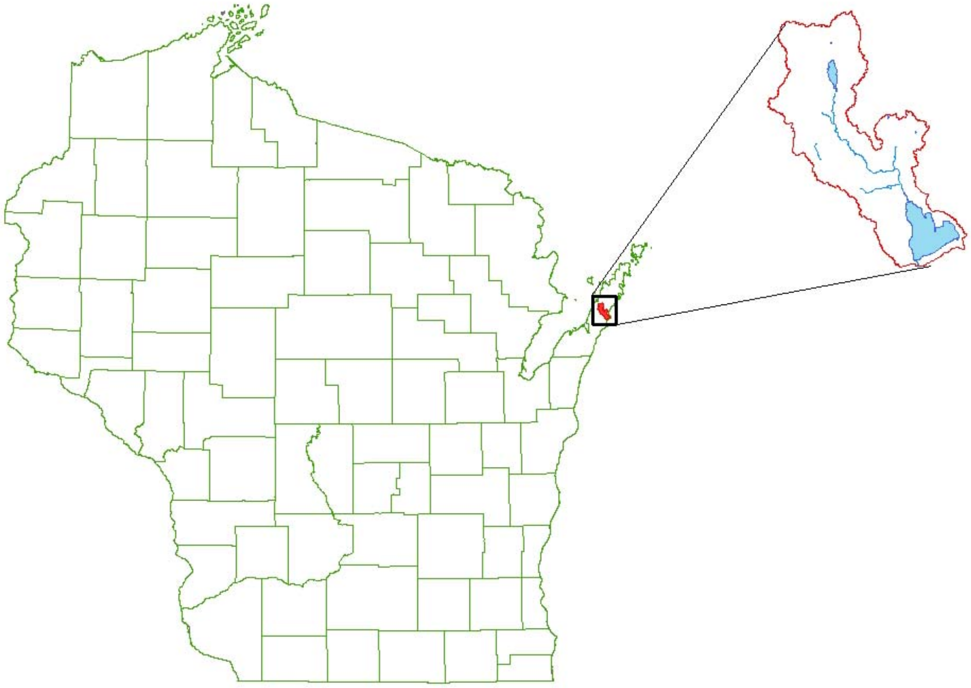
Water Quality and Bulrush Evaluation in Clark Lake, Door County, Wisconsin

Final Report



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Introduction

PHYSICAL CHARACTERISTICS AND DEVELOPMENT

Setting

Clark Lake and its watershed are located in the Door County towns of Jacksonport, Sevastopol and Egg Harbor. It is an impounded drainage lake that receives water from direct precipitation, groundwater, runoff, and stream flow from Logan Creek that drains Lost Lake (a 91 acre lake in the headwaters) (Figure 1). Logan Creek is a Class I trout stream and classified as an Outstanding Resource Water (ORW) (WI DNR 1990). Clark Lake drains to Lake Michigan after passing through a small dam. The south shore of Clark Lake is adjacent to Whitefish Dunes State Park. Clark Lake and the surrounding Door County is one of the prime tourist destinations in the Midwest.

Land use in the Clark Lake watershed and the lake shore basin is dominated by agriculture, particularly the dairy industry, and forested land; however, the trend in this area is a conversion from other land uses to residential developments. Much of the riparian land around Lost Lake and Logan Creek are intact forests/wetlands.

Lake Morphology and Geology

Clark Lake is triangular shaped impounded drainage lake encompassing 868 acres with a maximum depth of 22 feet and an average depth of 7 feet.

Clark Lake is on the western end of the Niagara Escarpment. The existing landscape is a result of the last glaciation when the Green Bay Lobe of the Laurentide ice sheet receded about 13,000 years ago. Clark Lake formed from a large bay that was cut off from Lake Michigan by beach and sand dune deposits of the Nipissing postglacial lake level.

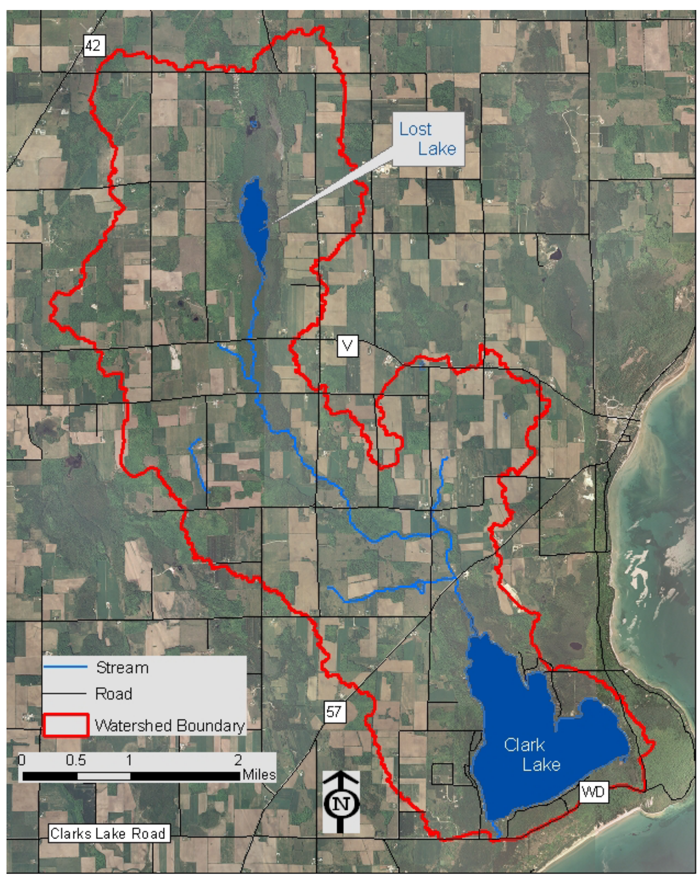

Figure 1. Surface Watershed for Clark Lake, Door County, WI

The geology of the Clark Lake watershed is dominated by Silurian Dolomite deposited nearly 440 to 415 million years ago. There is a very shallow layer of sandy loam till over the dolomite. This dolomite is a carbonate rock and similar to limestone it can be slowly dissolved by slightly acidic water and over time can form caves expanding existing fissures in the bedrock. As a result, runoff and contaminants on the land surface can easily enter groundwater through sink holes and once below ground can move very rapidly.

Soils within the watershed are very shallow to moderately deep, well drained and level to moderately steep (WI DNR 1990). The dissolution of dolomitic soils and rocks results in high concentrations of dissolved calcium and magnesium in the groundwater. Once this water discharges to streams or the lake, calcium can precipitate as calcium carbonate or marl. This marl is a conspicuous feature of the Clark Lake bottom. The lake bottom is composed mainly of marl and around the shores a thin deposit of marl covers the rocky and sandy bottom areas. At the north end of the lake the marl is up to 20 feet deep. Some organic muck has been deposited on top of the marl.

Cultural Development

Clark Lake lies within an area that was first sought after for its lumber. Agriculture followed, especially cherry growing, and then fishing and shipbuilding. Today agriculture is still the dominant use of land within the Clark Lake watershed (Figure 3). There is intense recreational residential development around much of Clark Lake.

UWSP CWSE STUDY GOALS AND OBJECTIVES

The recent history of declining bulrush beds and other aquatic vegetation coupled with less successful fishing and more boating traffic led many lake residents to push for a comprehensive study of the lake conducted by UW-Stevens Point Center for Watershed Science and Education (CWSE) in partnership with Clark Lake Association (CLA), Wisconsin Department of Natural Resources (DNR), Door County and The Ridges Conservancy.
The study was developed to:

1. Develop hydrologic and nutrient budgets and predictive models
    1.1. Estimate groundwater and surface water flow
    1.2. Evaluate general water quality conditions (Lost Lake, Logan Creek, and Clark Lake)
    1.3. Review private well data for general groundwater quality
2. Evaluate the impacts of boating on marl re-suspension
3. Survey water-related ecological sensitive areas adjacent to Clark Lake
4. Conduct rooted aquatic macrophyte survey
    4.1. Map current and historic bulrush beds
    4.2. Conduct density surveys of bulrush beds
5. Assess the changes in lake water levels over the years and relate to potential ecological impacts

In addition to this report, the results of this study are presented in a number of mini-reports. Titles include *2006 Summary and Comparisons of Clark Lake Aquatic Macrophyte Communities Survey*; *Clark Lake Watershed Sensitive Areas Survey*; *Waves, Wind, Watercraft, and Water Clarity, a study of Sediment Resuspension in Clark Lake; Delineation of Area Contributing Water to Clark Lake; Clark Lake Bulrush Mapping and Density; and 2005 Biological Water Quality Assessment of Logan Creek, Door Co., WI* (Szczytko and Dimick).

Methods

SAMPLING STRATEGY

Sampling was performed to establish the current water quality conditions, and to evaluate seasonal variation. Samples were collected throughout the year during the spring thaw, spring overturn, summer growing season, fall overturn, and winter. Additional sampling occurred within some seasons when conditions significantly changed to determine the effects of events such as high precipitation.

LAKE MEASUREMENTS

Mid-lake measurements were collected at the deepest point of the lake. The deep hole off of the west boat landing was identified and located using a global positioning system (GPS). Sampling involved the use of a *Hydrolab* Model 4600 data sonde to collect temperature, dissolved oxygen, conductivity, and pH data throughout the entire depth of the lake. Mid-lake measurements were collected between May and October 2005; and March and November 2006. Depending on the time of year, water samples from the lake were collected either through the use of an integrated bailer or an alpha bottle. The spring and fall overturn samples were analyzed for pH, conductivity, alkalinity, total hardness, calcium hardness, nitrate+nitrate-N (NO_2+NO_3-N), ammonium-N (NH_4-N), total Kjeldahl-N (TKN), total and reactive phosphorus (TP and DRP), chloride (Cl), sulfate, sodium, potassium, turbidity, and color. Samples were collected from the hypolimnion in September 2006. Samples were transferred to two 60 mL polypropylene bottles that contained sulfuric acid (H_2SO_4). One 60 mL bottle was unfiltered and the other was field filtered through a 0.45 micron membrane filter.

Other sample results that were used in this summary include those collected by CLA through the DNR self help monitoring program. These dissolved oxygen concentrations were measured using the azide modified Winkler method.

SAMPLE ANALYSIS

After collection, all water samples were stored and transported on ice to the state-certified Water and Environmental Analysis Lab (WEAL) at the University of Wisconsin-Stevens Point. The analyses run in the WEAL followed the methodology in Table 1. Nitrate+nitrite-N (NO_2+NO_3-N), ammonium-N (NH_4-N), total Kjeldahl nitrogen (TKN), total phosphorus (TP), dissolved reactive phosphorus (DRP), chloride (Cl) were all analyzed using Latchet methods. Total suspended solids, alkalinity, total hardness, calcium hardness, chloride, sulfur, sodium, potassium, turbidity and were all analyzed using standard methods (Standard Methods, 1995).

Table 1. Analytical methods and corresponding detection limits for water quality analyses run in the UWSP Water and Environmental Analysis Lab

ANALYSES	METHOD	METHOD DETECTION LIMIT
Alkalinity	Titrimetric 2320 B	4 mg/L
Chloride	Automated Ferricyanide 4500 C1 E	0.5 mg/L
Chlorophyll *a*	Spectrometric 10200 H	0.1 mg/L
Conductivity (in lab)	Conductivity Bridge 2510 B	1 umho
Hardness, Calcium	Titrimetric 3500 Ca D	4 mg/L
Hardness, Total	Titrimetric 2340 C	4 mg/L
Nitrogen, Ammonium	Automated Salicylate 4500-NH_3 G	0.01 mg/L
Nitrogen, Nitrate + Nitrite	Automated Cadmium Reduction 4500 NO_3 F	0.021 mg/L
Nitrogen, Total Kjeldahl	Block Digester; Auto Salicylate 4500-NH3 G	0.08 mg/L
Phosphorus, Soluble Reactive	Automated Colorimetric 4500 P F	0.003 mg/L
Phosphorus, Total	Block Digester, Automated 4500 P F	0.012 mg/L
Potassium	ICP 3120B	270 ug/L
Sodium	ICP 3120B	0.2 mg/L
Sulfur (SO4)	ICP 3120B	26 ug/L
Total Suspended Solids	Glass Fiber 103-105C 2540D	2 mg/L

TURBIDITY

To examine the different sources of sediment re-suspension and evaluate their relationship to lake water clarity, four different approaches were used. These methods and results can be found in the UWSP report titled *Wind, Waves, Watercraft and Water Clarity, a Study of Sediment Resuspension in Clark Lake.*

INFLOW/OUTFLOW MEASUREMENTS

Sampling Procedures

The inflow and outflow of Clark Lake were sampled and analyzed for NO_2 + NO_3-N, NH_4, TKN, TP, DRP, Cl, and total suspended solids (TSS). Water samples were collected by UWSP and CLA from each site using siphon samplers and/or the grab method. Water was transferred to three polypropylene bottles, one 500 mL unfiltered unpreserved sample, one 60 mL H_2SO_4 preserved unfiltered sample, and one 60 mL H_2SO_4 preserved filtered sample. Grab samples were collected by placing a capped bottle into the stream, facing the lid downstream, lowering it to the mid depth of the flowing water, and then opening the bottle.

Flow Measurement

Flow measurements were taken with a Marsh McBirney Model 2000 portable flow meter. Measurements were taken by measuring the width of the inflow or outflow's defined stream edges. Stream width was recorded and divided into 10 to 20 equal units. The Marsh McBirney current meter was used at each unit’s midpoint to determine the velocity and depth of the stream at each section. Velocity was measured at 60% of stream depth.

Along with discharge readings, a *Solinst Level Logger* pressure transducer was installed in the inflow and outflow stream to determine the stream’s stage. The loggers were set in an “event” mode, which triggered the logger to collect data when there was an increase in stage (increase in pressure). In event mode, the pressure transducer collected pressure and temperature readings at set intervals, which varied from 15 to 30 minutes. The unit was installed at locations and with procedures to minimize damage of equipment and ensure quality of recorded data. The two pressure transducers for Clark Lake were installed: in Logan creek and Whitefish Bay creek and barometric pressure was measured at a residence on the South Shore of Clark Lake.

AQUATIC MACROPHYTE SURVEY

Methodology employed in this survey is included in the UWSP report *2006 Summary and Comparisons of Clark Lake Aquatic Macrophyte Communities, and Clark Lake Aquatic Plant Survey*.

QUALITY CONTROL

When working in the field and the lab, quality control and quality assurance techniques were followed. All analysis not conducted in the field were completed at the state certified Water and Environmental Analysis Lab (WEAL) at UWSP.

METADATA

GIS land coverages, shapefiles, and historic orthophotography of Wisconsin were obtained from the Door County GIS division, and UWSP. Using ArcView 3.3 and ArcGIS 9.1 software spatial evaluation and map making was done with land use, hydrology, road coverage, city municipal structures, USGS maps, and others for data interpretation. Aerial photography was used for additional information and maps were digitized from historical aerial photos.

Results and Discussion

LAKE HYDROLOGY—WHERE THE WATER IS COMING FROM

Understanding how much water gets to and from a lake and where it comes from is important because it impacts the amount of time water stays in a lake, its water quality and chemistry and thus, the aquatic plants and biota in the lake. Clark Lake is receiving water from direct precipitation, surface runoff during rainstorms and snowmelt, and groundwater flow coupled with the inflow of Logan Creek. During snowmelt or a precipitation event, runoff moves across the surface of the landscape towards lower elevations such as wetlands, lakes and rivers, or internally drained areas (a depression on the landscape where water collects and infiltrates). The capacity of the land to hold water and filter particulates ultimately determines the water quality, habitat, and in-stream erosion. Simply put, the more the landscape can hold water during a storm, the slower the water is delivered to the streams and the greater the ability to filter the runoff.

As water moves across the land surface, soluble compounds and particulates are picked up and travel with the flow. Surface water runoff may be filtered when plants divert and slow water movement causing sediment and associated nutrients to be deposited or absorbed. The best plant filters (called buffers when near the riparian corridors) consist of a combination of trees, shrubs, deeply rooted perennial vegetation, and soils with an appropriate infiltration rate. Some of the land around Clark Lake still has a riparian buffer, especially in the northwest corner at the inlet of Logan Creek and the southeast portion of shoreline associated with Whitefish Dunes State Park. The majority of Clark Lake's shoreline is developed with large open corridors, groomed lawns, and rip-rap/concrete reinforced shorelines. These disturbed shorelines lead to an altered habitat and increased erosion and runoff. This can allow a potential for more nutrients and solids to enter the lake.

Precipitation feeds the lakes and their feeder streams directly and via surface runoff and groundwater inflow. Precipitation records for the last 30 years were acquired from the National Oceanic Atmospheric Association (NOAA); precipitation was shown to average approximately 30 inches per year in the nearby city of Sturgeon Bay. In Door County about one third of the precipitation that falls recharges the groundwater. The rest of the precipitation is either lost through vegetative evapo-transpiration or makes its way to wetlands, tributaries, or the lakes as surface runoff. A combination of interactions between topography, geology, soil, man-made structures, and land use practices influences the water chemistry and regional and local surface water flow.

GROUNDWATER WATERSHED

The groundwater watershed is the area of land where precipitation infiltrates to the groundwater and moves downgradient to a discharge area like a wetland, stream or lake (Figure 2). Like surface water, groundwater flows due to differences in elevation (head); moving from areas of higher elevation to areas of lower elevation. The groundwater watershed for Clark Lake is complex owing to the karst topography and difficulty in defining groundwater flow directions. Details of the assessment of the Clark Lake can be found in the UWSP document titled *Delineation of Area Contributing to Clark Lake's Water - Door County, WI*.

Clark Lake's ground watershed is 22.2 square miles (14,200 acres) with cropland covering approximately 41% of its watershed (Figure 3). The remaining land area includes forest (32%), open water (7%), open lands/agriculture (8%), residential (5%), tree plantations (5%), farm buildings (1%) and commercial/industrial, outdoor recreation and beaches all (<1%) respectively.

Clark Lake Contributing Area

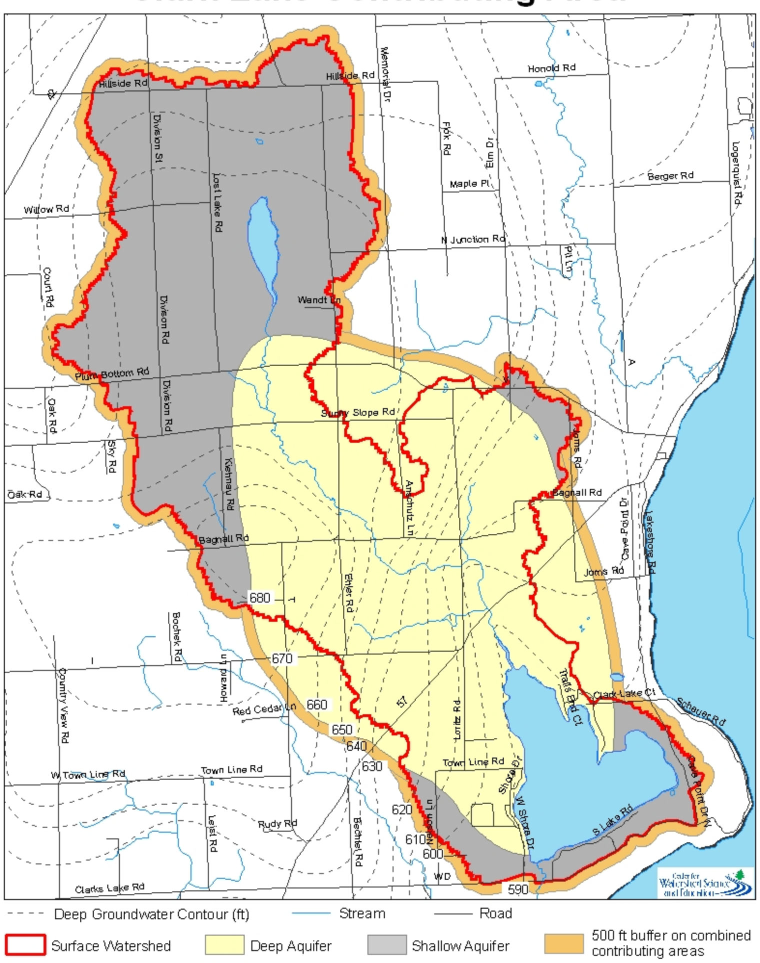

Figure 2. Ground watershed consisting of shallow and deep aquifers for Clark Lake.

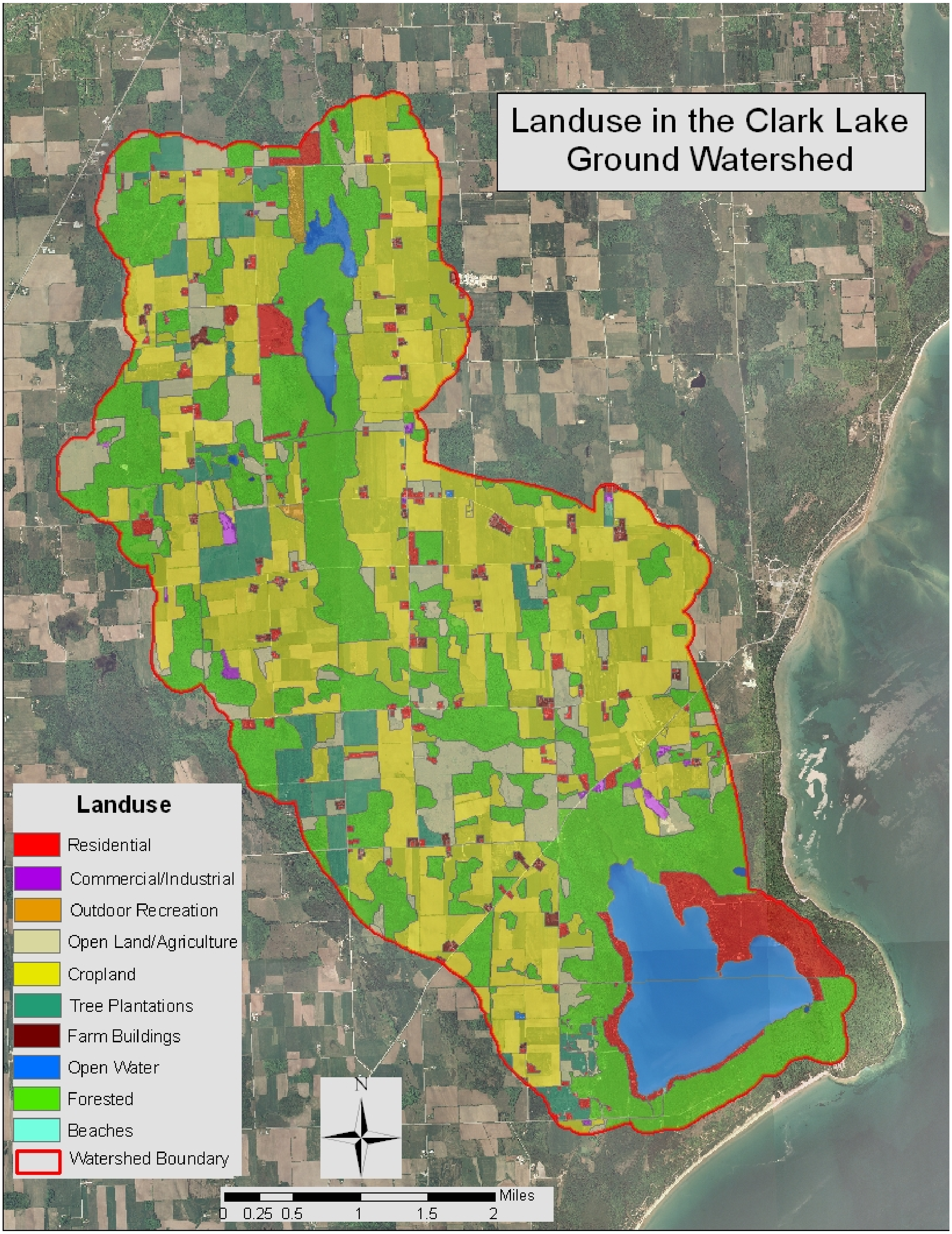

Figure 3. Landuse within the groundwater watershed, Clark Lake, Door County, WI.

SURFACE WATERSHED

A surface watershed is the land area where runoff from precipitation can drain to a water body. This is an important source of water to surface waters. In Wisconsin, approximately 1/3 of the precipitation that falls on the surface watershed ultimately enters the lake. Surface watersheds with large amounts of steeply sloped land, stream inflows to the lake, and a large percent of impervious surface (buildings, roads, compacted soil) deliver additional surface runoff by directing water to the streams or lake. The surface watershed for Clark Lake was determined using a watershed delineation tool (SWAT) in GIS software ArcView 3.3 and digital elevation model (DEM). The delineation was then verified by using a USGS topographic map of the region and visually ground proofed for areas of uncertainty. Currently the surface watershed does not include a large amount of impervious surface. The most densely developed area is directly around Clark Lake.

Clark Lake's surface watershed is 17.5 square miles (11,192 acres) with cropland covering approximately 39% of its watershed. The remaining land includes forest (31%), open water (9%), open lands/agriculture (8%), residential (6%), tree plantations (5%), farm buildings (1%) and the commercial/industrial, outdoor recreation and beaches which all encompass relatively small areas (<1%) (Figure 4).

In addition to surface water runoff, two streams/channels deliver or remove surface water to/from Clark Lake. They include the inflowing channel of Logan Creek entering on the north side of the lake. The average width of this channel is 8 feet and its length is 5.4 miles with a gradient of 17.7 ft/ mile. During the study the flow in Logan Creek varied seasonally with higher flows in the spring. The average discharge into Clark Lake was approximately 3 ft^3/sec.

The flow out of Clark Lake is through a channel of Whitefish Bay Creek that drains to Lake Michigan. It exits the lake on its south shore. This creek is 1.1 miles long with an average width of 28 feet and during the study it had an average discharge from Clark Lake of approximately 4 ft^3/sec.

SURFACE WATER QUALITY

This study characterized water quality in the lake, at inflow and outflow channels, and summarized those measurements through estimated water (hydrologic) and nutrient budgets. The results are presented first for the lake and conclude with the streams.

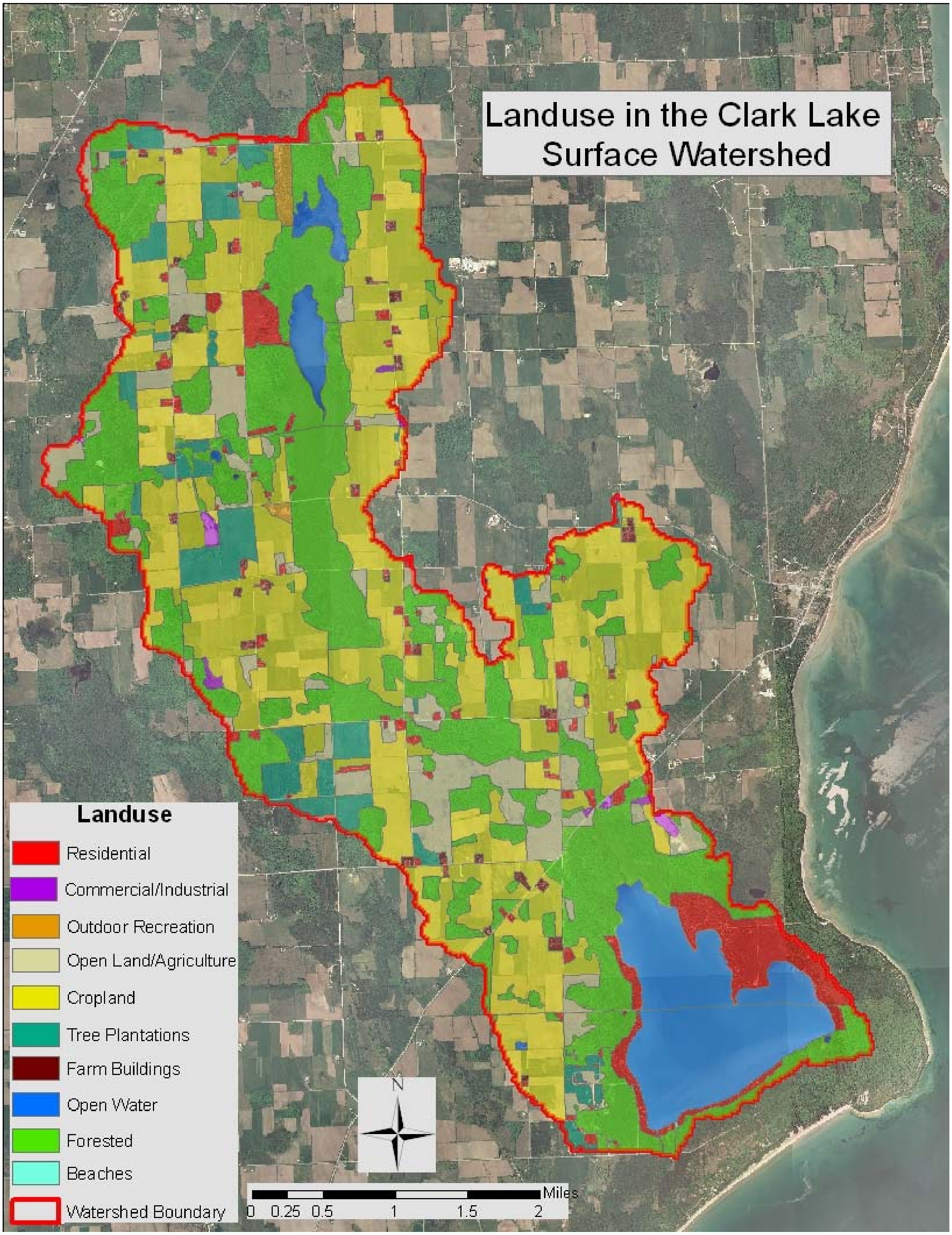

Figure 4. Landuse within the Surface Watershed, Clark Lake, Door County, WI.

MID LAKE MEASUREMENTS

Dissolved Oxygen and Temperature

Dissolved oxygen is the amount of oxygen in water and is crucial in aquatic ecosystems since many aquatic organisms depend on it for survival. Dissolved oxygen enters lake water by diffusion from the air and photosynthetic activity from plants. Greater wind and wave interaction causes greater diffusion of oxygen into the water and increases the rate at which oxygen is transferred.

A series of interactions between biological material, land use, and near shore land management can lead to reduced dissolved oxygen concentrations. Decaying material in the lake reduces oxygen as decomposers consume material using oxygen to drive their respiration. Nutrients moving into a lake will increase the oxygen consumption by decomposers because nutrient addition results in increased plant and algal growth. When plant and algae die, more oxygen is used by decomposers because of increased food sources. Nutrients come from fertilizers and surface runoff carrying eroding nutrient rich sediment to the lakes during runoff events as well as from groundwater entering the lakes.

Thermal stratification and mixing progressions occur in many of Wisconsin's lakes. In Clark Lake, a number of factors prevent stratification of the water. During the study temperature profiles showed that Clark Lake remained mixed throughout the year (Figure 5 and Figure 6). This mixing prevents definitive water layers from forming. As a result, concentrations generally vary little from top to bottom in the lake. Dissolved oxygen concentrations in Clark Lake did not vary significantly throughout the year (Figure 7 and Figure 8).

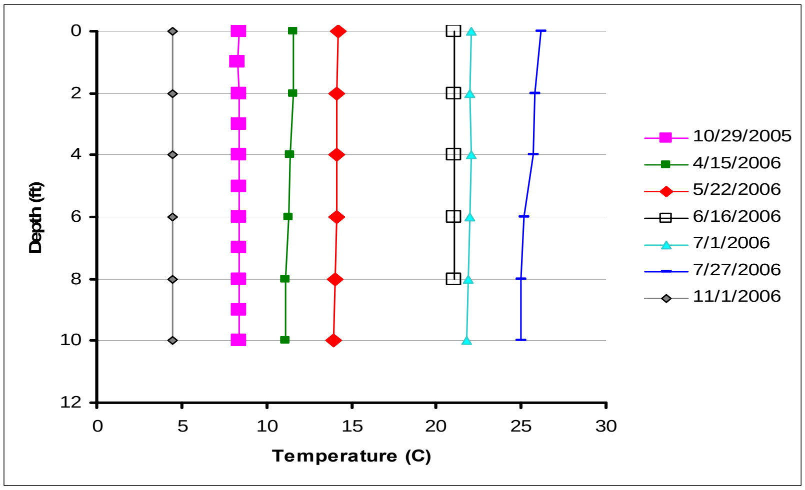

Figure 5. Temperature profiles in Clark Lake, East Bay location, (CWSE data).

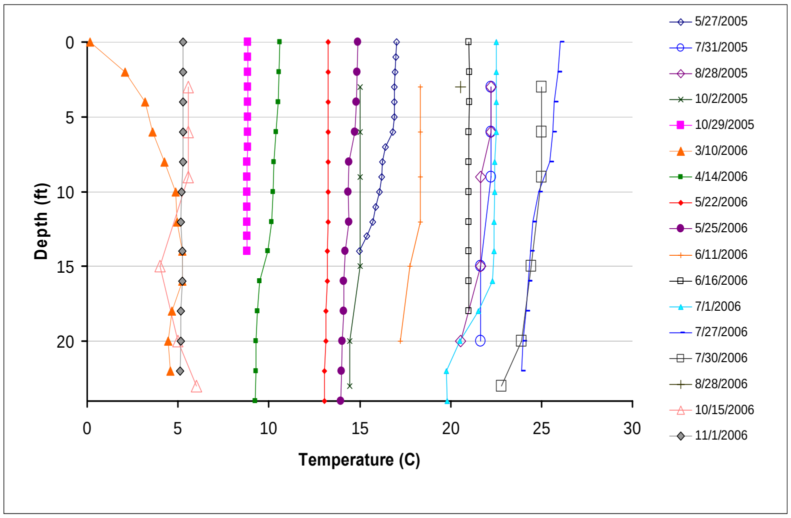

Figure 6. Temperature profiles in Clark Lake, Deep Hole location (CWSE and WDNR Self Help Data).

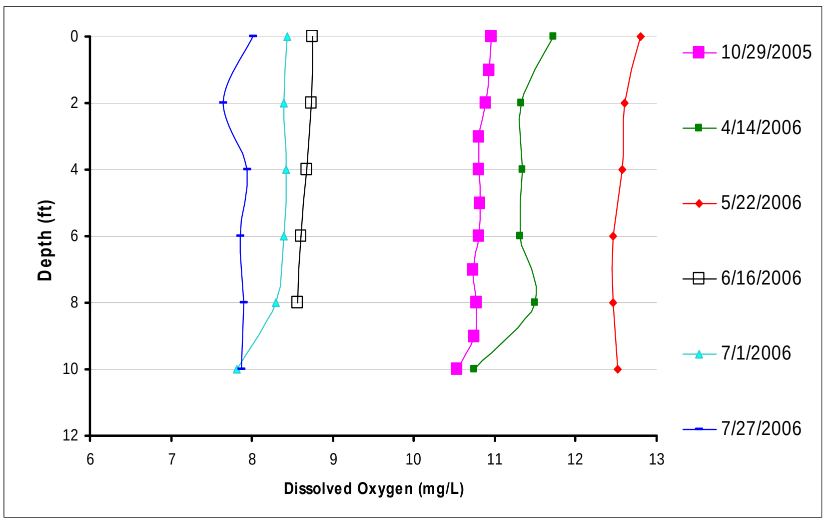

Figure 7. Dissolved oxygen profiles in Clark Lake, East Bay Location, (CWSE).

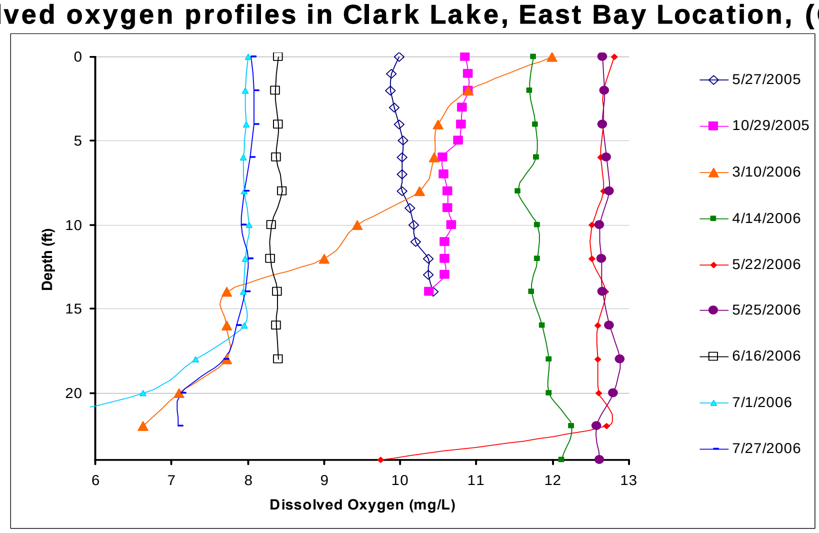

Figure 8. Dissolved oxygen profiles in Clark Lake, Deep Hole location, (CWSE and WDNR Self Help Data).

pH, Alkalinity, Hardness and Specific Conductance

pH describes the lake water acid concentrations on a scale ranging between 1 and 14 with lower values indicating acidic conditions and higher pH values indicating basic conditions. Lakes with a high pH provide buffering against acidic conditions. Higher pH values are created when limestone or dolomite (carbonate minerals) are found in the watershed geology. Groundwater dissolves these rocks and once in the lake, neutralizes the acid from rainfall. The value of pH can change throughout the day, year, and depth because of chemical interaction with photosynthesizing biota, which effectively lower the pH by releasing carbon dioxide during respiration and use carbon dioxide during photosynthesis.

In Wisconsin lakes, the range of pH is ideally between 6.8 (neutral) to 9 (basic) and water in Clark Lake is within this range throughout the water column (Figure 9 and Figure 10). All water samples were collected during the day; therefore, pH increases due to aquatic plant photosynthesis can be observed in the summer months.

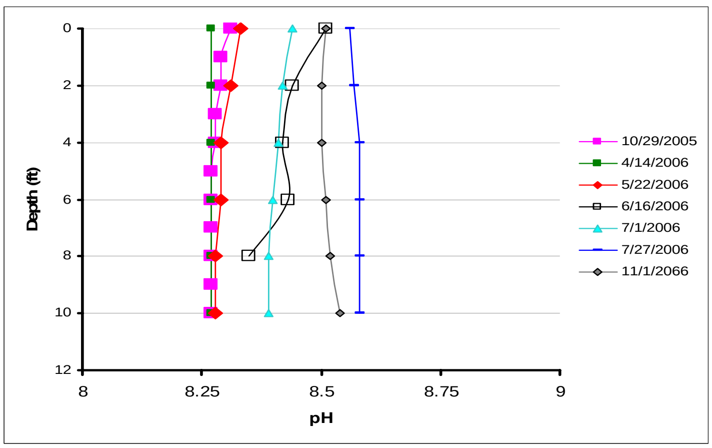

Figure 9. Profiles of pH in Clark Lake, East Bay location, (CWSE).

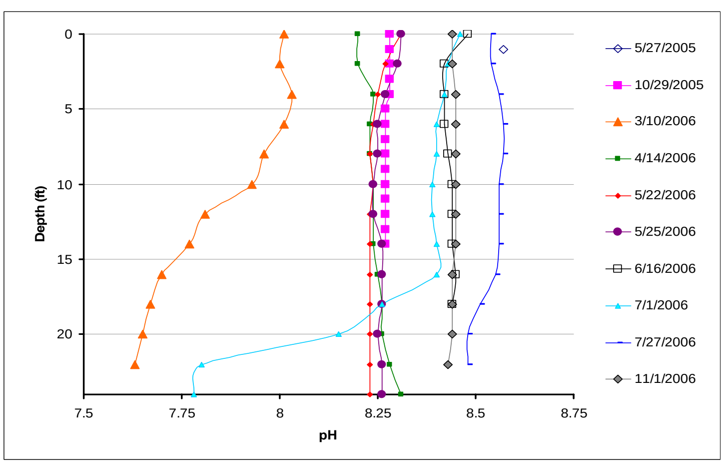

Figure 10. Profiles of pH in Clark Lake, Deep Hole location, (CWSE).

Alkalinity and hardness can drive the biological life within an aquatic system because of the need for calcium in the development of bones, shells, and exoskeletons. A lake's hardness and alkalinity are affected by the type of minerals in the soil and watershed bedrock and by how much the lake water comes in contact with these minerals (Shaw et al., 2000). Lakes with geology in the surrounding watershed that contain limestone minerals such as calcite and dolomite have water with higher hardness and alkalinity (Shaw et al. 2000). The alkalinity provides acid buffering and the hardness provides calcium (Ca^{2+}) and magnesium (Mg^{2+}). Lakes with high concentrations of calcium and magnesium are called hard water lakes. Hard water lakes tend to be more productive overall and produce more fish and aquatic plants than soft water lakes (Shaw et al. 2000). Some hard water lakes like Clark Lake produce a substance called marl, which can be a benefit to an ecosystem because it can hold nutrients such as phosphorus out of the internal cycling system of the lake (Wetzel 1972). Marl is a visible on the bottom of Clark Lake.

As anticipated, due to the dolomite in the Clark Lake watershed, high alkalinity and hardness concentrations are found in the lake water. Alkalinity ranged from 184 to 204 mg/L and total hardness ranged from 132 to 234 mg/L. Approximately half the total hardness was calcium hardness (83 to 124 mg/L). High concentrations of the hardness ions calcium and magnesium, categorize Clark Lake as a hard to very hard water lake (Table 2). The high alkalinity concentration categorizes Clark Lake as "nonsensitive" to acid rain.

Table 2. Descriptive levels of hardness found in Wisconsin lakes. The hardness range for Clark Lake is highlighted.

Level of Hardness	Total Hardness in mg/L as $CaCO_3$
Soft	0 – 60 mg/L
Moderately Hard	61 – 120 mg/L
Hard	121 – 180 mg/L
Very Hard	> 180 mg/L

Conductivity is a measure of water's ability to conduct an electric current which is a direct measure of dissolved minerals and salts in water. Many of these compounds can result naturally from dissolution of local minerals or unnaturally from wastewater from septic systems, agricultural/lawn/garden fertilizers, animal waste, and road salt. Values are commonly two times the water hardness unless the water is receiving high concentrations of contaminants introduced by humans (Shaw et al. 2000).

Clark Lake's conductivity ranged between 389 and 428 umhos during open water varying negligibly from top to bottom (Figure 11). The conductivity profile taken through the ice in March 2005 shows stratification with conductivity ranging from 42-568 umhos (Figure 12). This higher bottom conductivity is typical during winter as some ions in the sediment go into solution in the lower portion of the water column. Conductivity typically decreases throughout the summer especially in the upper layer of the lake and this trend occurred in Clark Lake. Decreasing conductivity over the summer may be due to marl formation and/or rain which can dilute concentrations.

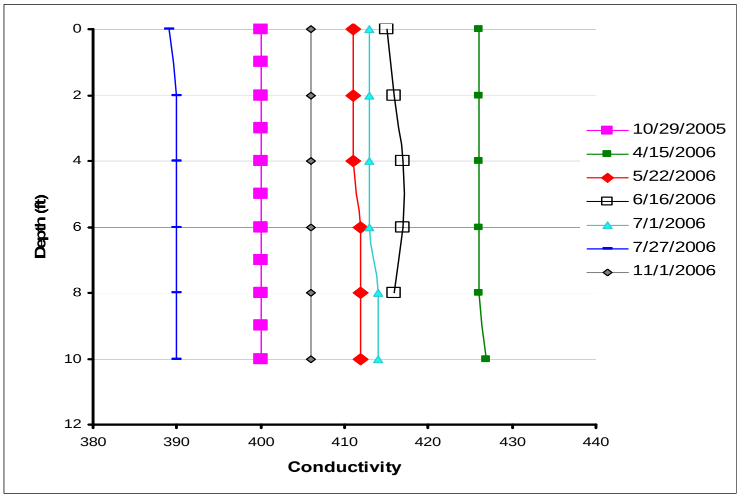

Figure 11. Conductivity profiles in Clark Lake, East Bay location, (CWSE).

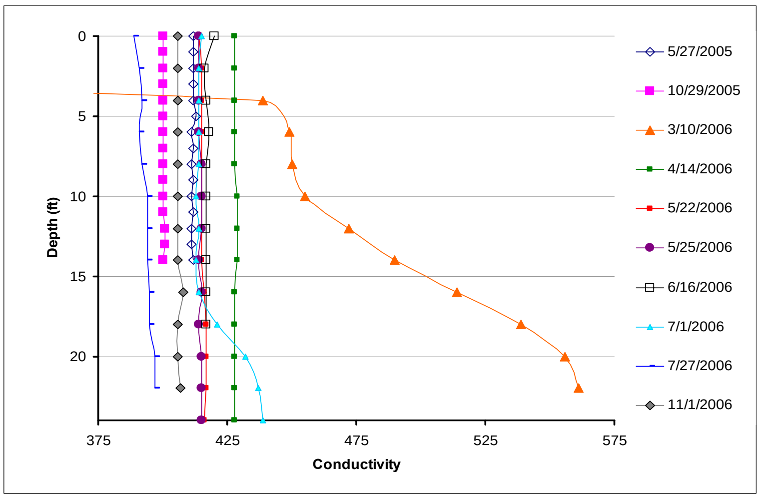

Figure 12. Conductivity profiles in Clark Lake, Deep Hole location, (CWSE).

Chloride, Potassium, Sodium, and Sulfate

Chloride, sodium, and potassium are not commonly found in Wisconsin rocks and soils and are usually not harmful because they are not toxic to aquatic biota at lower concentrations. Because of their naturally low concentrations, high concentrations of chloride, sodium, and potassium usually indicate human inputs to water. These elements are non-reactive in nature, and as a result, can be readily leached through the soil and into the groundwater from animal and human wastes, potash fertilizer, and road salt. Potassium is also found in human and animal waste with other sources including potash fertilizers and organic debris such as leaves etc. (Shaw et al. 2000).

Chloride concentrations in Clark Lake were very consistent, ranging from 9 to 10.5 mg/L. According to Shaw et al. 2000, chloride concentrations in this region of the state typically range between 3 and 10 mg/L. The measured concentrations are similar to those expected for the area and if they are slightly elevated they are likely from the use of road salts and fertilizers used on the urban roadways, lawns, and rural farms and fields located in watersheds. Potassium concentrations in Clark Lake ranged from 2.3 to 2.5 mg/L and sodium concentrations ranged from 3.3 to 4.3 mg/L. These concentrations are quite low.

Sulfate naturally enters into Wisconsin lakes through geological solution in groundwater and from acid rain deposition caused by the burning of sulfur containing products such as coal. Sulfate concentrations in Clark Lake ranged from 14.1 to 16.7 mg/L. These concentrations are within the range of 10 to 20 mg/L typical in this region of the state (Shaw et al. 2000).

Water Clarity

Water clarity is a measure of how deep sunlight penetrates into the water (measured by an instrument called a Secchi disc). This depth is important in a lake because it defines how much of the lake is habitable by aquatic plants; they can only grow in areas of the lake where light penetrates to the bottom. Water clarity is an indication of the amount of materials suspended in the water and materials dissolved in the water (color). Water clarity is affected by algae, dissolved minerals, organic acids, and suspended solids (turbidity). Typically water clarity varies throughout the year as changes occur with available nutrients, temperature, algae and aquatic plant growth.

During the study monthly averages were slightly less than historic averages, but were still within the historic ranges with water clarity measurements ranging from 3 to 15 ft (Figure 13 and Figure 14). Recent water clarity measurements (2000-2006) are similar to historic depths except for the months of May and June which have higher averages and maximums (Figure 13). The recent water clarity maximum measurements all came in 2006 except for August and September. In Clark Lake day to day variation can occur. Seasonal water clarity was greatest during early spring and late fall. Water clarity in Clark Lake from June through August has historically been approximately 4 feet (Figure 13) with the exception of the deepest recorded Secchi measurements; 15 feet in May and 12 feet in June of 2006. The low concentrations of chlorophyll *a* (a measure of algal abundance) suggest that marl and suspended solids have a greater affect on water clarity than algae in Clark Lake. Wind, runoff, recreational boat traffic, fish, and season all affect how much marl is suspended in the water column. Because of its light flocculent characteristics, the marl has a tendency to be suspended in the water column and remain suspended for a period of time while reducing water clarity. Turbidity in Clark Lake ranged from 2 to 6.5 NTU, with the lowest value measured in March. Color measures were always low, ranging from 5.9 to 15 CU.

A good indicator of the amount of algae affecting water clarity in the water column is chlorophyll *a*. Chlorophyll *a* concentrations are frequently inversely correlated with Secchi depth (the higher the chlorophyll *a* concentrations, the lower the Secchi depth). During the study Clark Lake chlorophyll *a* concentrations ranged from 1.9 to 6.6 mg/L. As the growing season progressed the chlorophyll *a* concentrations in Clark Lake generally decreased throughout the growing season; this was accompanied by relatively low phosphorus concentrations and is likely due to increases in marl production which prevents phosphorus from being available for use by algae.

The recent introduction of zebra mussels may also have an impact on water clarity due to their significant filtering capacity. One zebra mussel can filter about a liter of water per day (WI DNR 1995). Nearly all particulate matter, including plankton, is filtered from the water with uneaten plankton and particulate matter bound with mucous and deposited on the lake bottom (WI DNR 1995).

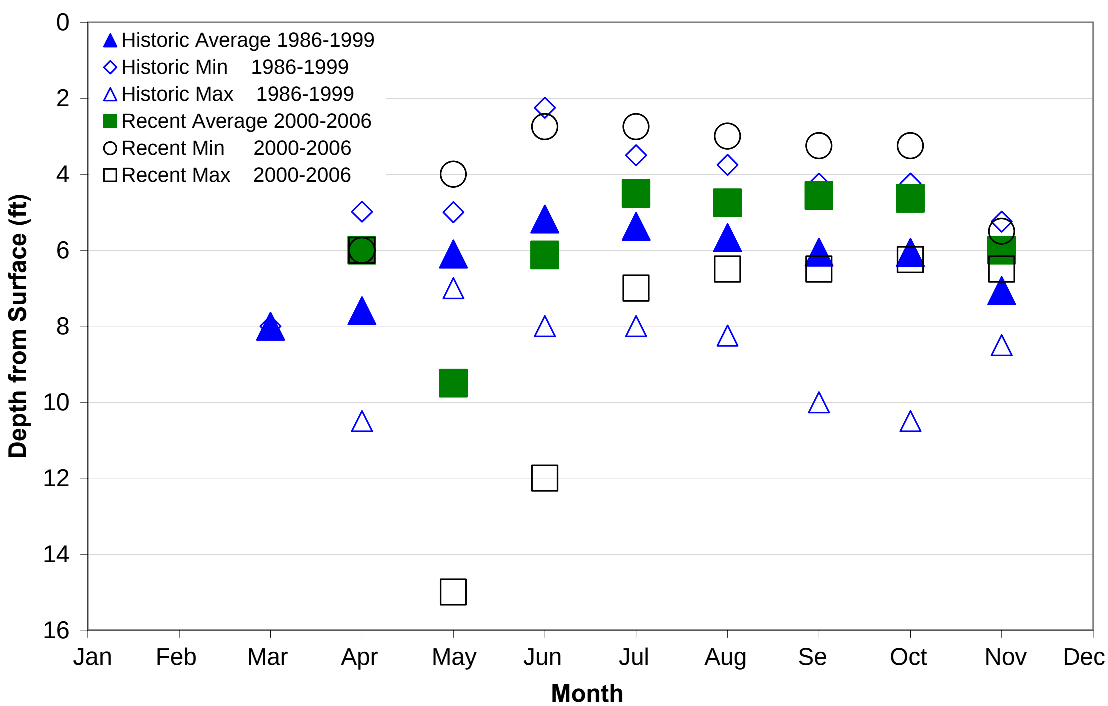

Figure 13. Average, minimum, and maximum water clarity measures in Clark Lake. Combined data includes UWSP, WI DNR Self-Help, and EPA STORET databases.

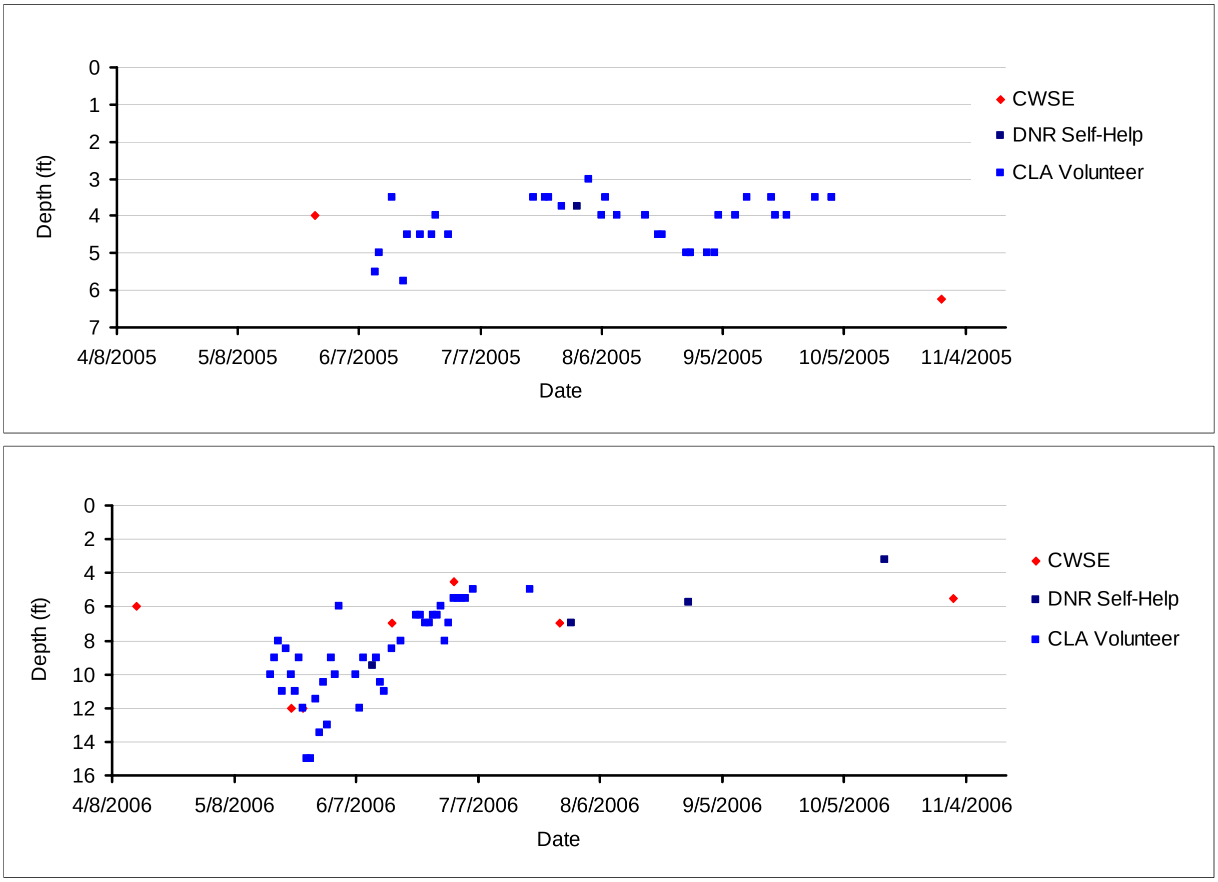

Figure 14. Water clarity measurements from the Clark Lake deep hole, 2005-2006.

Nutrients

Nitrogen is second only to phosphorus as a key nutrient that influences aquatic plant and algal growth in lakes. In lakes that are limited by nitrogen the ratio of total nitrogen to total phosphorus is 10:1. (For every 10 nitrogen molecules there is 1 phosphorus molecule.) If limitation varies from year to year there is a ratio between 10:1 and 15:1. When lakes are limited by phosphorus, ratios are above 15:1 (Wetzel 2002). Throughout the study phosphorus was the limiting element in Clark Lake with ratios ranging from 99:1 to 282:1. Phosphorus is expected to be the limiting nutrient in hard water lakes because of the marl production which forms around phosphorus making it unavailable for use by algae and aquatic plants.

In Wisconsin, small amounts of nitrogen occur naturally in soil minerals, but it is a major component of all plant and animal tissue, and therefore organic matter. It is found in rainfall and can be the primary source of nitrogen in some seepage lakes. Nitrogen can exist in both soluble and particulate forms and can travel in groundwater and surface water. Sources of nitrogen are often directly related to local land uses including septic systems, sewage treatment plants, lawn and garden fertilizers, and agricultural sources.

Nitrogen enters and exits lakes in a variety of forms. The most common include ammonium (NH_4^+), nitrate (NO_3^-), nitrite NO_2^-, and organic nitrogen. These forms combined yield total nitrogen. Aquatic plants and algae can use all inorganic forms of nitrogen (NH_4^+, NO_2^-, and NO_3^-); if these inorganic forms of nitrogen exceed 0.3 mg/L in spring, there is sufficient nitrogen to support summer algae blooms (Shaw et al., 2000).

Concentrations of nitrogen in Clark Lake are high relative to the concentrations of phosphorus (Table 3). The lack of phosphorus likely limits the plant growth that might otherwise result from these concentrations.

Table 3. Concentrations of nitrogen (mg/L) in Clark Lake (Deep Hole) throughout the year.

Date	NH4	NO2+NO3-N	Organic N	Total N
5/27/2005	0.02	1.1	0.57	1.7
10/29/2005	0.1	0.2	0.59	0.9
3/10/2006	0.13	0.8	0.46	1.4
4/14/2006	0.07	1.1	0.45	1.6
11/1/2006	0.14	0.2	1.08	1.4

Phosphorus is the primary element that leads to the development of nuisance algae (Wetzel 2002). Phosphorus is present naturally on the lake shore and in the watershed, found in the soil and plants. It transfers to the lake from the erosion of soil, animal waste, septic systems, fertilizers, inland recycling, and atmospheric deposition. In a study on urban lakes by the United States Geological Survey's Waschbusch, Selbig, and Bannerman, it was determined that streets and lawns were contributing 80% of the dissolved phosphorus to the urban lakes, with lawns contributing more than streets (1995).

High concentrations of phosphorus can be transported to lakes in surface runoff. Phosphorus is reactive and adheres to soil particles. If those particles are disturbed or if water containing phosphorus from decaying vegetation and fertilizer is conveyed directly to the lake, phosphorus is transferred from land to the water. Soil has a large capacity to hold phosphorus; however, where there are significant sources of phosphorus (i.e. barnyards, septic drainfields, over application of fertilizer) the soil holding capacity can be exceeded allowing excess phosphorus to leach to the groundwater. Once in a lake, a portion of the phosphorus becomes part of the aquatic system in the form of plant and animal tissue or sediments. The phosphorus continues to cycle within the system, and is very difficult to remove once it enters.

In this study, two forms of phosphorus were measured: soluble reactive phosphorus (SRP) and total phosphorus (TP). SRP is dissolved phosphorus in the water column that is readily available for plants and algae to utilize. It is usually present in low concentrations, and re-circulates quickly (Wetzel 2002). TP is a measure of the dissolved phosphorus plus organic and inorganic particulate phosphorus suspended in the water. Examples of organic phosphorus would be decaying plant or animal matter or phosphorus that is bound to soil particles.

TP is used as a measure of overall lake phosphorus because its concentrations are more stable than SRP. Clark Lake is classified as an excellent to very good water quality lake using TP as an indicator (Figure 15). Phosphorus availability can vary when a lake is stratified since oxygen concentrations and pH can cause reducing conditions in the bottom layer (*hypolimnion*) of the lake. Reducing conditions result in the release of soluble phosphorus from sediments and decaying plants and animal material. During spring and fall overturn, phosphorus-laden water mixes with the rest of the lake water, making it available to algae and aquatic plants. Phosphorus can form insoluble precipitate with calcium (marl), iron, and aluminum under appropriate conditions helping to reduce phosphorus concentrations and overall algal growth (Shaw et al. 2000).

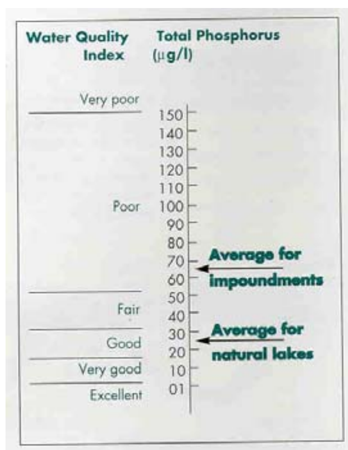

Figure 15. Index scale of water quality rankings associated with total phosphorus concentrations.

Over the course of this study, Clark Lake is rarely stratified; therefore, little emphasis was placed on determining the difference in the total phosphorus (TP) concentrations throughout the water column throughout the year. Typically in Clark Lake, TP concentrations are lower in the summer as a result of increased marl formation. Possibly this pattern is absent because of increased inputs of anthropocentric phosphorus input. Fall overturn concentrations of 9 µg/L were observed while in winter when the lake exhibited slight stratification, the concentration was 5 µg/L (Table 4). The November 2006 TP data may a result of P associated with particulates sampled during the turbid conditions on that date. Recent concentrations found within this study are consistent with the last 20 years of data (Figure 16).

Table 4. Concentrations of soluble reactive phosphorus and total phosphorus in mid lake samples collected from Clark Lake, Door County, WI.

Sample Date	Site	SRP (µg/L)	TP (µg/L)
5/27/2005	Clark Lake Deep Hole	2	6
10/29/2005	Clark Lake Deep Hole	7	9
3/10/2006	Clark Lake Deep Hole	10	5
4/14/2006	Clark Lake Deep Hole	12	9
5/18/2006	Clark Lake Deep Hole	3	8
11/1/2006	Clark Lake Deep Hole	4	89
10/29/2005	Clark Lake E10' Hole	3	9
4/14/2006	Clark Lake E10' Hole	6	9

Although phosphorus concentrations are low, extensive phosphorus inputs to other lakes have exceeded the capacity for marl to buffer the effects of phosphorus. Exceeding marl production capacities can result in significant algal and aquatic plant growth. Therefore, continuing to keep phosphorus applications to a minimum is desired in order to prevent the possibility of excessive algal and aquatic plant growth.

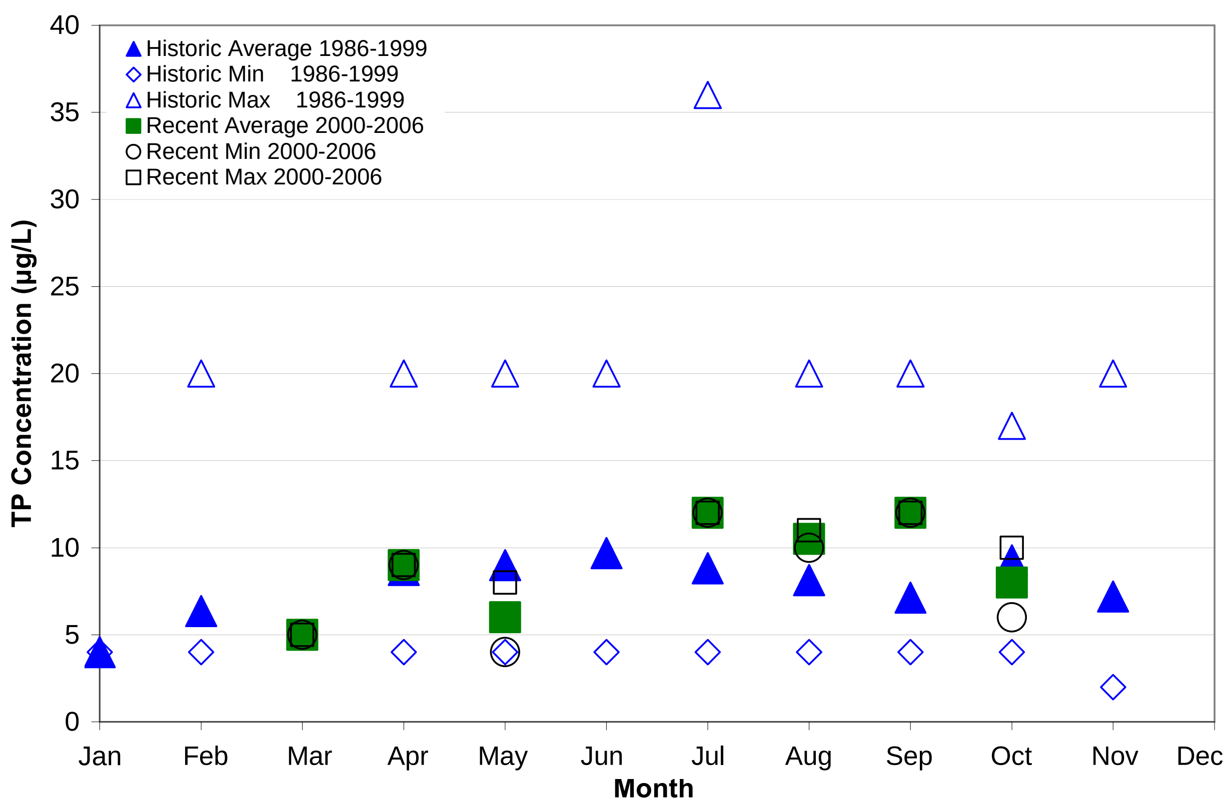

Figure 16. Historic and Recent Monthly Phosphorus Concentrations in Clark Lake.

INFLOW/OUTFLOW WATER QUALITY

The relatively thin soils and fractured rock geology of the Clark Lake watershed suggest that much of the inflow to the lake system will likely come through groundwater, but surface runoff can also be important, particularly with land use change that leads to more impervious surfaces and directing stormwater runoff into drainageways. The path that the water takes is important to water quality and water quantity; land use practices can alter these flowpaths. In developed settings, the amount of water and speed at which the water reaches the lake via surface runoff can be increased from reduced amounts of tree, shrub, and tall vegetation, which increase the amount of precipitation that reaches the ground. In undeveloped, forested settings, leaves and stems intercept some of the precipitation traveling to the ground. Some precipitation may be used by the vegetation, evaporate from the vegetation, or simply be slowed by the vegetation decreasing the rate at which water is hitting the ground as water slowly drips off leaves long after a storm has ended. The amount of impervious surface also effects water movement. Impervious surfaces (roofs, streets, sidewalks, and compacted soil) do not allow water to soak into the ground and results in more runoff. Water on impervious surfaces moves swiftly and will not be filtered as it would be when traveling through vegetation. Swiftly moving water carries particles and nutrients from the land surface and deposits them into the lake system.

In this study, Clark Lake's inflow (Logan Creek) and outflow (Whitefish Bay Creek) were measured during baseflow and event flow periods. Baseflow is the water flowing in a stream when only groundwater is contributing to it. Event flow is the flow that occurs during storm events or snowmelt. In addition, synoptic surveys of Logan Creek were conducted at eight road crossings including Plumbottom, Sunny Slope Rd, Cty Hwy T, Bagnall, Loritz, Highway 57, and Cty Hwy WD. Discharge was measured three times in April, May, and June 2006 and water samples were collected and discharge was measured in May 2005. Nutrient loading was estimated using the baseflow chemical concentrations and measured water volume.

TOTAL SUSPENDED SOLIDS

Total suspended solids (TSS) are a measure of the particles suspended in water that can be trapped by a filter. TSS enters the lakes through streams or rainwater. TSS concentrations in streams naturally fluctuate. Rain causes increases in TSS by washing deposited material from the watershed into streams. Also, during the growing season the adjacent wetlands grow algae and plants that can be released to the streams/lakes. Finally, sediments that have settled at the stream/lake bottom can be re-suspended with agitation created by wind or motorboats in shallow water or during lake mixing in spring and fall. This is especially true in Clark Lake with the layer of marl found throughout much of the lake.

In Clark Lake's tributaries the primary sources of TSS may include marl, soil erosion, pet/animal waste, trash, leaves, grass clippings, etc. TSS in Logan Creek was quite low, ranging from 1 to 26 mg/L with an average of 5 mg/L. At the outflow of Clark Lake TSS ranged from 1 to 37 mg/L with an average of 7.0 mg/L. TSS can also be formed in the lake as algae, plant and animal tissue and waste, microscopic animals, or by re-suspension of bottom sediments. As discussed earlier, cultural disturbances can increase the amounts of particulates to lakes.

NUTRIENTS

Nitrogen is an important biological element. It is second only to phosphorus as a key nutrient that influences aquatic plant and algal growth in streams and lakes. In Wisconsin, small amounts of nitrogen occur naturally in soil minerals, but are a major component of all plant and animal tissue, and therefore organic matter. It is often found in rainfall with precipitation as the primary nitrogen source in some seepage and drainage lakes. It also travels in groundwater and surface runoff; therefore, nitrogen enters the system both as soluble and particulate forms. Sources of nitrogen are often directly related to local land uses including septic systems, lawn and garden fertilizers, and agricultural sources.

Total Nitrogen (TN) in Logan Creek ranged from 2.0 to 4.7 mg/L, averaging 3.5 mg/L. In the outflow of Clark Lake TN ranged from 0.7 to 1.9 mg/L, averaging 1.2 mg/L. Most of the nitrogen was in the nitrate form with nitrate concentrations greatest during baseflow. This suggests that it is entering Logan Creek via groundwater inflow. Nitrate concentration at the inflow ranged from 1.2 to 4.4 mg/L, with an average of 3 mg/L. These are similar to the average concentrations in the private wells in the area (Appendix F). Nitrate concentrations were lower in the Whitefish Dunes Creek samples. Ammonium and organic nitrogen concentrations in Logan Creek and Whitefish Dunes Creek were low for both sites.

Phosphorus is the primary element that leads to the development of nuisance algae (Wetzel 2002). Phosphorus is present naturally throughout the watershed in the soil and plants. It is transferred to the stream and lake by the erosion of soil, animal waste, septic systems, fertilizers, and atmospheric deposition. Past research has shown how increased concentrations of soil phosphorus in agricultural land can increase the phosphorus concentration in runoff. Even phosphorus in urbanized areas can be transported to surface water.

High concentrations of phosphorus are primarily transported to streams in surface runoff. Phosphorus is reactive and adheres to soil particles. If those particles are disturbed or if water containing phosphorus from decaying vegetation and fertilizer is conveyed directly to the stream, phosphorus is transferred from land to the water. Soil has a large capacity to hold phosphorus; however, where there are significant sources of phosphorus (i.e. barnyards, septic drainfields, over application of fertilizer) the soil holding capacity can be exceeded allowing excess phosphorus to leach to the groundwater. Holding tank wastes have been pumped into Logan Creek in the past (WI DNR 1995). In Clark Lake, however, the dolomite geology may limit the movement of phosphorus through the groundwater. Total phosphorus in Logan Creek was relatively low, ranging from 4 to 32 µg/L, with an average of 15.1 µg/L. Similar concentrations were measured in the Whitefish Dunes Creek, ranging from 4 to 23 µg/L, with an average of 12.5 µg/L. The ratio of average N to average P in the stream was more than 200:1, a relatively large ratio and consistent with a system limited by phosphorus.

CHLORIDE

Chloride is not commonly found in Wisconsin rocks and soils and is usually not harmful because of its low concentrations and toxicity. Because of its naturally low concentrations, high concentrations of chloride usually indicate human inputs to water. Chloride is non-reactive in nature, and as a result, it is readily leached through the soil and into the groundwater from animal and human wastes, potash fertilizer, and road salt.

Chloride concentrations in Logan Creek ranged from 7.5 to 13.0 mg/L, with an average of 10.0 mg/L. Similar concentrations were measured in the Whitefish Dunes Creek, ranging from 8.5 to 12.0 mg/L, with an average of 10.4 mg/L. These concentrations are elevated and indicating some cultural sources of inputs.

GROUNDWATER

Groundwater flow in Door County is complex due to the karst topography. A map was developed to display a likely contributing area to groundwater in the Clark Lake watershed. The watershed is comprised of a deep and shallow aquifer, of which, the deep aquifer is inclusive of areas not included in the surface watershed (Figure 17). Details about this analysis can be found in the UWSP report *Delineation of Area Contributing to Clark Lake's Water.*

A minimal number of drinking water samples have been analyzed for water quality within the watershed. Results of these analyses show that nitrate concentrations were below the public drinking water standards: however, the risk of contamination in the karst topography is very high due to the rapid and frequently unfiltered water flow within the aquifer (Figure 18).

In August 2006, Amy Hefter and another CLAA volunteer reviewed Door County sanitary system records with the assistance of John Tischler, Door County Sanitarian to determine age and types of systems around Clark Lake. A total of 277 septic systems were evaluated. Sixty-six percent (183) of the septic systems are holding tanks (Table 5). The effluent contained in holding tanks should be pumped and delivered to wastewater treatment plants, resulting in no water quality impacts to the local surface and groundwater. Pumping records were not reviewed to evaluate the number of systems complying with these rules. Conventional septic systems comprised 15.8% of the systems around the lake that were built after 1967 and approximately 3% are mound systems. With the exception of holding tanks, septic systems are designed to treat pathogens and allow the water to recharge to the groundwater. Unless tertiary treatment is installed as part of the treatment, septic systems are not designed to remove nutrients, so even systems that are properly functioning can deliver nutrients to groundwater that eventually discharges to area streams and lakes. Generally the life of a well functioning septic system drainfield is approximately 20-25 years; after that pores in the soil plug up and result in drainfield failure. However in karst conditions drainfields may appear to be functioning because the effluent drains into cracks in the bedrock which virtually never plug. Once in the karst groundwater the nutrient rich effluent can readily move to nearby lakes and streams. Sixteen percent (44) of the systems around Clark Lake were constructed prior to 1967. These systems are likely failing and in addition, the design of these vintage systems would not meet current design standards.

Table 5. Septic System Data around Clark Lake.

Septic Prior to 1967		Post 1967 System Type		
Yes	No	Conventional	Holding	Mound/Other
44	232	44	183	9

Clark Lake Contributing Area

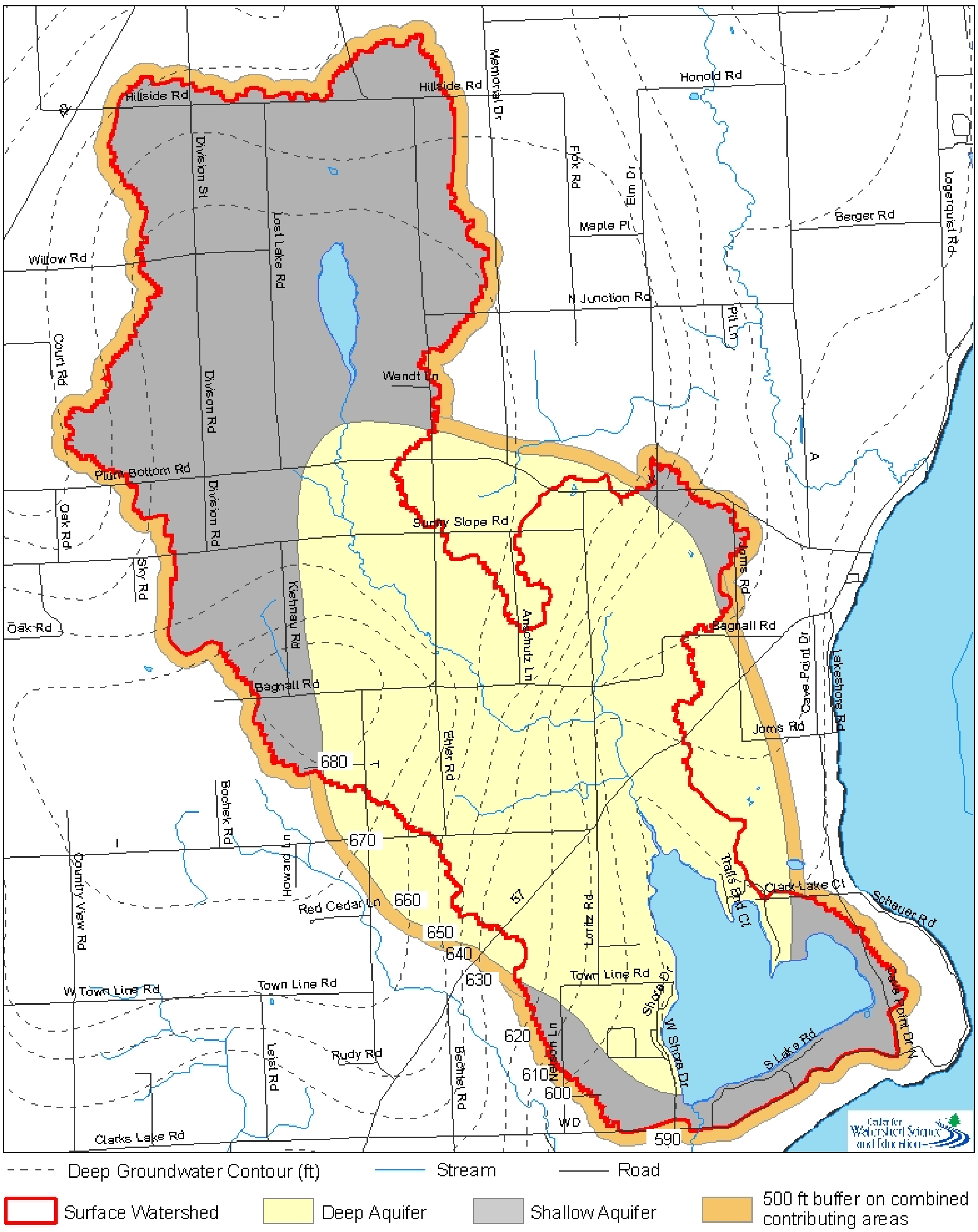

Figure 17. Areas contributing water to Lost Lake, Logan Creek and Clark Lake.

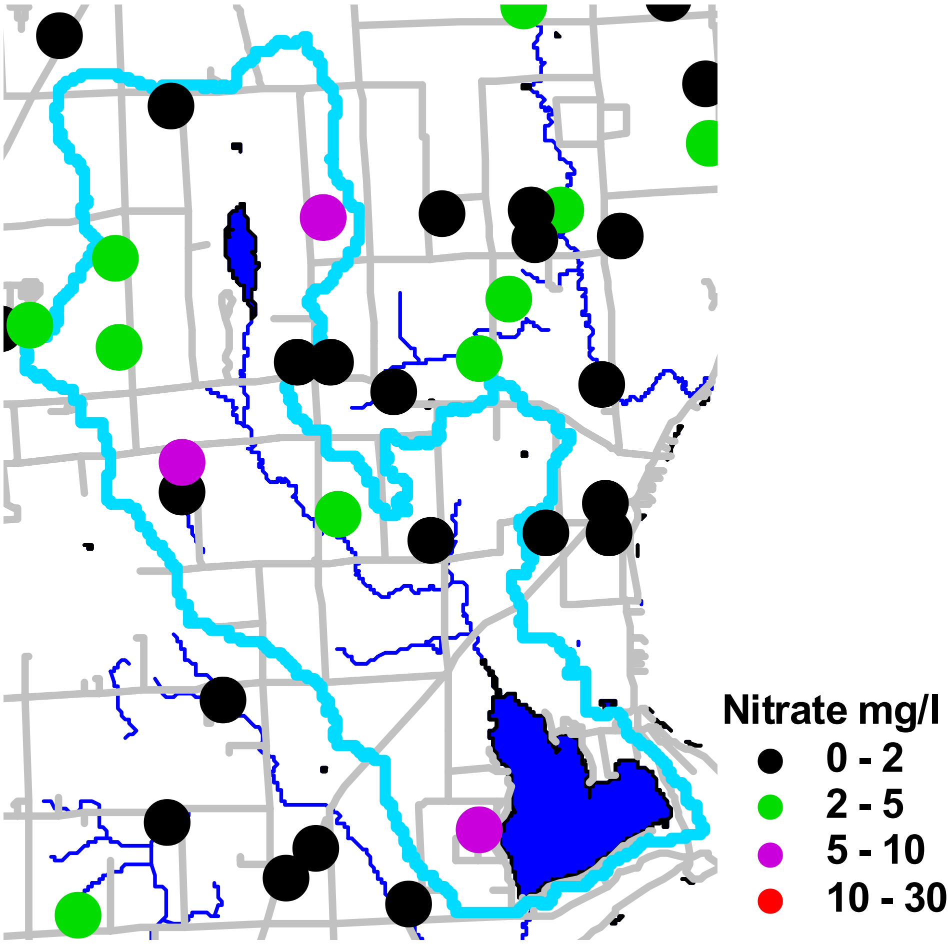

Figure 18. NO2+NO3-N concentrations (mg/L) in private well samples in the Clark Lake Watershed.

Water Budget

Continuous flow measurements were made at the inflow and outflow to the lake. Flow varied significantly throughout the year. Flow in Logan Creek was relatively high during the late winter and spring, and was much lower during the summer. Late summer baseflow in Logan Creek was as low as 1.5 cfs. In the winter, the average baseflow into the lake was 5.8 cfs. This variable flow is consistent with previous work in Door County showing a wide range groundwater levels that lead to changes in streamflow. The hydraulic residence time of Clark Lake is about 0.75 years or 270 days.

Another important source of water to Clark Lake is groundwater that discharges directly to the lake. Direct evidence of this water is the springs on the shore of the lake. During the winter months, measurement of flow out of the lake suggests approximately 5 cfs of water may be entering the lake from groundwater. Analysis was performed to investigate whether the groundwater contribution to the lake also changes throughout the year. During the summer months evaporation data were calculated using the Penman equation and precipitation data that was obtained from the Sturgeon Bay Experimental Station.

Evaporation was calculated using temperature, wind, and relative humidity data recorded at the Whitefish Dunes State Park office. These measurements suggest lower groundwater input to the lake late in summer. This range of contribution between summer and winter is consistent with the variations in water table elevations suggested by previous studies in Door County.

MODELING WITH WISCONSIN LAKE MODELING SUITE (WILMS)

Model Background

Eutrophication results when a water body receives excessive dissolved nutrients like phosphorus and nitrogen, naturally or as a result of human activity. This causes significant increases in algae and aquatic macrophyte (plants that grow in water) biomass, which may in turn result in low dissolved oxygen concentrations due to aerobic decomposition. The models applied to Clark Lake were part of the WiLMS (developed by the WDNR) which applies empirical eutrophication models to reservoirs and lakes. The WiLMS model uses an annual time step and predicts spring overturn, growing season mean and annual average total phosphorus concentration in lakes. It can be used as both a descriptive and predictive tool. By calibrating the model to observed data, one can than predict how changes in the watershed could impact water quality conditions in the lake/reservoir. The primary focus of this analysis was the relationship between phosphorus and potential effects of future increases in urbanization of the Clark Lake watershed. It should be noted that none of the eutrophication models used in WiLMS were designed to account for a highly dolomitic watershed.

Land use export values used in WiLMS were determined by calibrating the Logan Creek subwatershed to the CWSE measured in-stream phosphorus concentrations and the resulting annual load. Phosphorus loads were calculated by combining the stream concentration measurements with an estimate of annual runoff from the WiLMS database. As would be anticipated, the resulting phosphorus export rates are much lower than those provided as default values in WiLMS; phosphorus concentrations in the streams in the Clark Lake watershed are very low and consistent with chemical immobilization of phosphorus during passage through the calcareous soils and bedrock. This is consistent with the very high N:P ratios found in the stream samples.

The surface watersheds were used for both Logan Creek and the entire Clark Lake watershed in this modeling. Calibrated export values were 10% of the default values suggested in WiLMS. Export values were then used for the entire watershed to predict in-lake phosphorus concentrations.

Internal phosphorus loading is the amount of phosphorus that is re-released from sediment in a body of water. Because of the high calcium content of the Clark Lake sediments, phosphorus release from the sediment was considered insignificant.

Summary of Modeling Results

The results of this modeling exercise show why the concentrations of phosphorus are relatively low in Clark Lake (Table 6). The current conditions in Clark Lake suggest water pathways and chemical interactions in the lake that immobilize phosphorus. As the watershed changes, water pathways and chemical interactions can change. Future development could create a landscape with greater impervious areas which would result in more runoff flowing to wetlands, streams, and lakes and reduced groundwater recharge. As a result there would be less water storage as groundwater and the water would have less time to interact with soils and bedrock leading to potentially higher phosphorus inputs to Clark Lake. Changes to the hydrology of the land could also influence streamflow in Logan Creek. If baseflow contributions from the groundwater aquifer are reduced, Logan Creek would experience higher peak flows following storms and lower baseflow throughout the course of a year.

Table 6. Estimates of phosphorus concentrations in Clark Lake for 3 WiLMS models.

WiLMS Results	
Lake Phosphorus Model	Most Likely Total P (µg/L))
Nurnberg, 1984 Oxic	6
Dillon-Rigler-Kirchner	6
Vollenweider, 1982	9

BULRUSH

Large beds of hardstem bulrush (*Schoenoplectus acutus*) are absent or receding in Clark Lake in areas where the vegetation once dominated. This phenomenon is occurring in a number of Wisconsin lakes and is an environmental concern because of potential impacts to the fishery and shifts in the aquatic ecosystem. These beds of vegetation stabilize shorelines, prevent wave erosion and mixing of substrates, and are important food and habitat for fish, birds, insects, and other Clark Lake wildlife (Hoverson and Turyk 2006). Hardstem bulrush is commonly found in hard water lakes and reproduces both asexually via rhizomes and sexually via seeds. Seed reproduction by bulrush requires fluctuating water levels, typically low in the summer, to remain productive. A wetland ecologist for the U.S. Geological Survey, Douglas Wilcox, sums the sustainable life cycle of bulrush by saying that bulrushes do not last forever and they need to grow from seed occasionally (2006).

Stands of hardstem bulrush in Lost Lake were mapped in summer 2006 (Figure 19). Additionally, stands of hardstem bulrush in Clark Lake were mapped in September 2006 by J. Barrick and R. Crunkilton (Figure 20). Mapping revealed 76 separate bulrush beds in Clark Lake covering approximately 10.5 percent of the lake. Density measurements were taken on select beds to provide a quantitative measure of evaluating trends concerning the future health of bulrush. Bulrush densities ranged from an average of 1.4 to 13.4 emergent stems per 9 square foot quadrant within measured beds (Figure 21). Additional information can be found in the UWSP *Clark Lake Bulrush Mapping and Density* and *Clark Lake Watershed Sensitive Area* reports.

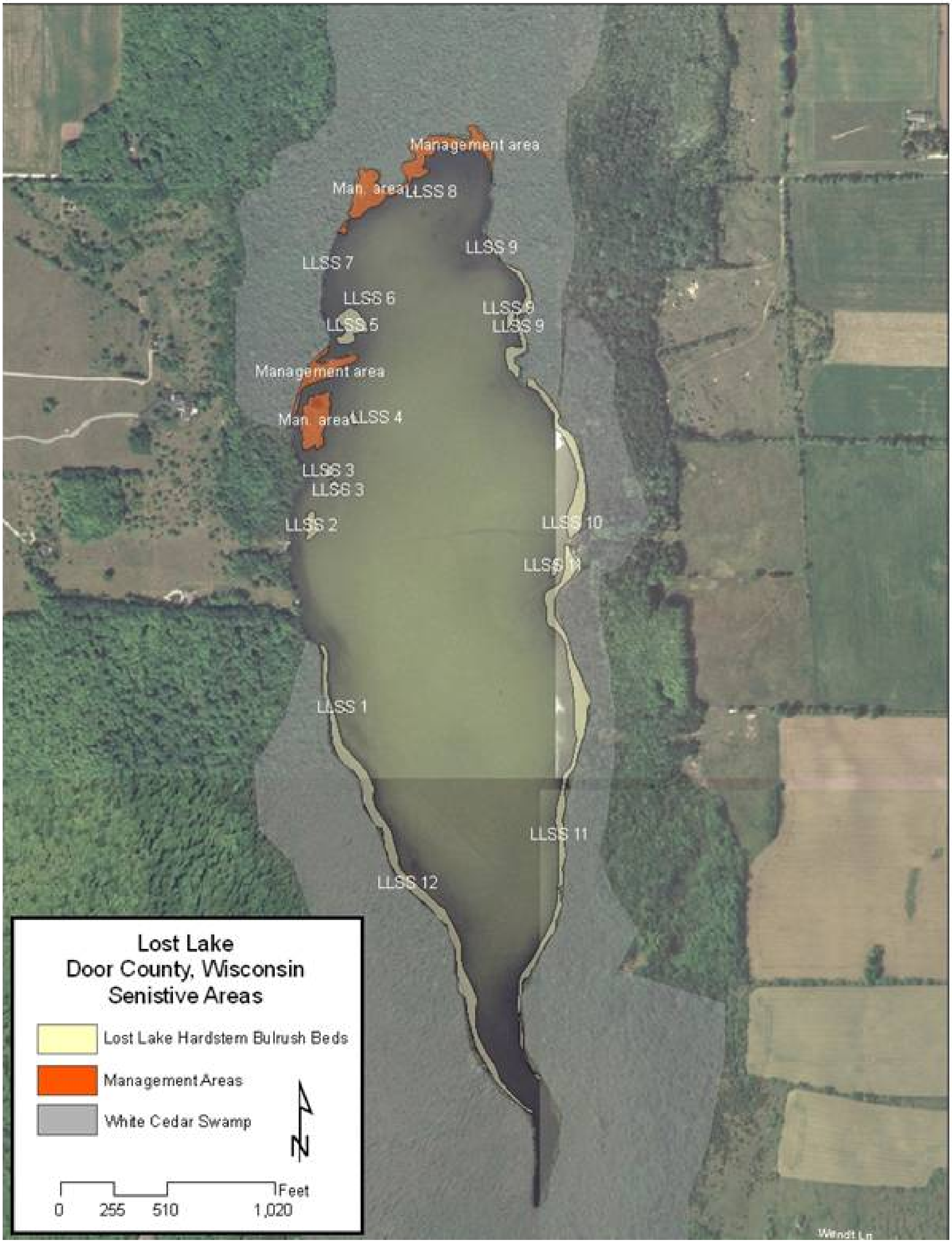

Figure 19. Hardstem bulrush beds in Lost Lake (2006).

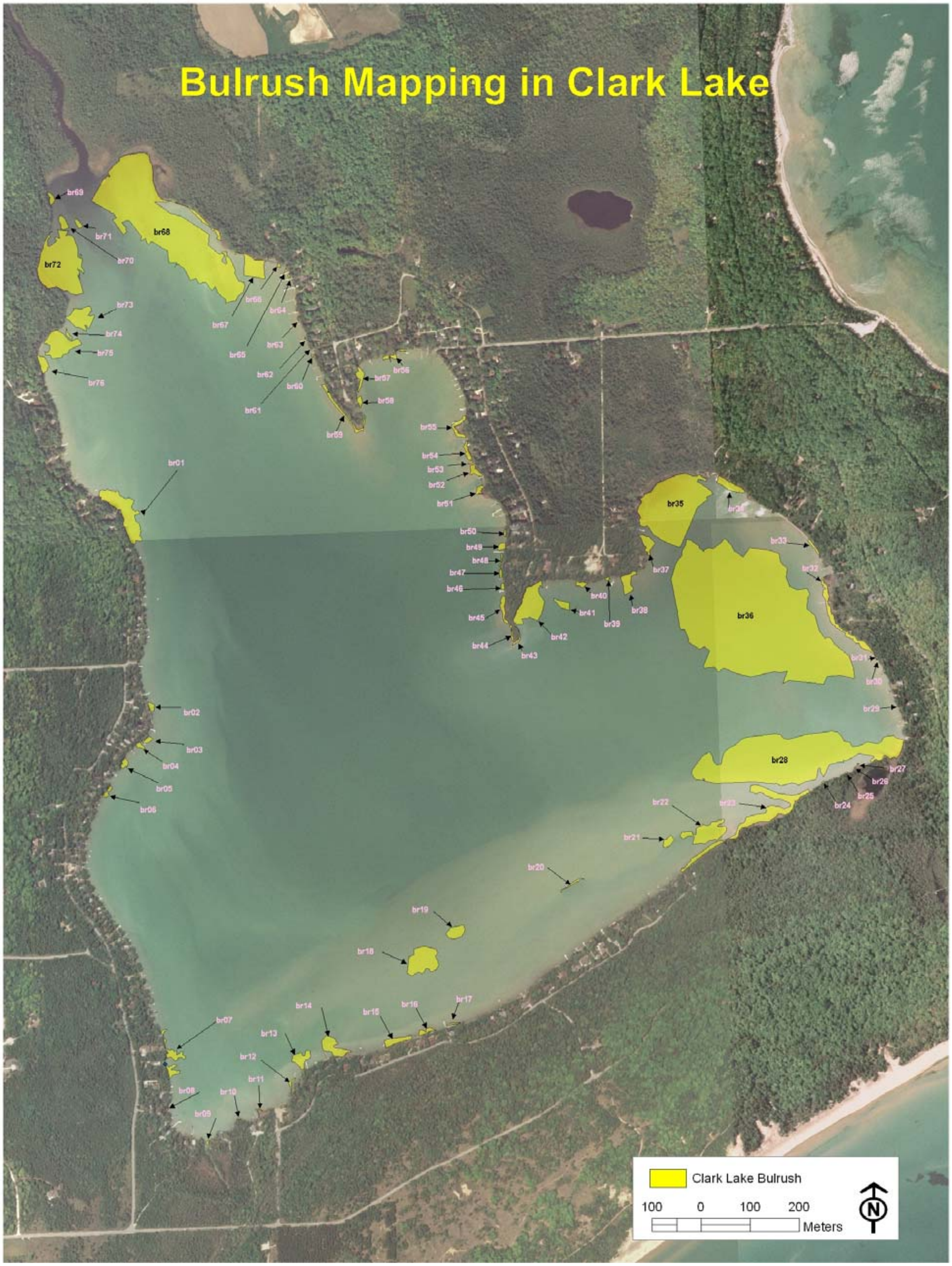

Figure 20. Hardstem bulrush beds in Clark Lake (2006).

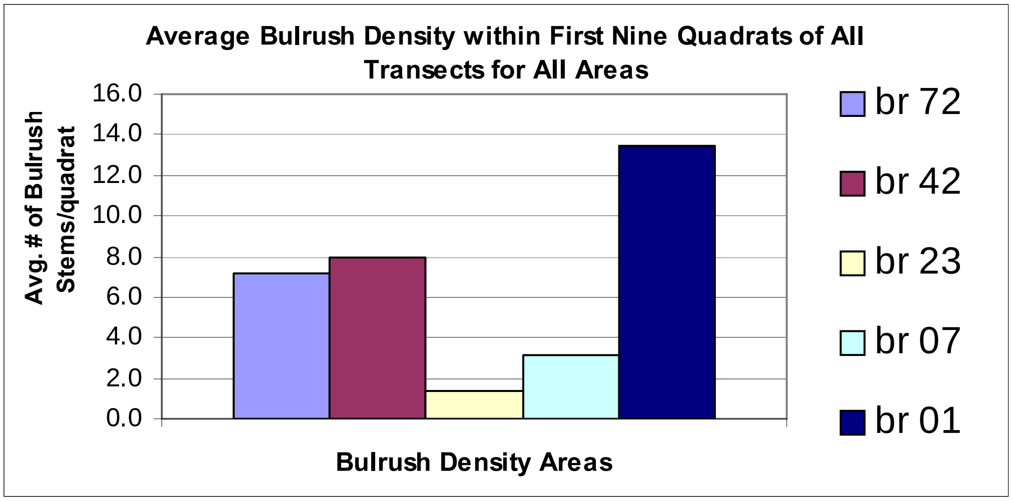

Figure 21. Density data summary for five bulrush beds measured.

BULRUSH LITERATURE REVIEW

Ecology and Phenology

Bulrush plays a very important role in the ecology of lake ecosystems. Dense emergent stands of bulrush provide living breakwaters, food, cover, and nesting and egg-laying substrates for fish and wildlife comprising an ecologically important resource (Kahl 1993). Emergent vegetation provides protective cover for certain organisms and creates microclimates that diversify the inshore zone and add complexity to the ecosystem (Engel 1990). This vegetation also helps build and modify lake sediment with the decomposition of leaves contributing to organic matter and inorganic nutrients needed for decomposition (Engel 1990). Young fish also seek shelter in macrophyte beds to avoid predation by other fish. Zooplankton also rely on aquatic vegetation and without it they are exposed to higher predation as young fish shift from preying on plant-dwelling invertebrates to eating the exposed zooplankton. Reduction in zooplankton may then lead to increased algal blooms (Engel 1990).

Hard-stemmed bulrush (*Schoenoplectus acutus*) is a perennial that grows from over wintering rhizomes—asexually and sexually by seeds. Typically individual stems are expected to live only one or two years (Wilcox 2007); however, rhizomes may exist indefinitely in suitable conditions (Smith 2007). Asexual reproduction can spread rapidly via rhizome clones given suitable conditions (Smith 1969). Seed production can be prolific, but requires very shallow water or exposed mud flats for germination and survival of seedlings (Kahl 1993; Kadlec 1962, Cooke et al. 1993). Wilcox continues by saying that the exposure of sediments to the air in early summer can elicit a very strong bulrush response from the seed bank (2006). High water levels in the UWPL during the growing season prevented most seed reproduction at shoreline and in-lake sites (Kahl 1993). Seeds can remain viable for decades because significant drops in water level natural occur only every 5 to 30 years (Van der Valk and Davis 1978). Furthermore, Harris and Marshall state that residual seed banks in the soil are often able to produce widespread stands of bulrush (1963).

A study by Kahl on the Upper Winnebago Pool Lakes (UWPL) found that rhizomes produced new shoots in mid to late April when water temperatures reached 10-13°C at the sediment surface (1993). Shoots grew rapidly, emerging from the water in early to mid-May as water temperatures increased to 20°C. Rhizomes store nonstructural carbohydrates over winter as energy stores which are quickly depleted in spring for rapid stem growth. A rhizome is highly dependent on aerenchyma for air supply and is likely the reason why bulrushes have a maximum water depth that they will inhabit (Wilcox 2006). Total nonstructural carbohydrates (TNC) typically reach a seasonal low in mid-June at the onset of flowering and it is at this time when Kahl says that severe damage to photosynthesizing stems could prove fatal to plants (1993). Kahl adds, "Moderate to severe damage to stems over several years in June and early July could reduce long-term survival, and thus reduce stand size and density, by reducing energy assimilation and slowly decreasing energy reserves in rhizomes. Other limiting factors such as high water levels, would further stress plants and diminish survival. During favorable conditions, especially years of low spring-summer water levels, re-colonization would proceed slowly because the plant relies on rhizome migration at these inundated sites" (1993).

Predation

Natural predation by insects and waterfowl can also affect bulrush populations within lakes. Smith states, there are stem-boring insects including two species of moths of the family *Noctuidae* which seem to be the most damaging (2006). Canadian geese are also known to adversely affect bulrush due to their herbivory on the plant.

Water Quality and Water Levels

Macrophyte communities improve water quality in many ways by: 1) Trapping nutrients, debris, and pollutants entering waterbodies, 2) Absorbing and breaking down some pollutants, 3) Reducing erosion by damping wave action and stabilizing shorelines and lake bottoms, 4) Removing nutrients otherwise available for algal blooms (Engel 1985). Additionally, increased vegetation and compaction of sediments during partial lake drawdowns improves water clarity and probably water quality (Riemer et al. 2001).

Lake levels historically fluctuate from year to year and more specifically within a single year. In the Midwest, climatic patterns produce a natural water level cycle in lakes typically consisting of spring highs and late summer, early fall lows (Figure 22). This hydrological phenomenon is a very simple cycle which has very complex and profound effects on a lake's vegetation community, water quality, and resulting ecology. Alteration or interruption of this natural process has resulted in significant losses of aquatic vegetation in some lakes; likely this has affected stands in Clark Lake. Historically Clark Lake water levels were managed with a 1.5 ft fluctuation over the course of the year with drawdown commencing by late fall and summer water levels attained by May 15 each year (Neustadter November 1981). Historical maximum allowable drawdown by the dam design was 2.79 ft; however, this did not occur with a low of 1.85 ft below the summer maximum occurring in January, 1981 (Neustadter November 1981). Historical lake levels on Clark Lake, dating back to 1937 shows up to a 1.5 ft water level fluctuation. The current lake level orders issued by the DNR allow for a 1.75 foot fluctuation, however according to P. Schumacher the "new" dam structure only allows for a 1 foot fluctuation, and in fact, over the last six years lake levels have not gone below 1 ft of the summer maximum. However, summer maximum levels have exceeded the allowable lake level orders, most noticeably on June 5, 2004 when lake levels were 0.6 ft above the summer maximum.

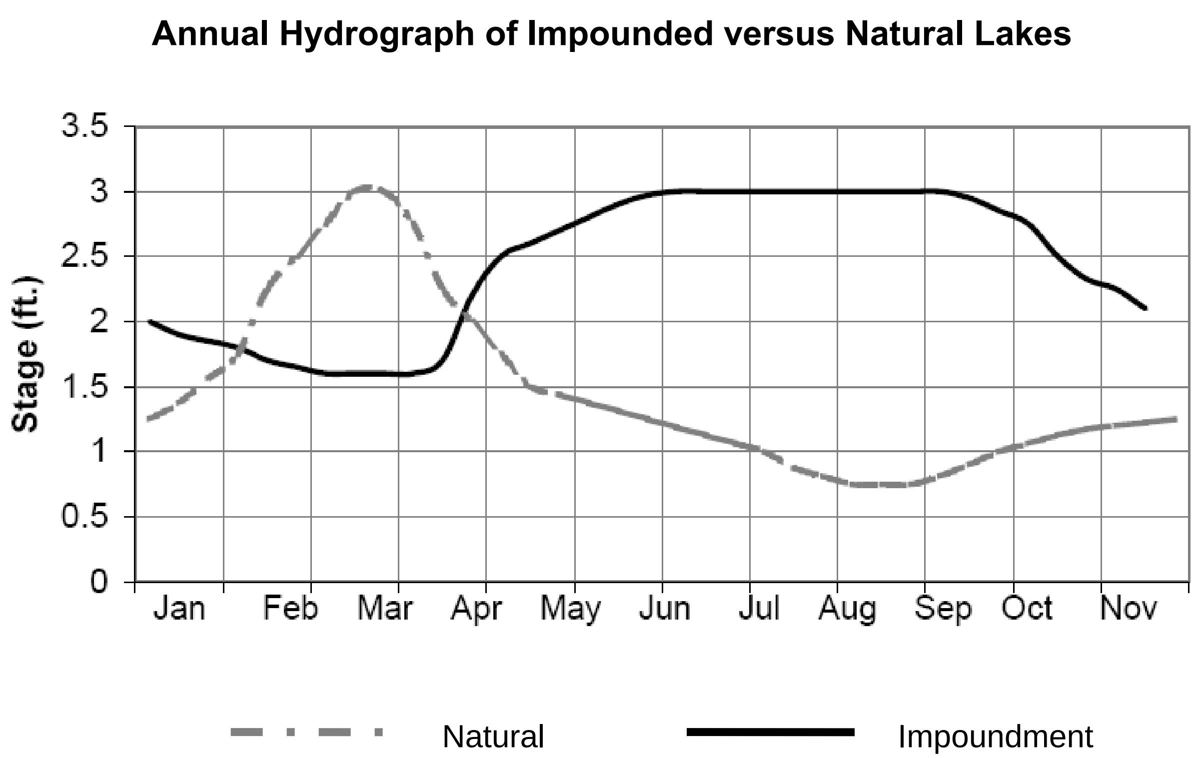

Figure 22. Example of Natural vs. Impoundment Water Levels.

In a study on the UWPL by Kahl states, "The primary factors limiting overall abundance of macrophytes during this study likely included high spring-summer water levels, abnormal timing and magnitude of water level fluctuations, and turbidity" (1993). Specific to Clark Lake's historic levels, Rasman states, "The overwinter drawdown on Clark Lake significantly limits the amount of vegetation in the areas that are exposed" (1981). With current conditions and only a 1 foot drop of elevation, these areas are further reduced. Neustadter goes on to say, "It is our position that the operation of the dam is having a significant impact on any apparent changes in the aquatic plant and animal communities on Clark Lake and that a change in the operation of dam should be made" (November 1981).

Another example includes Lake Erie, where increased water levels in marshes caused the die-off of several emergent plants including hard-stemmed bulrush (Beard 1973). Several studies have shown optimum water depths for hard-stem bulrush of 1.0 to 3.0 ft and a maximum water depth of 5.0 ft (Kahl 1993). Lentz and Dunson continue by saying that the ratio of final root to shoot mass (R:S) decreased with increasing water depth. Furthermore they suggest that at lower water levels more resources are allocated to below-ground structures, creating a larger reserve for asexual reproductive growth or the growth of new shoots the following spring (1998).

Effects of the current winter drawdown regime on Clark Lake could include propagules (offshoots) on exposed sediment flats perishing due to frost damage if ice cover is inadequate before drawdown begins, especially if warm weather in early spring breaks dormancy (Kahl 1993). Comparatively, an early summer drawdown with lower water levels, especially during the critical growth period from late April through June, would likely increase sediment temperatures and light availability which encourage earlier and faster growth. This might also allow plants to shunt more energy into vegetative reproduction and production of more overwinter propagules with larger energy stores (Kahl 1993).

Ecologically, water level manipulations resembling what would normally take place, have benefits as well. For example, a proposed late summer, early autumn drawdown on Rainy and Namakan lakes encouraged development of vegetation that improves spawning habitat for northern pike and yellow perch, cleanse the spawning shoals used by walleye, and provide better habitat for larval and juvenile fishes after hatching. In regulated systems, sustained high water prevents the cleaning; therefore, diminishing habitat quality. In the case of northern pike, delayed spring water level rise reduces access to critical spawning areas (Kitchell 1996). Furthermore, Lychwick states, "The winter drawdown on Clark Lake is causing significant concentrating of forage fish (perch) with the predator species (walleye), since during a typical winter a 20-40% reduction in surface area occurs" (1981).

Light Levels and Marl

Aquatic plants typically only inhabit the photic zone (light penetrating zone) of a lake because of their need for photosynthesis. This zone is largely determined by the clarity and color of lake water. Light levels generally limit the lakeward edge of the littoral zone and there is evidence that increased turbidity decreases maximum plant biomass (Robel 1961). Concerning turbidity, Steiner and Rasman reported that marl and periphyton covered most of the vegetation in a 1986 aquatic macrophyte survey. This situation could potentially have significant effects on the physiology of the plants. Furthermore, they stated that light absorption as well as exchange of nutrients may be affected (1986). Likewise, increased turbidity can decrease the maximum depth of plant growth (Spence 1967, Nichols 1992). Stevenson and Lee continue by saying that reducing light levels in lakes may result in lower dry weights of macrophytes (1978).

The highly flocculent marl sediments found in parts of Clark Lake are very easily re-suspended particles which potentially may limit the photic zone if they are continuously agitated. Another mechanism which marl may be affecting the bulrush population in Clark Lake is that of deposition.

Several studies have indicated that hard, compacted sediments, especially sand, comprise the optimum habitat for hard-stemmed bulrush (Kahl 1993). A recent macrophyte survey revealed that sand supports the majority of *Schoenplectus acutus* beds in Clark Lake (Hoverson and Turyk 2006). Similarly, Cooke, et al. states that consolidating flocculent sediments such as marl, using a drawdown is one method of improving habitat for aquatic plant restoration (2005).

Wave Action/Boat Activity

It is evident that boat traffic can be fairly heavy on Clark Lake with an increase in the size of boats and motors. Boat traffic, especially where it is heavier on the south end of the lake, may be impacting the bulrush population within Clark Lake. Rasman stated that the reduction in vegetation within Clark Lake was more pronounced on the south end of the lake and was very apparent between 1975 and 1980-81 (1981). Kahl continues by saying injuries to new shoots and rhizomes by wave action, boats, and undesirable fish may restrict the expansion of established bulrush stands or prevent their reestablishment in some locations (1993). Aquatic macrophyte growth decreased in near-shore regions during the 2006 macrophyte survey, in particular, *Schoenoplectus acutus* (Hoverson and Turyk 2006).

Wave action generated from wind can certainly have similar impacts as boating; however, this should be in a historical balance. It is the additional wave action created by boating which may be having an impact on the bulrush community. Wave action is known to severely erode unprotected shorelines, adjacent marshes, and shallow littoral sediments bulrush may occupy (Kahl 1993).

The bulrush plant itself once established seems to handle wave action fairly well. Wilcox says bulrushes can handle wave action because their walls are so thin (2006) and in some cases have been found primarily in areas exposed to severe wave action (Kahl 1993). An example of this occurred in the UWPL study when it was observed that solid-panel barriers placed in the lake to reduce wave action did not affect the abundance of round-stemmed bulrushes (Kahl 1993). At the same time, bulrushes are also quite fragile, if boats venture into bulrush, they can be damaged or killed (Wilcox 2006). Additionally, Asplund and Cook (1997) concluded that in Lake Ripley motorboats were reducing plant biomass by sediment scouring and direct cutting of plants, but not by generation of turbidity.

Reestablishment

The most effective tool for reestablishing bulrush in areas once present may be the revision of the water level management policy. The water levels should closely replicate natural fluctuations in lake levels and should include periodically simulating drought conditions. In the UWPL the most effective tool for increasing macrophytes was revision of the water level management plan to reduce spring and summer water levels. It was recommended that lower average spring-summer water levels be maintained with periodic partial drawdowns incorporated throughout 2-3 growing seasons to simulate drought conditions (Kahl 1993).

Bulrush can be planted as tubers or seeds. When planting, if possible, use native plant material/seeds from a locality near the restoration. These species and ecotypes will likely be the most successful for local conditions (Cooke et al. 2005). Complications in the UWPL reestablishment of bulrush included the following: 1) Damage to rhizomes and green shoots from harvest, storage and planting, 2) Deposition of plant material, especially filamentous algae, by waves on new shoots that submerged or severed stems, 3) Interference with elongating horizontal rhizomes by sediment-stabilizing materials, especially tires (Kahl 1993). Clark Lake may also have challenges with damage from geese. Geese are attracted to mowed lawns so the re-establishment of buffers around the shoreline would not only improve water quality and provide habitat for amphibians, reptiles, and wading birds, but would also reduce the amount of time that geese spend near bulrush stands.

Drawdown

ArcGIS 9.1 was used to evaluate potential areas of exposed sediments resulting from a lake level drawdown. A drawdown to the 1.5 foot contour would expose approximately 97 acres of the lake bottom while a drawdown to the 3 foot contour would expose approximately 193 acres of the 868 acre lake (Figure 23).

Figure 23. Approximate area within the 3 foot contour in Clark Lake.

Conclusions and Recommendations

- Hydrology in the watershed relies heavily on infiltration as a pathway of delivering groundwater to Clark Lake from the karst aquifer. Increased runoff and reduced infiltration may result in the expansion of dewatered sections of Logan Creek with decreased low flows and increased maximum flows that may potentially alter the stream morphology. Infiltration of precipitation throughout the watershed is essential in the prevention of degraded water quality and altered water quantity issues in the watershed. Increased impervious surfaces would reduce infiltration and increase runoff; use of water gardens and infiltration basins near developments should be implemented; however, drainage to known sinkholes and fractures on/near the land surface should be avoided.
- Phosphorus modeling of the Clark Lake watershed using WiLMS revealed that the limestone aquifer retains significant amounts of phosphorus from entering the lake.
- Measured parameters indicate that water quality in Clark Lake is good. Efforts should be made throughout the watershed to maintain this status. Water quality should be monitored in Lost Lake, Logan Creek, and Clark Lake for early detection of water degradation. Because of the karst geology, the use of chemicals and nutrients within the watershed should be minimized as the groundwater can quickly deliver solutions to Logan Creek and Clark Lake.
- Sixteen percent of the 277 septic systems around Clark Lake were constructed more than 30 years ago. These systems are likely failing and should be replaced.
- In Clark Lake turbidity due to the resuspension of marl is affected by waves resulting from wind and large motorized watercraft. Little can be done to reduce waves resulting from the wind, so much of the study focused on impacts that can be reduced. Large motorized boats can re-suspend sediment from areas in the lake that are less susceptible to wind resuspension. These deeper areas typically contain finer sediments that can remain suspended in the water for many hours. Once these finer sediments are in the water column they may then resettle in areas that are more likely to be disturbed by wind; consequently the marl is re-suspended many times before settling into areas that are more stable.
- Boats impact turbidity in varying degrees with larger boats and motors resulting in the re-suspension of more and finer sediment located in deeper areas of the lake. One hundred hp motors resuspend more sediment than a 30 hp motor. In trials with the same boat and motor combination more sediment is re-suspended in four feet of water than in a depth of six feet. A no-wake zone in depths less than four feet is

recommended in Clark Lake with start-up taking place in deeper water, especially for larger boats.

- Large beds of hardstem bulrush (Schoenoplectus acutus) are absent or receding in Clark Lake areas where the vegetation once dominated. This bulrush is important ecologically as well as aesthetically. Bulrush can help reduce turbidity and erosion of the shorelines. Preventative measures should be taken to keep naturally vegetated shoreline areas which will not only maintain high water quality but also deter geese from inhabiting mowed shoreline areas to potentially reduce herbivory of bulrush nutlets. Bulrush in Clark Lake can reproduce asexually through rhizomes; however, sustainable stands typically require water level fluctuations with lower summer water levels to promote development of young plants. Consequently, a revised water level management scheme is recommended for the lake to more closely resemble a natural hydrologic cycle. Under this scheme water levels would be about 1.5 feet lower from May to October and higher for the rest of the year.
- Physical damage of bulrush from boating is contributing to the decline of stands within the lake, especially in the southern portion of the lake. During mid summer physical damage is the most detrimental to the survival of the plant because this is the time when the least amount of energy is in the roots. This period of time coincides with the peak of boating activity and efforts should be made to deter boating activity from areas of bulrush.
- The Clark Lake bulrush community was mapped in September 2006 with density measurements taken on select beds. Methodology was established for volunteers to utilize to track changes in bulrush bed density. Density measurements should be conducted on an annual basis. Mapping all beds in the lake using GPS should take place at 5 year intervals.
- Manual reestablishment efforts should also be considered using plantings of native bulrush nutlets and tubers from Lost Lake and dense stands within Clark Lake. Site selection is preferable where there is hard-packed sandy substrate and where boats and other controllable disturbances can be restricted. Explore the use of snow fencing placed on the lake-ward side of the plantings to reduce wave action during this fragile early growth stage.
- Twenty-two sites throughout the watershed were identified as special areas that provide unique and/or critical ecological habitat. Sensitive areas were areas that had native vegetation, minimal or no disturbance, offered critical and unique habitat for the fish and wildlife, and/or were important to the water quality/quantity of Clark Lake. These areas included abundant and diverse aquatic macrophyte beds, undisturbed

shorelines with adjacent lowlands and uplands, areas of groundwater discharge, and those that contributed to the aesthetic value of Clark Lake. Additional information about these sites can be found in the UWSP *Clark Lake Watershed Sensitive Habitat* report. Protection may be accomplished through education/information activities, obtaining conservancy easements, providing incentives, adhering to or strengthening and enforcing regulations, land purchase, and other creative means. Developing a plan with interested parties is recommended to identify specific goals for protection of these special areas.

- If some or all of the sensitive area sites are to be officially designated as Wisconsin Critical Habitat, the WDNR will need to initiate this designation. This designation would provide protection for permit decisions regarding shoreline modifications and aquatic plant management.
- Shoreline vegetation provides important habitat, enhances infiltration, and helps to filter runoff moving to the lake. All riparian properties should be in compliance with the Door County/state shoreland ordinance.
- Aquatic macrophytes were surveyed in the summer of 2006 and it is recommended to replace riprap and concrete shoreline reinforcements with native emergent vegetation that is more beneficial to water quality, wildlife and shoreline stabilization. Additionally, a no-wake zone in the North Bay is recommended to help preserve the diversity and abundance of aquatic macrophytes in this ecologically significant part of the lake.
- Several aquatic invasive macrophytes exist in Clark Lake (Curly leaf pondweed and Eurasian water milfoil). Currently the range of these species within the lake are limited, but should be monitored to identify spread. Clark Lake Association should participate in the DNR Clean Boats Clean Waters program to learn to identify and monitor these and other aquatic invasive species. Many aquatic invasive species take advantage of open areas in lake beds, so removal of aquatic vegetation should be limited.
- Proper maintenance and operation of the dam at the outflow of Clark Lake should be continued to provide adequate flow for fish and other aquatic biota. Especially important, is the spring period when trout from Lake Michigan use the creek for spawning and could potentially be stranded with improper dam operation.

Summary of Recommendations from reports on Clark Lake Watershed.
Includes the 2006 and 2007 UWSP Center for Watershed Science and Education Reports, 2005 UWSP Biological Water Quality Assessment, and Hines Emerald Dragonfly Report by Williamson

UWSP Aquatic Macrophyte Community Survey Report Recommendations

Significant changes to the aquatic macrophyte community have occurred since the 1986, 1989, and 1992 surveys. Some species of aquatic macrophytes have suffered a decline and/or even absence in the 2006 survey. Shallow vegetation, which seems to be on the decrease, in particular *Schoenplectus acutus* is becoming less common in areas that this species once dominated. The recommendations of this study include:

1) Minimize the removal of aquatic macrophytes to reduce the opportunities for establishment of invasive species.

2) Routinely identify and monitor for exotic invasive species and participate with WDNR's Clean Boats/Clean Waters Program.

3) Replace riprap and concrete shoreline reinforcements with native emergent vegetation that are more beneficial to water quality, wildlife, and shoreline stabilization. Emergent vegetation acts as a buffer from near shore wave and will dampen the effects of wave and wind induced erosion and sediment disturbance which will in turn promote shallow growth of other aquatic macrophytes.

4) Establish a plan to re-establish Schoenplectus acutus and other native shallow species in regions of the lake that are experiencing a decline in population. This may be done by means of water level manipulation, manual planting, establishing no-wake or no-motor zones in regions of concern, or creating buffer barriers where wind and waves are problematic.

5) Establish a no-wake or no-motor zone in the north bay of Clark Lake and into Logan Creek to help preserve the diversity and abundance of aquatic macrophytes in this ecologically significant part of the lake.

6) Myriophyllum spicatum has become less dominant since 1992 but is still a potentially problematic species. Potamogetan crispus has yet to establish itself as a dominant species. Continued annual monitoring should be

conducted to track these non-native species. UWSP Aquatic Macrophyte Community Survey Report p.1

7) An endangered species of pondweed was identified in the 2006 survey, Potamogeton pulcher. This is significant because it is an endangered species of pondweed and has never been identified on Clark Lake before. Further monitoring will be needed to track the progress of this endangered species of pondweed. (Reported to WDNR in 2006 by Turyk) UWSP Aquatic Macrophyte Community Survey Report p.1

8) Shallower near-shore regions had less (aquatic plant) growth than previous surveys, in particular hardstem bulrush (Schoenplectus acutus, formally Scirpus acutus) which is a species of concern. This change should be monitored and if further decline occurs a rehabilitation plan should be considered. UWSP Aquatic Macrophyte Community Survey Report p.1,2

UWSP Water Clarity Recommendations

(From Wind, Waves, and Watercraft Report)

The principal objective of this study was to develop a better understanding of the water clarity in Clark Lake. Based on the experiments performed and a review of the literature, it appears that water clarity in Clark Lake is related to marl formation, sediment redistribution, wind mixing and watercraft activity. We combined this information to develop a conceptual model of marl formation, mixing, and redistribution, and resuspension. The recommendations of this study include:

1) Although the results of this study represent a relatively short term investigation of water clarity in Clark Lake, they should be able to assist identifying areas of the lake that may be more susceptible to sediment resuspension. The modeling and particle composition maps along with the boating experimentation should be used to aid in developing a plan to identify regions of the lake and depths that need to be managed to improve water clarity and decrease turbidity.

2) Recreational watercraft can resuspend solids from the lake bottom, particularly when operated in a startup or non-planing position. Minimal, if any resuspension occurs at the no wake, idle speed in both shallow and deeper depths. We found boats can resuspend sediment in 4 and 6 foot water depths where finer sediments are likely to be deposited. Larger boats and motors, such as the 100 hp outboard and 160 hp inboard-outboard had a great impact on sediment resuspension. This occurs if the boat is operated with continued start and stop movements.

i) A strategy should be developed to minimize the use of recreational watercraft of all sizes in depths less than 4 feet of water. Speeds no greater than no wake or idle should be operated in these depths.

ii) In depths greater than 4 feet, larger watercraft and motors have a potential to resuspend and reactivate marl when in the startup or non-planeing speeds. Precautions and limits on boat and motor usage and areas of operation may limit the reactivation of marl from the deeper depositional areas within the lake.

3) Shallow aquatic macrophyte beds, such as hardstem bulrush (*Schoenplectus acutus*) are declining (Hoverson and Turyk, 2006) and may contribute to decreased water clarity and increased turbidity because of the lack of sediment protection from wind and wave mixing. The effects of wind and waves can decrease with interception from aquatic plant beds. These communities can and do stabilize turbulent water and promote sediment settling. Reestablishment of a thriving shallow aquatic plant community would help to minimize sediment resuspension in shallow areas.

4) It has been shown that fluctuations in lake levels, including summer can consolidate sediment and expose part of the lake bed, thereby inducing growth of emergent plant species. Both can aid in decreasing sediment resuspension by consolidating sediment that will be less likely to become agitated and resuspended and by the promoting the growth of shallow aquatic plant communities that will aid in stabilizing turbulent water.

UWSP Sensitive Area Survey Recommendations

Lost Lake and Logan Creek lie in the 11,192 acre watershed of Clark Lake. Lost Lake is a 91 acre lake at the headwater of the Clark Lake watershed. It is drained by Logan Creek. Groundwater in the watershed feeds Lost Lake and Logan Creek throughout the year and these contributions can and do fluctuate with the changing levels of the water table. As the water table lowers, stretches of Logan Creek dry. Without additional recharge to groundwater these "losing" stretches migrate farther and farther up the watershed. These conditions have created unique vegetative and habitat characteristics to the region surrounding the Logan Creek and Lost Lake.

Much of the riparian areas around Lost Lake and Logan Creek are intact and in good condition. The riparian vegetation is providing good habitat and is functioning to help provide good quality water entering these waterbodies by surface runoff. Efforts should be made to protect this healthy condition by enforcing the existing shoreland zoning ordinances, obtaining conservancy easements, and/or purchasing land (when possible).

Much of the riparian and shallow regions of Clark Lake have not faired so well. Increased shoreland development that is inconsistent with shoreland zoning and lake use in the shallows has lead to a decrease in essential habitat, increased runoff, and increases in sediment and shoreline erosion and disturbance.

The recommendations of this survey include:

1) Most of the riparian vegetation around Lost Lake and Logan Creek are in good condition, providing good habitat and functioning to slow and filter runoff water draining to the water bodies. Efforts should be made to protect this healthy condition by utilizing a variety of tools including providing information to riparian landowners, strengthening and enforcing the shoreland zoning ordinances, providing incentives, obtaining conservancy easements, and/or purchasing land.

2) All of the areas around Clark Lake that are identified in this document play a role in supporting the lake's ecosystem. However, in addition to taking action to protect these areas efforts should be made to improve conditions in the riparian area of Clark Lake. As a first step, riparian land use around the lake should be consistent with the rules in the county zoning ordinance.

3) Nineteen sensitive shorelines, three areas recommended for conservancy, Logan Creek, and twelve Lost Lake sensitive areas were identified in the watershed because they contribute to what is believed to be unique and critical habitat within the Clark Lake Watershed. Future knowledge of these areas, a plan to refine actions associated with the management/protection of these areas and education of the Clark Lake Watershed users will prove critical to protect and/or restore this valuable resource. (p.1,2)

4) Sites RC1, RC2 and RC3 are the primary areas around Clark Lake that are essential for the health of the Clark Lake aquatic ecosystem. We recommend them for conservancy designation. (p. 7)

5) Overall, the aquatic macrophyte community appears healthy in the current conditions in Logan Creek; however, any substantial changes to the creek, its shorelines and/or water quality/quantity may promote changes to this community. These changes could alter conditions in Clark Lake and is again why Logan Creek is considered sensitive for the health of the creek itself and the lake. (p.20)

6) A low lying white cedar wetland surrounds Lost Lake as well as dense beds of healthy hardstem bulrush (Figure 21). These areas are considered important to the fishery, wildlife, water quality, aquatic and riparian

vegetation, and aesthetic beauty of Lost Lake. Riparian areas exhibit good conditions with low lying areas essential to nesting birds, insects, and other wildlife while exhibiting buffering capabilities. Intact shorelines and aquatic vegetation beds aid in stabilizing shorelines and preventing wave erosion and substrate mixing. Therefore these stands of hardstem bulrush and white cedar swamp should be considered for conservancy or other forms of protection.

7) Monoculture stands of broad leaved cattail (*Typha lattiflora*) and common reed (*Phragmites australius)* exist on the north and northwest sides of the lake and it appears to be encroaching on the adjacent bulrush beds. We have defined these areas as management areas due to the aggressive nature of these species in which continued monitoring should be done to examine changes that may be detrimental to the Lost Lake macrophyte community. (p.24)

2005 Fish Survey of Clark Lake

By Steve Hogler, Steve Surendonk and Pat McKee Wisconsin Department of Natural Resources

Fish populations in Clark Lake appear to be in a state of change based on the results of the fish Survey. The recommendations of this study include:

1) Encourage the re-colonization of aquatic plants by establishing no wake areas or by temporary placement of wave and turbidity barriers to get plants started. Aquatic plants provide critical nursery, feeding and refuge habitat and are necessary for maintaining healthy, stable fish communities in lakes.

2) Encourage shoreline residents to reestablish natural shorelines. This will also help plant communities as well as many other animal populations.

3) Monitor the movement and abundance of exotics into Clark Lake. If these species get firmly established in the lake, more changes in the fish community are likely.

4) Encourage the Lake Association and its members to protect sensitive areas.

2005 Biological Water Quality Assessment of Logan Creek, Door Co., WI

Stanley W. Szczytko & Jeffrey J. Dimick College of Natural Resources, University of Wisconsin-Stevens Point.

Based on the mean water quality rankings of the individual sites Logan Creek can be generally classified by the HBI max 10 as having “fair” to “good” water quality. Additionally, since it is a small stream (steam order 2 – ca. 6.0 mi length) with low discharge it should be considered fragile and susceptible to impairment. It appears that the two main potential threats to this watershed are water quantity and lost of riparian area due to development and agriculture. Any land use change that draws on the groundwater aquifer in a significant way may have detrimental effects on this small watershed. Additional development along the shoreline of Lost Lake and increased use may also affect the downstream water quality of Logan Creek. There is also some evidence that this watershed may support the Hine’s Emerald Dragonfly (*Somatochlora hineana*) which is a federally endangered species. This dragonfly does occur in nearby areas and appears to be associated with karst geological outcroppings.

1) In light of these facts this watershed should be protected from development and monitored closely in the future. (following recommendations in the April 2007 UWSP Final Report)

Results of a Limited Search of the Clark Lake Watershed for Adult and Exuvia of Hine’s Emerald Dragonfly Somatochlora Hineana (Williamson) Summer 2006.

The Hine’s emerald dragonfly was listed as endangered under the Endangered Species Act of 1973 on January 26, 1995. It is also listed as endangered in Wisconsin by the Wisconsin Department of Natural Resources. This species occurs in several western Lake Michigan States (Michigan, Wisconsin, Illinois) and Missouri. The largest populations appear to occur in Door County, Wisconsin, with large numbers occurring at the Mink River and in the Ridges Sanctuary / Mud Lake wetland complex. Other wetlands in Door County in which some evidence of HED use (e.g., foraging, egg laying, successful breeding) has been documented include; Peil Creek, Ephraim Swamp, Three Springs / North Bay, Arbter Lake, Kellner Fen, Big and Little Marsh and Black Ash Swamp. As the Clark Lake watershed lies between or near several of these wetlands a search of wetlands of similar structure and hydrology within the watershed was warrented.

1) All sites within the Clark Lake Watershed surveyed (Upper Lost Lake Wetland, Outlet of Logan Creek, and Embayed wetland-SE corner of Clark Lake) had features that would indicate a potential for HED usage, and warrant perhaps further survey work, including crayfish burrow pumping.

Clark Lake Watershed Strategic Plan

(Prepared by Kelly Mumm)

A strategic planning process was conducted to utilize some of the information obtained in the study by developing goals and identifying what the group wants to accomplish in the future, how the goals/actions will be achieved, and who will be involved in the identified activities. The Clark Lake Watershed Planning Committee (CLWPC) was formed to carry out the strategic planning process with facilitation by Door County UW-Extension. The CLWPC was comprised of representatives from CLAA, landowners in the watershed, Town of Sevastopol and Town of Jacksonport, and Door County. CWSE and WDNR attended three of the meetings as technical resources. CLWPC met four times to develop this strategic plan.

The first meeting included a presentation of the final results from the UWSP CWSE evaluation of Clark Lake and its watershed. The presentation provided recommendations based on the science and current literature. The results from a 2002 *Clark Lake Survey Results and Action Plan* were reviewed by CLAA and were also utilized to identify important issues by the CLAA membership. The two following meetings were the "teeth" of the strategic planning process. CLWPC prioritized the study recommendations to help them with the next steps of their strategic planning process which involved identifying goals/objectives under four topics: Education, Land Use, Water Quality, and Ecosystem/Biodiversity (Table 7). Goals/objectives and associated activities follow.

Table 7. Study (and other) recommendations prioritized by the Clark Lake Watershed Plan Committee for use in developing strategic plan activities.

<u>What are the most important recommendations we should try to implement in the strategic plan?</u>

1. Designate north end of Clark Lake as no motor.
1b. Designate Logan Creek as no motor. – Possibly conservancy.
2. Monitor septic systems.
3. Educate property owners and users.
4. Stop new invasives, prevent new invasions.
5. Educate why Lost Lake is important.
6. Designate selected shallow areas (less than 4') as no wake
7. Develop and implement protection approaches for sensitive areas within Clark Lake, Logan Creek and Lost Lake. Consider Wild Lake and/or a State Natural Area Designation.
8. Get more of the maps and information out to places where people gather.
9. After education, survey Lost Lake owners about issues and actions needed.
10. Land acquisition and easements.
11. Re-establish the bulrushes
12. Watershed residents take an active role in monitoring development on the watershed; increased groundwater use; home site development; increased impervious areas; non-metallic mining; and promoting proper land use and management.
13. Continue monitoring efforts and monitor progress on the strategic plan.
14. Re-survey Clark Lake owners.
15. Maintain operation of dam per DNR rules.
16. Encourage natural shorelines, lawn management.
17. Include adjoining wetlands and cedar swamps to natural area designation especially the pond located in the State Park.
18. Manage existing invasives, develop aquatic plant management plan.
19. Protect endangered species.
20. Implement Clean boat/clean water program.

Topic: **Education**

How do we inform citizens about the importance of Lost Lake and Logan Creek? (3, 5, 9)

Action:	Who:	Target Date:
Prepare information package for Lost Lake residents & hold a meeting with educational materials for Lost Lake landowners/residents	Dennis Dietrich Rich Dirks, Paul Schumacher	September, 2007
Develop landowner survey for Lost Lake/Logan Creek residents	Paul Schumacher Dennis Dietrich Rich Dirks	May, 2008

Topic: **Education**

How do we inform people on the no-wake areas, sensitive and natural shoreline areas, and fertilizer and herbicide use? (3, 8, 16)

Action:	Who:	Target Date:
Update Clark Lake Map and distribute to public within watershed	Lawrie Kull	Fall, 2007
Work on developing an information packet, get samples, and consider funding through DNR Lake Planning Grant	CLAA Information and Education Committee	May, 2008
Create a watershed map that provides information on no-wake areas, sensitive and natural shoreline areas. Distribute to watershed property owners and other lake users	CLAA Information and Education Committee	May, 2008

Topic: **Education**

How do we obtain Clark Lake landowner/resident opinions? How can we evaluate our education efforts? (3, 14)

Action:	Who:	Target Date:
Re-survey Clark Lake residents using similar format of previous survey	CLAA	July, 2008

Topic: **Education**

How do we inform people about aquatic invasive species? (3, 20)

Action:	Who:	Target Date:
Approach Sevastopol High School for help	Paul Schumacher	May, 2007
Send letter to CLAA membership on the	Paul Schumacher	June 1, 2007

DNR Clean Boats/Clean Water program		
Participate in DNR Clean Boats/Clean Water training program & become active participant in Door County Invasives Team	CLAA & volunteers	June 23, 2007

Topic: **Education**

How do we continue to monitor current vegetation and water quality status and provide updates to the community? (4, 13, 19, 20)

Action:	**Who:**	**Target Date:**
Continue DNR Self Help water quality monitoring	Paul Schumacher	Ongoing
Conduct annual bulrush monitoring in Lost Lake and Clark Lake using recommended protocols and ask UWSP for training	CLAA	August, 2007
Routinely monitor for new and existing exotic aquatic invasive species	CLAA	Ongoing
Monitor the extent of broad leaved cattail (*Typha lattiflora*) and common reed (*Phragmites australius)* beds in the Watershed	CLAA	Ongoing
Monitor the endangered species of pondweed *Potamogeton pulcher*.	WDNR	Ongoing
Conduct an annual review of strategic plan implementation and provide a report of review to CLAA members	CLWPC CLAA	Ongoing, first report due first quarter, 2008.

Topic: **Land Use**

How do we encourage constituents of the watershed area to take an active role in monitoring development within the watershed, promoting land use and management decisions that protect the groundwater, lakes, and stream and implementing appropriate land management practices? (3, 12)

Action:	Who:	Target Date:
Watershed residents & CLAA provide input into land use decisions within the watershed.	Watershed residents	Ongoing
Create awareness of land use practices and their importance to the watershed among the broader informal network of watershed residents.	Watershed residents	Ongoing
Reconsider forming a lake district to create a unified voice in the protection of habitat, water quality, and/or water quantity	CLAA	August, 2008

Topic: **Land Use**

How do we help with the protection of habitat, water quality, and water quantity in the Clark Lake Watershed? (10)

Action:	Who:	Target Date:
Consider purchase or easements for land within the watershed. Focus areas include land to the north of Lost Lake and land near Logan Creek beginning with the seepage areas north of Highway 57 down to Clark Lake and those areas identified in the sensitive survey report	CLAA with help from land trust organizations.	Ongoing

Topic: **Water Quality / Education**
How do we encourage more natural shorelines (to provide habitat and improve water quality in the watershed) around Clark Lake, Logan Creek and Lost Lake? (16)

Action:	Who:	Target Date:
Provide opportunities for landowners to become knowledgeable on buffer plants and techniques for establishing natural shorelines	CLAA	Spring, 2008
Encourage demonstration sites of natural plantings with signage	CLAA	Spring, 2008

Topic: **Water Quality**
How do we ensure that septic systems in the Clark Lake Watershed are functioning properly? (2)

Action:	Who:	Target Date:
Promote voluntary inspection of septic systems around lake area.	CLAA	Summer, 2007
Request reprioritization of septic system survey in Clark Lake area by Door County Sanitarian.	CLAA	Summer, 2007

Topic: **Water Quality / Ecosystem and Biodiversity**
How do we protect the most sensitive areas in the Watershed? (1, 1b, 6)

Action:	Who:	Target Date:
Designate north end of Clark Lake, Logan Creek and other areas identified within Clark and Lost Lakes as “critical habitat” or “sensitive areas”	DNR CLAA Science Committee	Summer 2007
Designate north end of Clark Lake and Logan Creek as “no-motor” by requesting creation of ordinance by Town of Jacksonport.	CLAA	Summer 2007
Designate shallow areas (less than 4 feet) in the north end of east bay as “slow no wake” by requesting creation of ordinance by Town of Jacksonport. Designate shallow areas (less than 4 feet) along state park shoreline as “slow-no-wake” by requesting ordinance by Town of Sevastopol.	CLAA	Summer 2007

Topic: **Ecosystem and Biodiversity**
How do we develop and implement approaches for the protection of the sensitive areas? (7, 9)

Action:	Who:	Target Date:
Consider protection measures for remaining S2 and S3 sensitive areas	CLAA	2008
Include questions and information on natural area and no-motorized designation in Lost Lake landowner survey	Dennis Dietrich Rich Dirks	2008
Place buoys to identify the north end of Clark Lake as “no-motor” sensitive area	CLAA	After ordinance
Mark north end of east bay, and S5 (along State Park) as sensitive areas and “no-wake” in 4 ft or less of water	CLAA	After ordinance

Topic: **Ecosystem and Biodiversity**
How do we protect and re-establish the bulrush beds? (11)

Action:	Who:	Target Date:
Consider the following techniques: plugs, seeds, wave and turbidity barriers	CLAA Science Committee	Fall 2007
Re-establish bulrush beds and monitor for success.	CLAA	Ongoing after CLAA Sci Comm Recommendations
Develop an Aquatic Plant Management Plan	CLAA	September, 2008

Topic: **Ecosystem and Biodiversity**
How do we protect the wetlands in the watershed? (17)

Action:	Who:	Target Date:
Stay involved in Town and County planning processes and urge for proper definition and protection of wetlands	CLAA & watershed residents.	Ongoing

Topic: **Ecosystem and Biodiversity**
How do we protect the aquatic biota in Clark Lake, Lost Lake, and Logan Creek? (4, 18, 20)

Identify grant programs and funding to help with invasive species control	CLAA Science Committee	August, 2008
Develop an Aquatic Plant Management Plan for Clark Lake, Lost Lake, and Logan Creek	CLAA	September, 2008
Maintain all fish passage screens in place per DNR rules to prevent fish from entering Clark Lake from Lake Michigan.	Town of Sevastopol	ongoing

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Appendix A. Summary of Inflow and Outflow Water Chemistry (mg/L unless noted)

all values are in mg/L unless otherwise stated

Sample Date	Sample Time	Site	Coordinates (UTM)	SRP (µg/L)	TP (µg/L)	Organic N	Total N	NH4 (N)	NO2 + NO3 (N)	Cl	TSS	TDP
5/27/2005	12:00	Clark Lake Outflow	0483440 / 4974372	1.5	4	0.500	1.620	0.02	1.1	8.5	1	
7/27/2005	UA	Clark Lake Outflow		3		0.480	1.070	0.18	0.41	10.5	11	0.016
11/14/2005	UA	Clark Lake Outflow		7	19	0.710	1.090	0.13	0.25	9.5	14	
12/2/2005	5:00	Clark Lake Outflow		4	9	0.530	0.920	0.11	0.28	9	1	
3/10/2006		Clark Lake Outflow		9	6	0.390	1.120	0.09	0.64	11.5	1	
4/15/2006		Clark Lake Outflow		8	16	0.560	0.683	0.04	0.083	11	37	
4/24/2006		Clark Lake Outflow		10	12	0.460	1.420	0.05	0.91	10.5	6	
5/12/2006		Clark Lake Outflow		6	10	1.000	1.850	0.07	0.78	9.5	6	
5/22/2006		Clark Lake Outflow		12	13	0.470	1.530	0.12	0.94	10.5	5	
6/20/2006	10:30 AM	Clark Lake Outflow		11	23	0.500	1.210	0.03	0.68	10.5	3	
7/5/2006	9:30 AM	Clark Lake Outflow		**76**	20	0.220	1.280	0.26	0.8	10.5	3	
7/27/2006	10:00 AM	Clark Lake Outflow		11	12	0.390	0.890	0.1	0.4	10.5	1	
8/14/2006	11:30 AM	Clark Lake Outflow		13	11	0.480	0.860	0.1	0.28	11	8	
9/26/2006	10:45 AM	Clark Lake Outflow		**94**				0.17	0.29	12	1	
11/1/2006	2:00 PM	Clark Lake Outflow		3	8	0.390	0.780	0.16	0.23	11	4	
Averages				17.9	12.5	0.51	1.2	0.11	0.5	10.40	6.80	
5/26/2005	17:30	Logan Creek @ Hwy 57	0482841 / 4978269	9	4	0.400	2.210	0.01	1.8	7.5	1	
7/27/2005	UA	Logan Creek @ Hwy 57		**82**		1.030	4.400	0.14	3.23	8	7	0.092
11/14/2005	UA	Logan Creek @ Hwy 57		21	32	0.580	3.870	0.03	3.26	9	6	
12/2/2005	2:00	Logan Creek @ Hwy 57		7	15	0.310	4.740	0.04	4.39	11	1	
3/10/2006		Logan Creek @ Hwy 57		10	8	0.380	4.090	0.02	3.69	11	1	
4/15/2006		Logan Creek @ Hwy 57		10	12	0.445	3.150	0.005	2.7	10	1	
4/24/2006		Logan Creek @ Hwy 57		9	28	1.050	3.690	0.01	2.63	9.5	1	
5/12/2006		Logan Creek @ Hwy 57		12	13	0.750	2.040	0.06	1.23	8.5	3	
5/22/2006		Logan Creek @ Hwy 57		19	15	0.350	2.620	0.27	2	8.5	1	
6/20/2006	10:00 AM	Logan Creek @ Hwy 57		17	25	0.430	3.010	0.01	2.57	10	17	
7/5/2006	8:30 AM	Logan Creek @ Hwy 57		16	18	0.380	3.600	0.02	3.2	10	7	
7/27/2006	9:00 AM	Logan Creek @ Hwy 57		17	11	0.190	4.290	0.03	4.07	11.5	1	
8/14/2006	10:30 AM	Logan Creek @ Hwy 57		11	9	0.310	3.560	0.03	3.22	12	26	
9/26/2006	10:00 AM	Logan Creek @ Hwy 57		15				0.05	3.58	13	1	
11/1/2006	3:30 PM	Logan Creek @ Hwy 57		7	6	0.160	3.370	0.04	3.17	11	3	
Averages				17.5	15.1	0.48	3.5	0.05	3.0	10.03	5.13	
5/26/2005	15:32	Logan Creek @ Plum Bottom	0479695 / 4981799	7	4	0.445	0.490	0.005	0.04	6	1	
8/23/2006	2:00 PM	Clark Lake Upwelling	0482828 / 4978156	14	12	0.130	3.360	0.03	3.2	9.5		
11/1/2006	5:30 PM	Logan Creek @ Plum Bottom	0479695 / 4981799	10	7	0.180	1.010	0.07	0.76	6	1	
11/1/2006	5:00 PM	Logan Creek @ Sunny Slope	0479886 / 4981020	9	9	0.330	0.830	0.07	0.43	7.5	1	
11/1/2006	4:30 PM	Logan Creek @ Hwy T	0480746 / 4979765	6	6	0.440	1.790	0.05	1.3	7.5	1	
11/1/2006	4:00 PM	Logan Creek @ Bagnall Rd.	0481269 / 4979306	6	8	0.400	1.760	0.06	1.3	8.5	4	

UA=Unavailable--Lake Group Samples

Organic N = TKN - NH4

Total N = TKN + NO2 + NO3

Water Chemistry Logan Creek--Outflow

	Average		Range	
Total Phosphorus	12.5	µg/L	4 - 23	µg/L
Soluble Reactive Phosphorus	17.9	µg/L	1.5 - 94	µg/L
Total Nitrogen	1.2	mg/L	0.7 - 1.9	mg/L
Organic Nitrogen	0.51	mg/L	0.22 - 1.00	mg/L
Chloride	10.4	mg/L	8.5 - 12.0	mg/L
Total Suspended Solids	7	mg/L	1 - 37	mg/L

Water Chemistry Logan Creek--Hwy 57

	Average		Range	
Total Phosphorus	15.1	µg/L	4 - 32	µg/L
Soluble Reactive Phosphorus	17.5	µg/L	7.0 - 82	µg/L
Total Nitrogen	3.5	mg/L	2.0 - 4.7	mg/L
Organic Nitrogen	0.48	mg/L	.16 - 1.05	mg/L
Chloride	10.0	mg/L	7.5 - 13.0	mg/L
Total Suspended Solids	5	mg/L	1 - 26	mg/L

Appendix B. Summary of In-Lake Water Chemistry

Clark Lake Water Chemistry (mg/L unless otherwise noted)

all values are in mg/L unless otherwise stated

Sample Date	Sample Time	Site	Coordinates (UTM)	pH	Cond	Alk	T Hard	Ca Hardness	SRP (µg/L)	TP (µg/L)	Organic N	Total N	NH4 (N)	NO2 + NO3 (N)	Cl	SO4	Na	K	Turb (NTU)	Color (CU)	TSS
5/27/2005	9:00 AM	Clark Lake Deep Hole	0483568 / 4975987	8.41	337	200	212	124	1.5	4	0.57	1.69	0.02	1.1	9	14.1	3.3	2.3			1
10/29/2005	10:45 AM	Clark Lake Deep Hole	0483568 / 4975987	8.44	375	184	205	84	7	6	0.59	0.92	0.10	0.23	9.5	14.07	3.7	2.5	4.5	14	
3/10/2006		Clark Lake Deep Hole	0483568 / 4975987	8.06	412	204	132	106	10	5	0.46	1.36	0.13	0.77	10.5	16.67	3.9	2.5	2	7	
4/14/2006		Clark Lake Deep Hole	0483568 / 4975987	8.17	389	200	231	114	12	9	0.45	1.62	0.07	1.1	10	16.5	4.3	2.3	4.8	9	
5/18/2006		Clark Lake Deep Hole	0483568 / 4975987	8.14		196		104	3	8											2
9/16/2006	6:00 PM	Clark Lake Deep Hole (Surface)	0483568 / 4975987							12											
11/1/2006	11:00 AM	Clark Lake Deep Hole	0483568 / 4975987	8.36	384				4	89	1.08	1.43	0.14	0.21	10.5				6.5	5.9	
Summary				8.26	379.4	197	195	106.4	6.25	19	0.63	1.4	0.092	0.7	9.9	15.34	3.8	2.4	4.5	9.0	
9/16/2006	6:00 PM	Clark Lake Deep Hole (20' Deep)	0483568 / 4975987							13											
10/29/2005	10:00 AM	Clark Lake E10' Hole	0484677 / 4975705	8.44	375	188	204	83	3	6	0.57	0.89	0.11	0.21	9.5	14.19	3.7	2.5	4.8	15	
4/14/2006		Clark Lake E10' Hole	0484677 / 4975705	8.18	390	200	234	117	6	9	0.42	1.52	0.05	1.05	10	16.59	4.2	2.3	5.5	10	
Summary				8.31	382.5	194	219	100	4.5	7.5	0.50	1.2	0.08	0.6	9.75	15.39	3.95	2.4	5.1	12.5	

Sample Date	Sample Time	Site	Coordinates (UTM)	As	Ca	Cu	Fe	K	Mg	Mn	Na	P	Pb	S	Zn
11/1/2006	11:00 AM	Clark Lake Deep Hole	0483568 / 4975987	0.003	34.1	0.0005	0.007	2.5	29.8	0.0005	3.9	0.0025	0.001	16.2	0.001

Water Chemistry for Mid-lake--Deep Hole

	Average		Range	
Total Phosphorus	19.00	µg/L	4-89	µg/L
Soluble Reactive Phosphorus	6.25	µg/L	1.5-12	µg/L
Total Nitrogen	1.4	mg/L	0.9-1.7	mg/L
Organic N	0.63	mg/L	0.45-1.08	mg/L
Chloride	9.90	mg/L	9-10.5	mg/L
Turbidity (NTU)	4.45		2-6.5	
Alkalinity	197	mg/L	184-204	mg/L
Total Hardness	195	mg/L	132-231	mg/L
Calcium Hardness	106	mg/L	84-124	mg/L
Color (CU)	8.975		5.9-14	
SO4	15.34	mg/L	14.07-16.67	mg/L
Na	3.80	mg/L	3.3-4.3	mg/L
K	2.40	mg/L	2.3-2.5	mg/L

Organic N = TKN - NH4

Total N = TKN + NO2 + NO3

Water Chemistry for Mid-lake--East Bay

	Average		Range	
Total Phosphorus	7.50	µg/L	6-9	µg/L
Soluble Reactive Phosphorus	4.50	µg/L	3-6	µg/L
Total Nitrogen	1.2	mg/L	0.9 - 1.5	mg/L
Organic N	0.50	mg/L	0.42-0.57	mg/L
Chloride	9.75	mg/L	9.5-10	mg/L
Turbidity (NTU)	5.13		4.75-5.5	
Alkalinity	194	mg/L	188-200	mg/L
Total Hardness	219	mg/L	204-234	mg/L
Calcium Hardness	100	mg/L	83-117	mg/L
Color (CU)	12.5		10-15	
SO4	15.39	mg/L	14.19-16.59	mg/L
Na	3.95	mg/L	3.7-4.2	mg/L
K	2.40	mg/L	2.3-2.5	mg/L

Lost Lake Water Chemistry

all values in mg/L unless otherwise stated

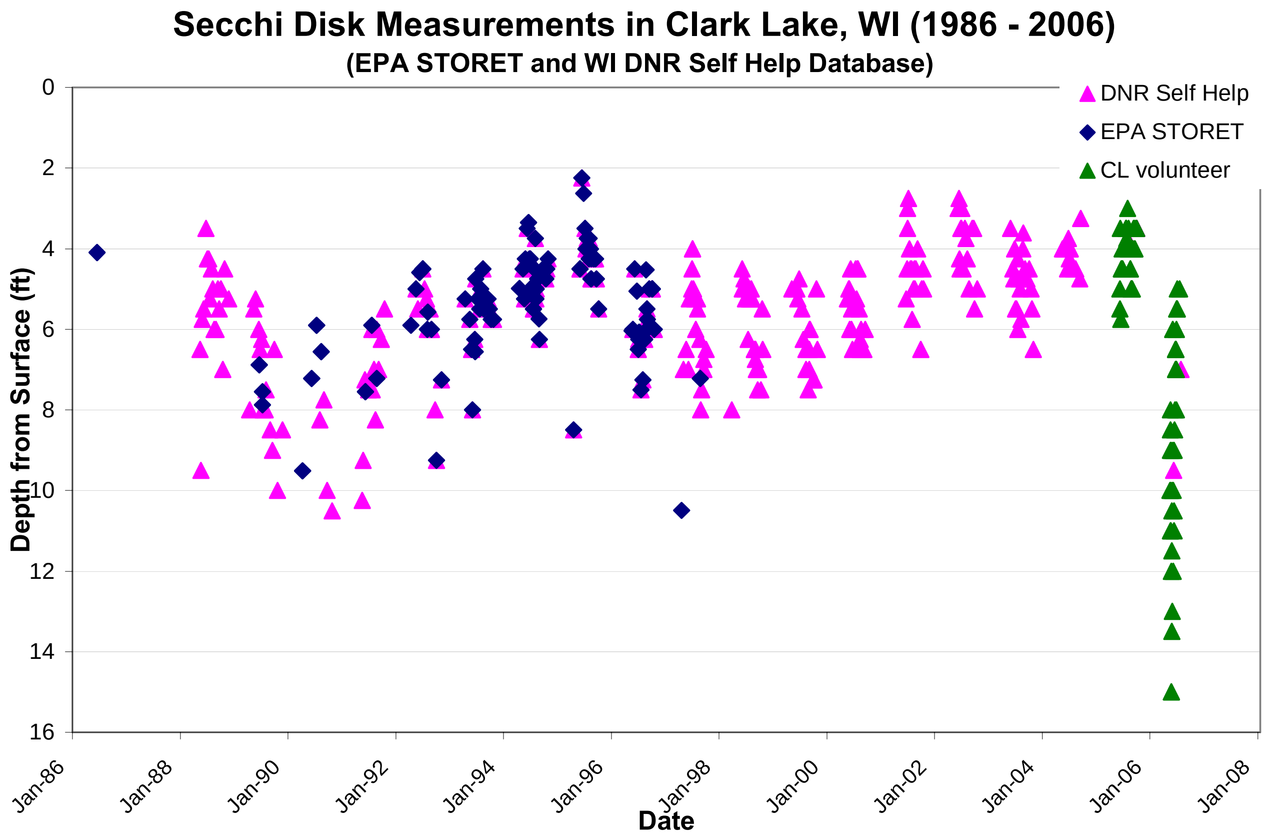
Sample Date	Site	Site Description	Temp (C°)	Cond	D.O.	% D.O.	pH	As	Ca	Cu	Fe	Pb	Mg	K	Na	SO_4	Zn	TP (ug/L)	Alkalinity	Mn
7/22/2005	Lost Lake	West Side @ 2' depth	25.7	379	10.0	120.3	8.67													
		West Side @ 4' depth	25.3	377	9.6	118.9	8.68													
		East Side @ 2' depth	25.5	399	9.8	118.4	8.57													
		East Side @ 4' depth	26.1	383	9.9	119.6	8.61													
5/25/2006	Lost Lake	Headwaters		396			8.14	<0.003	45.1	<0.001	0.008	<0.002	26.6	1.5	1.6	18.27	0.005	7	205	0.001

Appendix C. Land Use Acreages and Percent

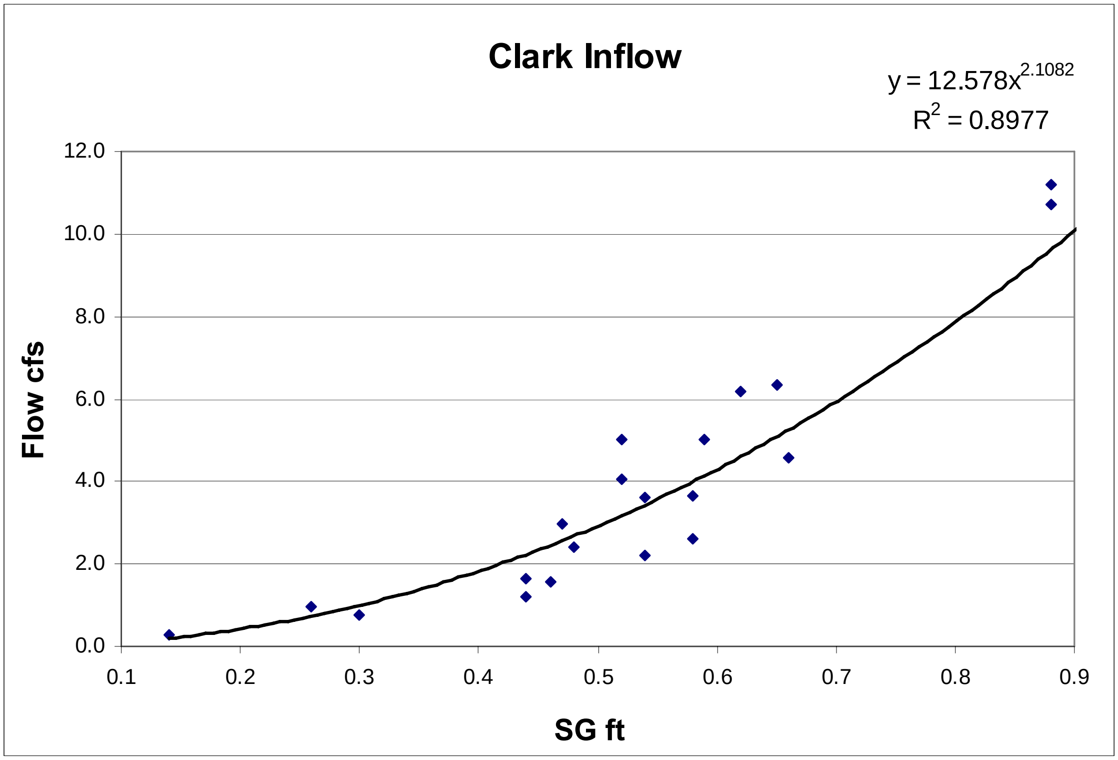
Land Use for Clark Lake Surface Watershed			
Area (acres)	**%**	**Land Use Description**	**Door County ID Codes**
3475	31	Forested	951,960
0.6	<.1	Beaches	954
91	0.8	Farm Buildings	870
1011	9	Open Water	905,911,912,913
4402	39	Cropland	810,830
580	5	Tree Plantations	835
53	0.5	Outdoor Recreation	712,731
904	8	Open Lands/Agriculture	805
618	5	Residential	110,180,199
51	0.5	Commercial / Industrial	210,250,360,381,382,691

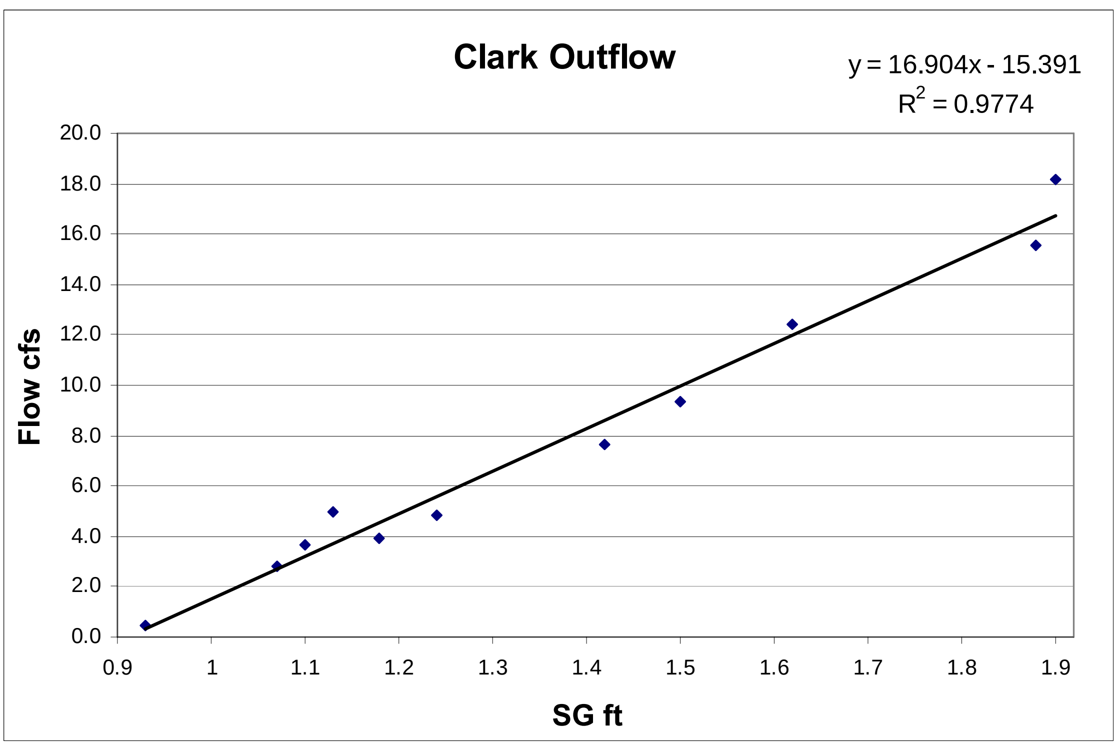
Land Use in Clark Lake Groundwater Watershed			
Area (acres)	**%**	**Land Use Description**	**Door County ID Codes**
4517	32	Forested	951,960
0.6	<.1	Beaches	954
131	0.9	Farm Buildings	870
1016	7	Open Water	905,911,912,913
5804	41	Cropland	810,830
709	5	Tree Plantations	835
53	0.3	Outdoor Recreation	712,731
1142	8	Open Lands/Agriculture	805
760	5	Residential	110,180,199
67	0.5	Commercial / Industrial	210,250,360,381,382,417,546,691

Appendix D. Secchi disk measurements



Appendix E. Rating curves for staff gages located at on Logan Creek at Hwy 57 and the Outflow of Clark Lake.





Appendix F. Private well water quality in Clark Lake Watershed.

PH	COND (umho)	ALK (mg/L)	THARD (mg/L)	NO2+NO3-N (mg/L)	Cl (mg/L)	BACT	PH	COND (umho)	ALK (mg/L)	THARD (mg/L)	NO2+NO3-N (mg/L)	Cl (mg/L)	BACT
7.81	526	260	272	<0.2	11.0	NEG	7.47	557	272	308	1.0	4.0	NEG
7.59	534	240	292	6.5	11.0	NEG	7.46	669	264	324	7.2	33.0	POS
7.67	456	240	256	<0.2	5.0	NEG	7.65	501	256	264	<0.2	6.0	NEG
7.41	637	304	360	6.4	16.0	NEG	7.52	504	272	280	<0.2	1.0	NEG
7.48	595	284	332	3.8	15.0	NEG	7.56	515	268	280	<0.2	3.0	NEG
7.42	678	272	372	12.0	19.0	POS	7.79	413	204	216	2.5	3.0	NEG
7.44	648	300	364	5.0	19.0	POS	7.62	566	268	312	4.0	10.0	POS
7.31	756	288	396	18.5	39.0	POS	7.69	442	236	252	<0.2	3.0	NEG
7.45	561	260	310	4.0	22.0	POS	7.70	468	244	256	0.5	4.0	NEG
7.50	552	252	304	5.0	17.0	POS	7.67	508	252	280	1.0	6.0	NEG
7.52	554	256	304	5.0	11.0	NEG	7.51	525	264	284	1.2	6.0	NEG
7.23	722	344	384	5.6	22.0	POS	7.47	458	196	212	4.0	8.0	POS
7.51	578	264	319	5.6	16.0	NEG	7.81	480	240	268	0.2	1.0	NEG
7.55	557	256	306	7.0	16.0	POS	7.74	472	244	256	<0.2	2.0	NEG
7.54	542	296	304	0.5	3.0	NEG	7.53	425	224	244	0.5	3.0	NEG
7.56	524	244	285	6.5	10.0	NEG	7.62	374	172	200	3.2	4.0	POS
7.29	760	272	344	12.6	47.0	POS	7.59	527	260	284	2.2	6.0	NEG
7.50	455	252	256	<0.2	4.0	NEG	7.45	381	220	228	0.5	2.0	POS
7.45	689	316	378	14.8	23.0	POS	7.49	290	156	172	1.5	8.0	POS
7.51	508	308	289	0.5	7.0	NEG	7.56	400	224	248	1.5	9.0	POS
7.45	612	288	342	5.8	10.0	NEG	7.69	433	248	272	2.5	10.0	NEG
7.36	758	244	333	23.8	40.0	POS	7.58	368	216	236	0.5	1.0	NEG
7.65	422	240	240	<0.2	3.0	NEG	7.57	352	192	216	1.5	2.0	NEG
7.34	659	296	332	9.2	16.0	POS	7.50	480	264	292	2.5	6.0	NEG
7.58	479	252	272	0.2	5.0	NEG	7.57	396	236	248	<0.2	1.0	NEG
7.44	506	252	281	1.8	10.0	POS	7.60	380	224	236	<0.2	3.0	NEG
7.52	554	288	316	2.5	11.0	POS	7.56	413	256	248	<0.2	2.0	NEG
7.59	515	252	4	3.8	12.0	NEG	7.46	597	252	284	10.2	45.0	POS
7.62	429	232	256	0.5	2.0	NEG	7.61	596	276	4	10.0	24.0	NEG
7.63	449	252	260	<0.2	1.0	NEG	7.60	472	236	52	4.0	7.0	NEG
7.32	636	268	317	12.0	29.0	NEG	7.47	475	220	276	7.0	10.0	POS
7.56	538	284	316	<0.2	12.0	NEG	7.75	462	252	260	<0.2	4.0	NEG
7.57	462	236	272	<0.2	6.0	POS	7.62	451	224	256	1.5	3.0	NEG
7.59	452	248	264	<0.2	3.0	NEG	7.59	504	268	288	0.5	6.0	POS
7.41	510	260	297	2.8	7.0	POS	7.82	517	248	288	4.2	9.0	POS
7.34	596	276	326	7.8	14.0	POS	7.70	455	232	244	<0.2	2.0	NEG
7.58	483	264	280	<0.2	22.0	NEG	7.76	477	244	256	0.5	1.0	NEG
7.43	720	340	392	3.5	23.0	NEG	8.05	501	242	280	4.6	6.0	POS
7.42	463	256	390	<0.2	2.0	NEG	7.61	720	107	364	4.2	41.0	NEG
7.35	484	240	283	3.8	11.0	POS	7.56	691	350	376	<0.1	10.5	NEG
7.46	552	268	354	3.0	10.0	NEG	7.72			328			NEG
7.36	614	264	340	9.5	15.0	POS	7.76	572	252	296	7.1	11.0	NEG
7.52	618	276	328	5.0	16.0	POS	7.96	517	240	272	4.6	13.5	POS
7.42	617	292	328	4.5	9.0	POS	7.61	545	212	248	3.3	32.5	POS
7.52	441	220	236	0.2	4.0	NEG	7.55	526	280				
7.56	509	252	283										

Appendix G. Current lake level orders.

CLARK LAKE WATER LEVEL OBSERVATION FORM

The purpose of this form is to record observations of lake level and operation of the Clark Lake dam.
Users of this form should record all information and foreward the form to the Clark Lake Association.
SAFETY: Remember that the most important thing is safety. Watch for slippery footing.
ROLE: Remember that your role is to record lake level and dam operation only. Do not remove/add boards or adjust the fish barrier.

DNR ORDER (June 24, 1991)

Time Period	Min level (ft)	Max level (ft)	Language
5/15 to 12/1	97.5	98	
12/1 to 12/15	97.5	97.5	Max. level dropped to 97.5. Drawdown to be done slowly. No more than 1 board removed at a time.
12/15 to 3/20	97.3	97.5	
3/20 to 5/1	96.25	97.5	Min. level dropped to 96.25. Drawdown to be done slowly. No more than 1 board removed at a time.
5/1 to 5/15	97.5	98	Raise levels to "summer" levels.

Additional Requirement:
The fish barrier shall be in place at all times.

LAKE LEVEL TO STAFF GAUGE CONVERSION
The staff gauge is placed on the west concrete wall of the lake side approach to the dam.
Lake level is reported in feet. The staff gauge is calibrated to lake levels as follows:

Lake Level (feet)	Gauge
98	9
97.5	8.5
97.3	8.3
97	8
96.5	7.5
96.25	7.25

You may have to wipe off the staff gauge to get a good reading. **Remember: Safety First.**