilfoil	1	1			2
Sago Pondweed	4				4
White Water Crowfoot	1				1
				Total	41
Observations:					

Waterbody:	Twin Lakes		**Collectors:**	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				
TRANSECT:	G1	G2	G3		Total
Depth feet	2.5	5	10.5		
Substrate	muck	muck	muck		
GPS Coordinates	N43º 47.655'	N43º 47.648'	N43º 47.647'		
	W88º 58.824'	W88º 58.814'	W88º 58.811'		
Species / Occurrence					
Clasping Leaf Pondweed	3				3
Cattail	1				1
Coontail	1				1
Curly Leaf Pondweed		1			1
Eurasian Watermilfoil	1				1
Filamentous Green Algae	4	1			5
Flatstem Pondweed	4	4	1		9
Lesser Duckweed	4				4
Musk Grass (Chara)			1		1
Northern Watermilfoil	2				2
Sago Pondweed	1				1
No Plants Found			3		3
				Total	32
Observations:					

Waterbody:	Twin Lakes		**Collectors:**	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				
TRANSECT:	H1	H2	H3		Total
Depth feet	2.5	5	10		
Substrate	muck	muck	muck		
GPS Coordinates	N43º 47.694'	N43º 47.677'	N43º 47.664'		
	W88º 58.643'	W88º 58.653'	W88º 58.655'		
Species / Occurrence					
Clasping Leaf Pondweed	4				4
Coontail	2	1	2		5
Curly Leaf Pondweed		4			4
Eurasian Watermilfoil	1	1			2
Filamentous Green Algae	4				4
Flatstem Pondweed	2	4	3		9
Star Duckweed			3		3
Northern Watermilfoil	2				2
Sago Pondweed	4				4
					37
Observations:					

Waterbody:	Twin Lakes		Collectors:	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				
TRANSECT:	I1	I2	I3		Total
Depth feet	2.5	5	10		
Substrate	muck	muck	muck		
GPS Coordinates	N43º 47.813'	N43º 47.814'	N43º 47.796'		
	W88º 58.307'	W88º 58.289'	W88º 58.202'		
Species / Occurrence					
Coontail	4	3	1		8
Curly Leaf Pondweed	3	4	3		10
Filamentous Green Algae	1	3	2		6
Flatstem Pondweed	4				4
Large Duckweed	4				4
Lesser Duckweed	4	2			6
Sago Pondweed	1				1
No Plants Found			1		1
				Total	40
Observations:					

Waterbody:	Twin Lakes		Collectors:	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				
TRANSECT:	J1	J2	J3		Total
Depth feet	2.5	5	10		
Substrate	muck	muck	muck		
GPS Coordinates	N43º 47.853'	N43º 47.842'	N43º 47.809'		
	W88º 58.244'	W88º 58.233'	W88º 58.184'		
Species / Occurrence					
Cattail	2				2
Coontail	3	3			6
Curly Leaf Pondweed	1	4	1		6
Filamentous Green Algae	4	4			8
Flatstem Pondweed	2				2
Large Duckweed	4	1			5
Lesser Duckweed	4	4			8
Northern Watermilfoil	2				2
Star Duckweed	1				1
No Plants Found			3		3
				Total	43
Observations:					

Waterbody:	Twin Lakes		**Collectors:**	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				

TRANSECT:	K1	K2	K3		Total
Depth feet	2.5	5	10		
Substrate	muck	muck	muck		
GPS Coordinates	N43º 47.890'	N43º 47.874'	N43º 47.833'		
	W88º 58.160'	W88º 58.160'	W88º 58.170'		
Species / Occurrence					
Cattail	1				1
Coontail	4	3	1		8
Curly Leaf Pondweed	2	3			5
Filamentous Green Algae	4	4			8
Flatstem Pondweed	2				2
Large Duckweed	4				4
Lesser Duckweed	4	1			5
Northern Watermilfoil		1			1
Star Duckweed	2				2
No Plants Found			3		3
				Total	39
Observations:					

Waterbody:	Twin Lakes		**Collectors:**	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				

TRANSECT:	L1	L2	l3		Total
Depth feet	2.5	5	10		
Substrate	muck	mcuk	muck		
GPS Coordinates	N43º 47.876'	N43º 47.858'	N43º 47.845'		
	W88º 58.084'	W88º 58.105'	W88º 58.125'		
Species / Occurrence					
Cattail	1				1
Coontail	3		1		4
Curly Leaf Pondweed	2	4	4		10
Eurasian Watermilfoil	1				1
Filamentous Green Algae	4	3			7
Flatstem Pondweed	4				4
Large Duckweed	2				2
Lesser Duckweed	2				2
Northern Watermilfoil	2				2
Sago Pondweed	3				3
				Total	36
Observations:					

Waterbody:	Twin Lakes		**Collectors:**	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				

TRANSECT:	M1	M2	M3		Total
Depth feet	2.5	5	10		
Substrate					
GPS Coordinates	N43º 47.737' W88º 58.102'	N43º 47.748' W88º 58.108'	N43º 47.778' W88º 58.144'		
Species / Occurrence					
Cattail	1				1
Coontail	3		2		5
Curly Leaf Pondweed	1	4			5
Filamentous Green Algae	3	4			7
Flatstem Pondweed	4				4
Large Duckweed		2			2
Lesser Duckweed	2	2			4
Northern Watermilfoil	1				1
No Plants Found			2		2
				Total	31

Observations:

Waterbody:	Twin Lakes		**Collectors:**	A. Chikowski	
County:	Green Lake			B. Roost	
Date:	6/10/2004				

TRANSECT:	N1	N2	N3		Total
Depth feet	2.5	5	8		
Substrate	muck	muck	muck		
GPS Coordinates	N43º 47.729' W88º 58.209'	N43º 47.742' W88º 58.210'	N43º 47.787' W88º 58.214'		
Species / Occurrence					
Cattail	2				2
Coontail	3	1			4
Curly Leaf Pondweed	4	4	4		12
Filamentous Green Algae	1	4			5
Flatstem Pondweed	4				4
Large Duckweed	4	1			5
Lesser Duckweed	4	2			6
Northern Watermilfoil	4				4
				Total	42

Observations:

Waterbody:	Twin Lakes	Collectors:	A. Chikowski
County:	Green Lake		B. Roost
Date:	6/10/2004		

TRANSECT:	O1	O2	O3		Total
Depth feet	2.5	5	8		
Substrate	muck	muck	muck		
GPS Coordinates	N43º 47.748' W88º 58.302'	N43º 47.757' W88º 58.292'	N43º 47.792' W88º 58.227'		
Species / Occurrence					
Cattail	1				1
Coontail	4	3			7
Curly Leaf Pondweed			4		4
Filamentous Green Algae		2	1		3
Flatstem Pondweed	4	4			8
Large Duckweed	4	4			8
Lesser Duckweed	4	4			8
Northern Watermilfoil	3	4			7
				Total	46

Observations:

Waterbody:	Twin Lakes	Collectors:	A. Chikowski
County:	Green Lake		B. Roost
Date:	6/10/2004		

TRANSECT:	P1	P2	P3		Total
Depth feet	2.5	5	8		
Substrate	muck	muck	muck		
GPS Coordinates	N43º 47.781' W88º 58.317'	N43º 47.784' W88º 58.303'	N43º 47.792' W88º 58.239'		
Species / Occurrence					
Coontail		2	1		3
Curly Leaf Pondweed	4	4	4		12
Elodea	3				3
Filamentous Green Algae		4	2		6
Flatstem Pondweed	4	4			8
Large Duckweed	2	4			6
Lesser Duckweed	2	4			6
Northern Watermilfoil	2	4			6
				Total	50

Observations:

Twin Lakes emergent aquatic plant survey data by transect.

Species		Transect/Abundance Ranking																
common name	**scientific name**	**AB**	**BC**	**CD**	**DE**	**EF**	**FG**	**GH**	**HA**	**IJ**	**JK**	**KL**	**LM**	**MN**	**NO**	**OP**	**PI**	**Total**
Blue Flag Iris	*Iris versicolor*		1	1														2
Bottlebrush Sedge	*Carex comosa*								1	1			1		1			4
Broad Leaved Arrowhead	*Sagittaria latifolia*	1	1						1	1	1				1		1	7
Burreed	*Sparganium eurycarpum*	1	4	4	4	3		2	4				1			1	1	25
Cattail	*Typha* spp.	4	3	1	4	4	4	3	4	4	4	4	4	4	4	4	4	59
Hardstem Bulrush	*Scripus acutus*		3	1				2										6
Reed Canary Grass	*Phalaris arundinacea*			2	2		1		1									6
Softstem Bulrush	*Scirpus validus*		1													1		2
Spatterdock	*Nuphar variegata*	2	2	4	2													10
Sweetflag	*Acorus calamus*		2	2														4
Water Plantain	*Alisma* spp.																1	1
Species per transect		**4**	**8**	**7**	**4**	**2**	**2**	**3**	**5**	**3**	**2**	**1**	**3**	**1**	**3**	**3**	**4**	**11**

Relative abundance Ranking		
	1 Rare	found along less than 5% of transect
	2 Present	foung along 5-25% of transect
	3 Common	found along 25-50% of transect
	4 Abundant	found along more than 50% of transect

Analysis of variance between 2003 (top row) and 2004 (*bottom row*) for Twin Lakes submergent plant survey data.

Species	Transect / Occurences A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	total	t-value*	stat. sig. difference	increase/ decrease
Bushy Pondweed	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1.00	N	
(Najas flexilis)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*			
Cattail	0	0	0	0	0	0	3	0	0	0	1	1	0	1	1	2	9	0.00	N	
(Typha spp.)	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*2*	*1*	*1*	*1*	*2*	*1*	*0*	*9*			
Clasping Leaf Pondweed	1	2	4	2	4	5	3	4	0	0	0	0	0	0	0	0	25	0.17	N	
(Potamogeton richardsonii)	*0*	*1*	*4*	*5*	*6*	*1*	*3*	*4*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*24*			
Common Bur-reed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1.00	N	
(Sparganium eurycarpum)	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*			
Coontail	7	4	6	7	3	5	8	3	11	9	7	7	6	5	7	9	104	2.22	Y	decrease
(Ceratophyllum demersum)	*1*	*5*	*1*	*10*	*5*	*3*	*1*	*5*	*8*	*6*	*8*	*4*	*5*	*4*	*7*	*3*	*76*			
Curly Leaf Pondweed	8	1	1	2	3	4	0	0	10	5	8	6	7	8	4	5	72	-2.06	N	
(Potamogeton crispus)	*5*	*10*	*2*	*5*	*2*	*7*	*1*	*4*	*10*	*6*	*5*	*10*	*5*	*12*	*4*	*12*	*100*			
Elodea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1.46	N	
Elodea canadensis)	*1*	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*3*	*5*			
Eurasian Watermilfoil	6	1	1	5	2	3	1	0	8	1	4	2	2	2	4	4	46	2.44	Y	decrease
(Myriophyllum spicatum)	*0*	*3*	*0*	*8*	*2*	*0*	*1*	*2*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*17*			
Flatstem Pondweed	9	6	7	7	10	11	10	6	6	4	4	2	3	3	7	4	99	-0.63	N	
(Potamogeton zosteriformis)	*2*	*7*	*9*	*11*	*12*	*11*	*9*	*9*	*4*	*2*	*2*	*4*	*4*	*4*	*8*	*8*	*106*			
Green Algae	4	4	4	7	4	0	2	2	8	2	5	4	3	2	3	4	58	-1.14	N	
(Cladophora, Pithophora, etc.)	*0*	*4*	*2*	*2*	*0*	*8*	*5*	*4*	*6*	*8*	*8*	*7*	*7*	*5*	*3*	*6*	*75*			
Large Duckweed	0	0	0	0	0	0	0	0	0	2	2	1	0	1	0	1	7	-3.02	Y	increase
(Spirodela polyrhiza)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*4*	*5*	*4*	*2*	*2*	*5*	*8*	*6*	*36*			
Lesser Duckweed	0	0	0	0	1	0	0	1	5	4	4	3	1	1	1	1	22	-2.99	Y	increase
(Lemna minor)	*0*	*0*	*0*	*0*	*0*	*4*	*4*	*0*	*6*	*8*	*5*	*2*	*4*	*6*	*8*	*6*	*53*			
Musk Grass	2	5	5	2	0	0	0	0	0	0	0	0	0	0	0	0	14	0.70	N	
(Chara spp.)	*0*	*4*	*6*	*1*	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*12*			
Northern Watermilfoil	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	4	-3.42	Y	increase
(Myriophyllum sibericum)	*0*	*0*	*0*	*6*	*4*	*2*	*2*	*2*	*0*	*2*	*1*	*2*	*1*	*4*	*7*	*6*	*39*			
Sago Pondweed	7	3	5	5	7	9	7	8	1	1	2	0	1	2	3	2	63	3.64	Y	decrease
(Stuckenia pectinata)	*4*	*0*	*1*	*6*	*6*	*4*	*1*	*4*	*1*	*0*	*0*	*3*	*0*	*0*	*0*	*0*	*30*			
Small Pondweed	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1.00	N	
(Potamogeton pusillus)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*			

Analysis of variance between 2003 (top row) and 2004 (*bottom row*) for Twin Lakes submergent plant survey data.

	Transect / Occurences																		stat. sig.
Species	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**total**	**t-value***	**difference**
Spadderdock	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	1.29	N
(Nuphar variegata)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*		
Star Duckweed	3	0	0	0	0	0	1	0	0	2	0	3	1	2	2	2	16	1.54	N
(Lemna trisulca)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*3*	*0*	*1*	*2*	*0*	*0*	*0*	*0*	*0*	*6*		
Water Stargrass	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1.00	N
(Zosterella dubia)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*		
White Water Crowfoot	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0.00	N
(Ranunculus longirostris)	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*		
No Plants Found	1	1	1	1	0	0	1	1	1	0	4	4	4	4	4	3	30	0.90	N
	3	*0*	*2*	*0*	*4*	*0*	*3*	*0*	*1*	*3*	*3*	*0*	*2*	*0*	*0*	*0*	*21*		

*** Paired t-test for two sample means; 95% Confidence limit, df = 15, t = 2.1314**

Dissolved oxygen and temperature data for Little Twin Lake, Green Lake County, May 2004 to January 2005.

Depth	May 27, 2004				June 23, 2004				July 19, 2004			
(ft)	Temp (°C)	Temp (°F)	D.O. (mg/l)	% Sat.	Temp (°C)	Temp (°F)	D.O. (mg/l)	% Sat.	Temp (°C)	Temp (°F)	D.O. (mg/l)	% Sat.
0	15.1	59.2	6.03	58	23.1	73.6	9.61	110	19.5	67.1	7.89	85
1	15.1	59.2	6.10	60	23.2	73.8	9.30	107	19.3	66.7	7.66	79
2	15.1	59.2	6.08	60	23.2	73.8	9.41	108	19.2	66.6	7.47	77
3	15.1	59.2	5.84	57	23.2	73.8	9.52	109	19.1	66.4	7.88	83
4	15.1	59.2	5.97	58	23.3	73.9	9.06	104	19.1	66.4	7.19	75
5	15.0	59.0	5.63	54	23.2	73.8	9.09	104	19.1	66.4	7.24	76
6	14.9	58.8	5.08	49	23.2	73.8	6.98	79	19.0	66.2	7.12	74
7	14.6	58.3	3.90	36	22.6	72.7	2.60	28	18.9	66.0	6.46	67
8	14.3	57.7	2.78	26	21.8	71.2	1.47	15	18.7	65.7	4.35	44
9	14.2	57.6	1.95	18	20.5	68.9	0.37	1.5	18.3	64.9	1.82	17
10	14.0	57.2	1.26	11	20.1	68.2	0.33	1.2	16.6	61.9	0.60	3.7
11	13.9	57.0	1.01	8.3	19.5	67.1	0.32	1.2	16.0	60.8	0.42	1.5
12	13.8	56.8	0.77	5.7	18.8	65.8	0.24	1.0				
13	13.7	56.7	0.36	2.4	18.5	65.3	0.21	0.9				

Depth	August 16, 2004				November 15, 2004				January 31, 2005			
(ft)	Temp (°C)	Temp (°F)	D.O. (mg/l)	% Sat.	Temp (°C)	Temp (°F)	D.O. (mg/l)	% Sat.	Temp (°C)	Temp (°F)	D.O. (mg/l)	% Sat.
0	19.9	67.8	13.84	150	4.9	40.8	12.38	101	1.2	34.2	9.07	64
1	19.9	67.8	12.46	136	4.9	40.8	12.33	96				
2	19.8	67.6	12.81	139	4.9	40.8	12.32	96	1.2	34.2	9.26	65
3	19.8	67.6	13.12	143	4.9	40.8	12.43	97				
4	19.7	67.5	12.63	136	4.9	40.8	12.48	97	3.6	38.5	4.48	33
5	19.7	67.5	12.12	131	4.9	40.8	12.32	96				
6	19.1	66.4	2.64	26	4.9	40.8	11.92	94	4.1	39.4	3.44	25
7	18.5	65.3	1.40	13	4.9	40.8	12.06	95				
8	18.3	64.9	0.57	4.2	4.9	40.8	8.70	68	4.1	39.4	2.98	22
9	18.3	64.9	0.35	1.5	4.9	40.8	8.27	65	4.3	39.7	0.41	1.8
10	18.1	64.6	0.34	1.5	4.9	40.8	5.84	45				
11	18.1	64.6	0.38	1.7								
12	18.0	64.4	0.24	1.3								
13												

Dissolved oxygen and temperature data for Big Twin Lake, Green Lake County, May 2004 to January 2005.

Depth	May 27, 2004			June 23, 2004			July 19, 2004		
(ft)	Temp (ºC)	Temp (ºF)	D.O. (mg/l)	Temp (ºC)	Temp (ºF)	D.O. (mg/l)	Temp (ºC)	Temp (ºF)	D.O. (mg/l)
0	15.6	60.1	8.02	18.8	65.8	10.36	23.4	74.1	11.64
1									
2	15.6	60.1	8.13	18.7	65.7	10.06	22.9	73.2	11.16
3									
4	15.6	60.1	8.08	18.7	65.7	9.87	22.9	73.2	11.08
5									
6	15.6	60.1	7.97	18.7	65.7	10.00	22.7	72.9	10.95
7									
8	14.4	57.9	6.31	18.6	65.5	10.08	20.7	69.3	9.45
9									
10	14.3	57.7	6.15	17.3	63.1	7.92	19.3	66.7	8.29
11									
12	14.0	57.2	5.66	16.1	61.0	5.20	17.6	63.7	3.47
13									
14	13.5	56.3	5.02	15.0	59.0	2.97	17.6	63.7	3.35
15									
16	13.4	56.1	5.43	14.5	58.1	2.67	16.3	61.3	0.54
17									
18	13.3	55.9	5.76	13.6	56.5	1.58	15.2	59.4	0.26
19									
20	12.6	54.7	4.57	12.8	55.0	0.63	12.8	55.0	0.24
21									
22	12.2	54.0	2.12	12.3	54.1	0.48	12.3	54.1	0.23
23									
24	11.3	52.3	0.74	11.7	53.1	0.45	11.7	53.1	0.23
25									
26	10.8	51.4	0.34	10.7	51.3	0.46	10.9	51.6	0.24
27									
28	10.4	50.7	0.31	10.2	50.4	0.46	10.5	50.9	0.24
29									
30	9.6	49.3	0.31	9.7	49.5	0.42	10.2	50.4	0.23
31									
32	9.1	48.4	0.31	9.2	48.6	0.40	9.7	49.5	0.22
33									
34	7.6	45.7	0.30	8.6	47.5	0.42	9.0	48.2	0.22
35									
36	7.2	45.0	0.30	8.3	46.9	0.40	8.3	46.9	0.22
37									
38	7.0	44.6	0.28	8.0	46.4	0.40	8.0	46.4	0.24
39									
40	6.9	44.4	0.29	7.8	46.0	0.40	7.9	46.2	0.23
41									
42	6.8	44.2	0.26	7.7	45.9	0.39	7.8	46.0	0.22
43									
44	6.8	44.2	0.25	7.5	45.5	0.38	7.8	46.0	0.21
45									
46	6.8	44.2	0.25				7.8	46.0	0.21

Dissolved oxygen and temperature data for Big Twin Lake, Green Lake County, May 2004 to January 2005.

Depth (ft)	August 16, 2004 Temp (°C)	August 16, 2004 Temp (°F)	August 16, 2004 D.O. (mg/l)	November 15, 2004 Temp (°C)	November 15, 2004 Temp (°F)	November 15, 2004 D.O. (mg/l)	January 31, 2005 Temp (°C)	January 31, 2005 Temp (°F)	January 31, 2005 D.O. (mg/l)
0	20.3	68.5	13.56	7.2	45.0	8.68	0.5	32.9	10.36
1									
2	20.1	68.2	13.47	7.4	45.3	8.49	1.6	34.9	9.97
3									
4	20.0	68.0	13.27	7.5	45.5	8.40	2.4	36.3	10.44
5									
6	19.9	67.8	13.23	7.5	45.5	8.37	2.5	36.5	10.15
7									
8	19.9	67.8	13.17	7.5	45.5	8.34	2.5	36.5	9.81
9									
10	19.9	67.8	13.64	7.6	45.7	8.27	2.4	36.3	10.13
11									
12	18.0	64.4	7.08	7.6	45.7	8.26	2.5	36.5	9.93
13									
14	17.6	63.7	1.33	7.6	45.7	8.27	2.5	36.5	9.72
15									
16	17.0	62.6	0.35	7.6	45.7	8.23	2.5	36.5	9.52
17									
18	14.6	58.3	0.39	7.6	45.7	8.23	2.5	36.5	9.14
19									
20	13.1	55.6	0.22	7.6	45.7	8.26	2.6	36.7	9.08
21									
22	11.8	53.2	0.23	7.6	45.7	8.20	2.6	36.7	8.79
23									
24	11.5	52.7	0.20	7.6	45.7	8.16	2.6	36.7	8.65
25									
26	11.1	52.0	0.21	7.6	45.7	8.21	2.7	36.9	8.36
27									
28	10.5	50.9	0.25	7.6	45.7	8.23	2.7	36.9	7.85
29									
30	9.4	48.9	0.24	7.6	45.7	8.26	2.7	36.9	7.81
31									
32	8.8	47.8	0.23	7.6	45.7	8.21	2.7	36.9	6.68
33									
34	8.3	46.9	0.26	7.6	45.7	8.23	2.7	36.9	5.92
35									
36	8.2	46.8	0.22	7.6	45.7	8.12	2.8	37.0	4.81
37									
38	7.9	46.2	0.14	7.6	45.7	8.10	2.8	37.0	4.87
39									
40				7.5	45.5	7.81	3.0	37.4	4.54
41									
42				7.5	45.5	7.75	3.2	37.8	3.30
43									
44				7.5	45.5	7.75	3.7	38.7	0.65
45							3.8	38.8	0.72
46				7.4	45.3	2.84			

Dissolved oxygen and temperature data for Little Twin Lake, Green Lake County, April 2005 to January 2006.

Depth	April 14, 2005			June 13, 2005			August 10, 2005		
(ft)	Temp (°F)	D.O. (mg/l)	% Sat.	Temp (°F)	D.O. (mg/l)	% Sat.	Temp (°F)	D.O. (mg/l)	% Sat.
0	57.6	18.16	172.0	80.5	8.16	102.5	83.1	12.40	165.3
1	57.2	16.90	162.0	80.5	8.19	102.9	82.7	12.70	167.7
2	56.8	17.17	164.0	80.3	8.04	98.9	82.0	12.80	168.0
3	56.7	17.91	179.0	79.9	6.73	82.5	81.3	7.11	92.1
4	56.7	17.61	163.5	79.2	5.42	64.5	80.0	4.85	57.9
5	56.1	18.08	179.8	78.5	4.85	57.2	79.4	2.97	38.1
6	53.6	15.17	146.2	75.5	2.85	32.8	78.8	0.16	2.1
7	53.2	12.46	148.5	72.9	1.96	21.1	78.1	0.12	1.5
8	53.1	8.67	79.9	69.0	0.57	5.5	77.1	0.11	1.4
9	52.3	2.20	19.3	66.0	0.18	0.3	76.7	0.10	1.2
10							75.7	0.09	1.2
11							74.7	0.06	0.6
12									
13									

Depth	August 23, 2005			November 10,2005			January 11, 2006		
(ft)	Temp (°F)	D.O. (mg/l)	% Sat.	Temp (°F)	D.O. (mg/l)	% Sat.	Temp (°F)	D.O. (mg/l)	% Sat.
0	72.3	5.72	64.00	46.2	10.90	93.70	34.5	9.22	68.00
1	72.2	5.69	63.90	45.8	11.00	94.10	35.1	9.75	73.00
2	72.0	5.68	63.80	45.6	10.90	93.70	38.3	7.74	61.10
3	72.0	5.67	63.80	45.6	10.90	93.30	39.8	5.22	42.00
4	71.8	5.69	63.80	45.5	10.80	92.00	40.7	2.52	20.40
5	71.9	5.72	63.90	45.4	10.80	92.50	40.6	2.18	17.60
6	72.0	5.49	62.20	45.3	10.90	93.30	40.4	2.19	17.60
7	71.8	2.92	30.90	45.3	10.80	91.90	40.3	2.21	17.70
8	71.5	2.44	25.80	45.3	10.80	92.20			
9	71.4	2.80	30.50	45.1	10.90	93.40			
10	71.2	2.90	31.20	45.1	10.80	91.40			
11	71.0	2.93	31.30	45.3	10.80	92.30			
12	70.9	2.94	31.40	45.3	5.30	43.00			
13	71.1	0.07	7.20	45.7	0.49	4.10			

Dissolved oxygen and temperature data for Big Twin Lake, Green Lake County, April 2005 to January 2006

Depth	April 14, 2005			June 13, 2005			August 10, 2005		
(ft)	Temp (°F)	D.O. (mg/l)	% Sat.	Temp (F.)	D.O. (mg/l)	% Sat.	Temp (F.)	D.O. (mg/l)	% Sat.
0	55.8	16.50	>150	79.5	11.20	135.2	84.0	9.90	135.1
1									
2	52.7	18.08	>150	79.6	11.20	135.3	82.5	10.20	125.2
3									
4	52.3	16.88	>150	79.6	11.10	135.2	81.3	9.74	126.8
5									
6	51.6	16.67	>150	78.7	8.04	105.0	80.8	9.46	122.6
7									
8	49.8	15.33	>150	76.5	6.42	74.7	80.1	6.57	84.6
9									
10	49.1	16.30	142.5	71.8	4.24	45.8	79.1	2.29	29.1
11									
12	48.7	14.74	128.4	66.1	4.31	43.7	75.1	0.17	2.1
13									
14	48.4	13.60	118.0	61.0	4.06	38.9	68.5	0.11	1.2
15									
16	47.3	11.61	99.9	55.7	3.40	31.0	62.1	0.10	1.1
17									
18	45.7	10.52	90.0	51.7	2.25	19.2	55.1	0.07	0.8
19									
20	43.0	8.41	67.2	48.0	0.34	2.1	51.0	0.05	0.5
21									
22	39.9	5.92	45.9	45.9	0.10	0.5	48.5	0.03	0.3
23									
24	38.5	5.03	38.9	44.0	0.06	0.6	46.2	0.02	0.2
25									
26	38.1	3.75	27.2	42.4	0.03	0.3	44.2	0.01	0.1
27									
28	37.9	2.20	15.9	41.2	0.02	0.2	43.6	0.01	0.1
29									
30	37.9	1.28	7.3	40.4	0.01	0.1	43.1	0.01	0.1
31									
32	37.9	0.48	3.3	39.8	0.01	0.1	42.4	0.01	0.1
33									
34	37.9	0.41	2.2	39.6	0.01	0.1	42.0	0.01	0.1
35									
36	37.9	0.43	3.0	39.4	0.00	0.0	41.3	0.01	0.1
37									
38	37.9	0.50	3.3	39.3	0.00	0.0	41.0	0.01	0.1
39									
40	38.1	0.56	3.9	39.3	0.00	0.0	40.8	0.01	0.1
41									
42	38.1	0.59	4.2	39.3	0.00	0.0	40.7	0.01	0.1
43									
44	38.3	0.56	3.8	39.3	0.00	0.0	40.6	0.01	0.0
45	32.0	0.53	4.7						
46				39.3	0.00	0.0	40.6	0.00	0.0

Dissolved oxygen and temperature data for Big Twin Lake, Green Lake County, April 2005 to January 2006

Depth (ft)	August 23, 2005 Temp (F.)	D.O. (mg/l)	% Sat.	November 10, 2005 Temp (F.)	D.O. (mg/l)	% Sat.	January 11, 2006 Temp (F.)	D.O. (mg/l)	% Sat.
0	73.8	6.96	78.9	47.8	8.24	73.0	36.2	12.00	90.6
1									
2	74.1	6.85	77.9	48.1	8.23	72.7	37.0	10.60	81.1
3									
4	74.1	6.84	77.5	48.2	8.17	72.3	36.9	10.30	79.2
5									
6	74.1	6.78	77.0	48.1	8.18	72.2	36.9	10.30	78.8
7									
8	74.2	6.58	75.1	48.3	8.13	71.9	36.9	10.30	78.7
9									
10	74.0	6.44	73.2	48.3	8.04	71.2	36.8	10.30	78.6
11									
12	73.5	5.67	63.8	48.3	8.06	71.3	36.8	9.80	75.0
13									
14	67.5	0.14	2.3	48.3	8.02	71.0	36.8	9.21	70.5
15									
16	61.2	0.08	0.1	48.3	7.92	70.1	36.9	9.00	69.0
17									
18	55.5	0.04	0.4	48.4	7.78	69.0	36.9	8.64	66.2
19									
20	51.7	0.05	0.5	48.2	7.76	68.7	37.0	8.24	63.3
21									
22	49.0	0.04	0.4	48.2	7.43	65.8	37.0	7.79	59.8
23									
24	45.7	0.03	0.3	47.9	7.45	65.5	37.3	7.36	56.7
25									
26	44.1	0.03	0.3	48.0	7.39	65.2	37.3	6.46	49.7
27									
28	43.1	0.02	0.2	48.0	7.30	69.4	37.4	5.40	41.8
29									
30	42.3	0.01	0.1	48.0	7.28	64.2	37.3	5.42	41.8
31									
32	41.6	0.02	0.2	47.2	2.23	19.2	37.2	4.99	38.4
33									
34	41.2	0.02	0.2	46.9	0.34	3.0	37.6	3.30	25.5
35									
36	41.0	0.01	0.1	43.1	0.13	1.1	37.7	0.83	6.6
37									
38	40.8	0.02	0.2	42.5	0.10	0.9	38.0	0.37	2.8
39									
40	40.6	0.01	0.1	42.2	0.09	0.7	38.1	0.26	2.0
41									
42	40.6	0.01	0.1	42.0	0.09	0.7	38.4	0.10	0.7
43									
44	40.5	0.01	0.1	41.9	0.07	0.6			
45									
46	40.5	0.01	0.1						

Soils types found in the Twin Lakes watershed, Green Lake County, WI

Soil type	Percent of Watershed
Plano silt loam, 0 to 2 percent slopes	17.5
St. Charles silt loam, 2 to 6 percent slopes	11.5
Mendota silt loam, 2 to 6 percent slopes	9.2
Lomira silt loam, 2 to 6 percent slopes	7.1
Ossian silt loam	4.9
Knowles silt loam, 6 to 12 percent slopes, eroded	4.5
Lomira silt loam, 6 to 12 percent slopes, eroded	3.7
Plano silt loam, 2 to 6 percent slopes	3.5
Dodge silt loam, 2 to 6 percent slopes	3.2
Knowles silt loam, 2 to 6 percent slopes	3.1
Marshan silt loam	2.6
St. Charles silt loam, 0 to 2 percent slopes	2.2
Kidder loam, 6 to 12 percent slopes, eroded	2.1
Rock land and Ritchey soils, 6 to 45 percent slopes	2
Ritchey silt loam, 6 to 12 percent slopes, eroded	1.9
Markesan silt loam, 6 to 12 percent slopes, eroded	1.7
LeRoy silt loam, 6 to 12 percent slopes, eroded	1.4
Ritchey silt loam, 12 to 20 percent slopes, eroded	1.4
Dodge silt loam, 6 to 12 percent slopes, eroded	1.2
Joy silt loam, 0 to 3 percent slopes	1.2

Soil type	Percent of Watershed
Kidder loam, 12 to 20 percent slopes, eroded	1.1
Markesan silt loam, 2 to 6 percent slopes, eroded	1.1
Kidder loam, 20 to 30 percent slopes	1
St. Charles silt loam, 6 to 12 percent slopes, eroded	0.8
Knowles silt loam, 12 to 20 percent slopes, eroded	0.7
Rotamer sandy loam, 6 to 12 percent slopes, eroded	0.6
Marcellon loam, 0 to 3 percent slopes	0.5
Mendota silt loam, 0 to 2 percent slopes	0.4
Mendota silt loam, 6 to 12 percent slopes, eroded	0.4
Ritchey silt loam, 2 to 6 percent slopes, eroded	0.4
Colwood silt loam	0.2
Houghton muck	0.2
LeRoy silt loam, 12 to 20 percent slopes, eroded	0.2
Markesan silt loam, 12 to 20 percent slopes, eroded	0.2
Knowles silt loam, 0 to 2 percent slopes	0.1
Lomira silt loam, 12 to 20 percent slopes, eroded	0.1
Kidder loam, 2 to 6 percent slopes	0
Water	3.7
Marsh	2.3