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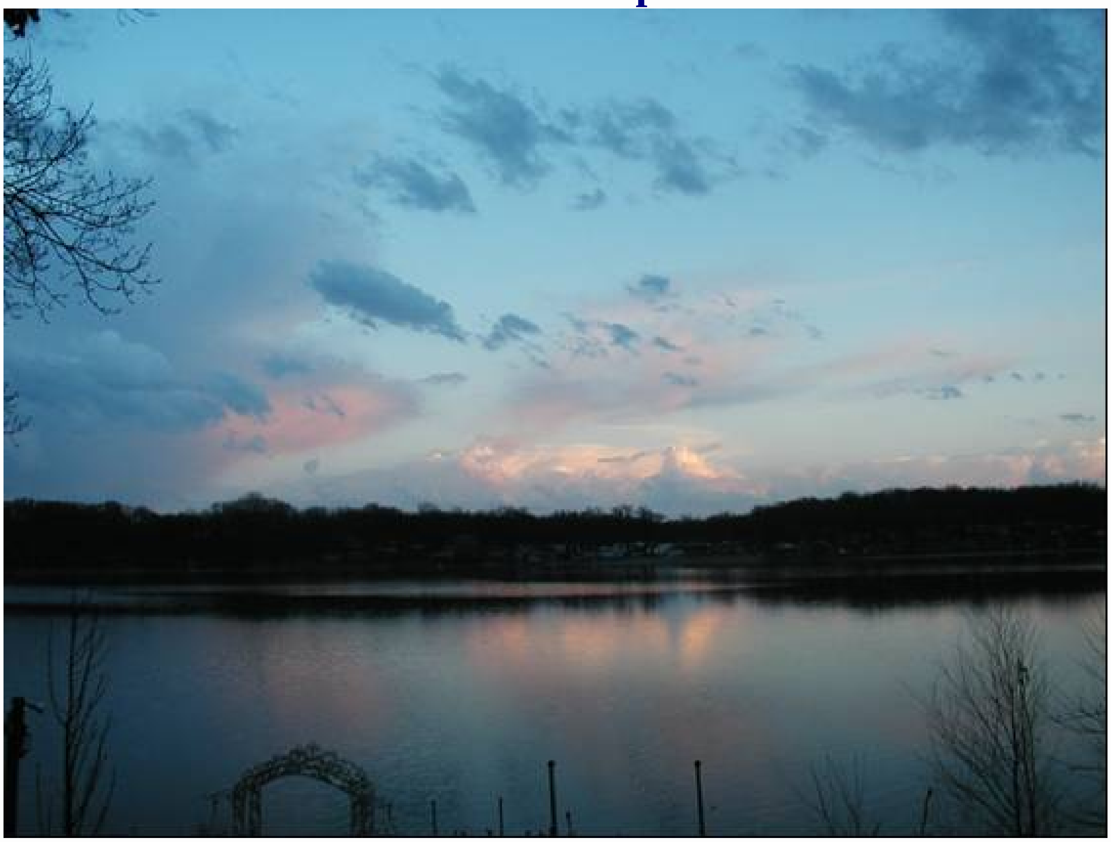
2004 Clear Lake Water Quality Technical Report



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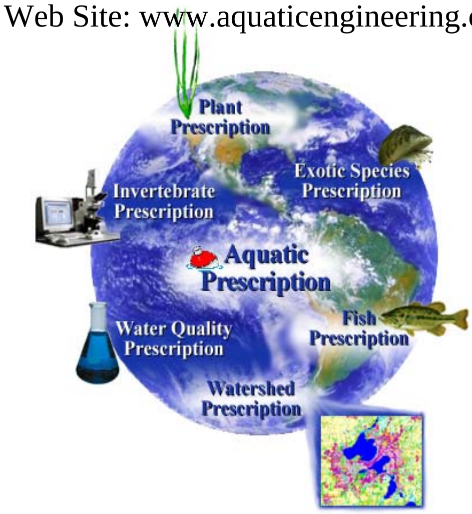

2004 Clear Lake Water Quality Technical Report

September 2006

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In cooperation with the Wisconsin Department of Natural Resources

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Acknowledgements

The 2004 Clear Lake Water Quality Monitoring Technical Report was completed with the assistance of the Clear Lake Association and through a Wisconsin Department of Natural Resources (WDNR) Lake Planning Grant (#LPL-937-04) which provided funding for 75% of the monitoring costs. A special thanks to the following individuals for their help throughout the project:

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Executive Summary

Clear Lake is an 82 acre seepage lake located in Rock County, Wisconsin. Historical data, including Secchi depth and phosphorus concentrations, show that Clear Lake is a mesotrophic lake. Recent data suggest that elevated phosphorus concentrations are creating extensive macrophyte growth and algae blooms within the lake. The trophic status of the lake has increased rapidly over the last few years and intervention is necessary to slow the eutrophication process.

Water quality of Clear Lake was sampled from May to October of 2004 and analyzed for several key chemical properties at the Wisconsin State Laboratory of Hygiene in Madison, Wisconsin. Other physical water characteristics were measured and recorded on site at one meter intervals from the surface to the bottom. Secchi depth readings were also taken at the water quality sampling point during each sampling event.

The 2004 water quality monitoring results show that Clear Lake is a eutrophic lake with a composite[1] TSI value of 52.4. The water quality is similar to that of other shallow, eutrophic lakes; relatively high concentrations of phosphorus and chlorophyll *a* produce nuisance plant growth and frequent algae blooms. The source of the excessive nutrients is not known. A watershed analysis and WiLMS modeling was performed to quantify contributions of known sources of phosphorus.

The WiLMS analysis showed septic system contributions were the single largest source of phosphorus. The campground patrons produce the large majority of grey water and are responsible for the majority of the septic system contributions. The campground was allowed to pump grey water until 2006. Commercial development (campground area) and medium density residential development each contributed approximately one-fifth of the phosphorus load.

[1] A composite TSI value was calculated by averaging the TSI_{TP}, $TSI_{Chl\ a}$ and TSI_S values from 2004.

2004 Clear Lake Water Quality Monitoring

Technical Report

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1.0 Introduction

1.1 Scope

Lake Clear is an 82 acre seepage lake located near the town of Milton in Rock County, WI (WBIC 775000). The watershed of Clear Lake is a mix of general agricultural land, urban development, and deciduous forests and has recently experienced advanced eutrophic conditions even though the watershed is small and development is primarily medium density. Nutrient high runoff from the watershed is suspected of causing elevated phosphorus concentrations which, in turn, is promoting extensive macrophyte growth and algal blooms within the lake.

In 2003, the Clear Lake Improvement Association contracted TLI to write a grant for WDNR funding. The purpose of the funding was to conduct baseline water quality monitoring in 2004, conduct a bathymetric survey to update the current map and conduct a watershed phosphorus analysis. This report covers the water quality parameters sampled on site, water quality analyzed at the Wisconsin State Laboratory of Hygiene (WSLOH), WiLMS phosphorus modeling, and a bathymetric survey and the results of the monitoring are discussed in section 4 and 5 of this report and recommended management actions are provided in section 6.

1.2 Water Quality Issues

Planktonic Algae blooms

Self-help monitoring collector comments indicate that Clear Lake experienced a couple planktonic algae blooms in the summer of 2004. Algae have the ability to position themselves at certain depths of the water column based on nutrient availability and light concentration. As the planktonic algae respond to elevated nutrient levels within the lake, they are capable of rapid reproduction. The rapid reproduction can form an algal bloom. The formed bloom can form below the water’s surface. As light concentration decreases, the bloom will move upward in the water column to compensate for the lack of light. Therefore, as light decreases, the bloom can move to the surface of the water column overnight. This late-day bloom movement usually is not noticed until the next day light and therefore considered an overnight bloom.

Phosphorus

Clear Lake has historical phosphorus levels that indicate the trophic status of the lake is mesotrophic. Sources of phosphorus can include atmospheric deposition, surface runoff, ground water interactions, failing septic systems, and internal loading from lake sediments. Though nutrient levels within the lake are well documented, the specific sources of phosphorus have not been studied. In the last few years, Clear Lake has experienced phosphorus levels higher than reported historical conditions which is causing some concern for lake residents.

Curly-leaf pondweed

Curly-leaf pondweed (CLP) was unintentionally introduced to Wisconsin during common carp stocking activities in the 1800's and is present in many Wisconsin lakes. Curly-leaf pondweed releases nutrients into the water column in mid-summer promoting algal blooms (Crowell 2003). All aquatic plants contribute nutrients to lakes as they decay, but native plants die off in the late summer or early fall and their nutrients are consumed by bacteria instead of fueling algal growth. As much as 5.5 pounds of phosphorus per acre can be released from monotypic CLP beds (McComas 2000). Excess nutrients cause murky water conditions and algal blooms.

Self-help Secchi depth and total phosphorus (TP) data are available from 1990 to the present. The TP sampling protocols were not consistent from 1990 to 2003 in that from 1991-92, and 1995 the surface TP and bottom TP were both measured while in all the other years, water samples were only collected from the middle of the water column (either three or six feet deep). Even though the protocols for sampling the water are not identical, there is a trend that epilimnetic phosphorus concentrations oscillate but are currently on a sharp increase (Figure 1).

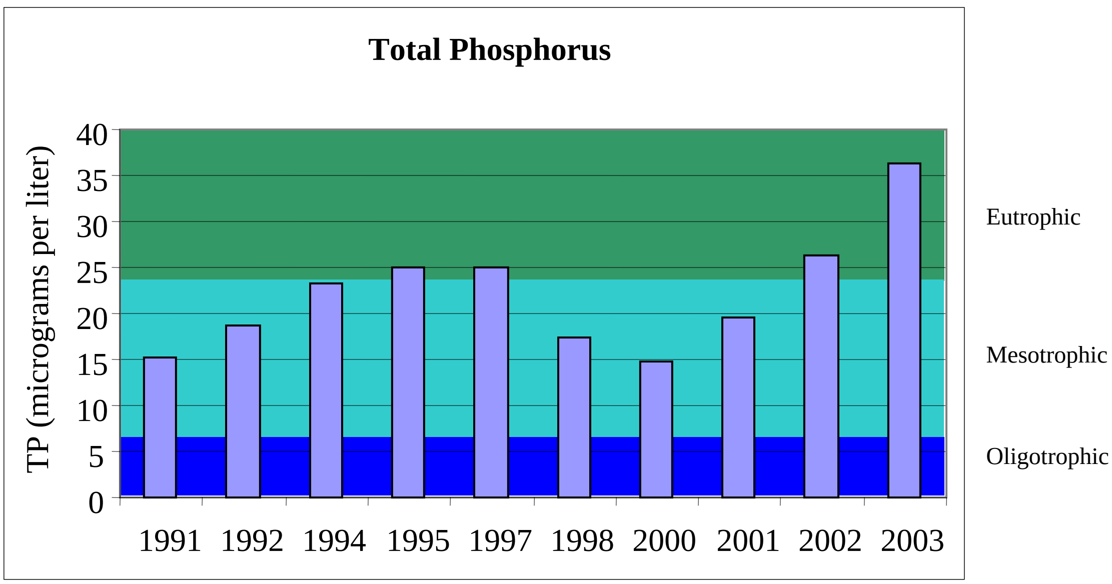

Figure 1. Historical total phosphorus annual averages. Years of single sample collection were omitted to reduce bias created when sampling different times of the year.

The 1991-92, and 1995 hypolimnetic samples allow us to identify possible internal loading events. Total phosphorus concentrations in the hypolimnion during the summer of those years spiked (Table 1). The bottom TP was 78 µg/L, 30 µg/L, and 132 µg/L in July 1991, September 1992, and July 1995 respectively. The surface water TP concentrations were lower at 15 µg/L, 19 µg/L, and 25 µg/L in July 1991, September 1992, and July 1995 respectively. The spikes indicate internal loading is likely occurring where oxygen depletion in the hypolimnion forms favorable conditions for phosphorus to become soluble in the lake water. The total area of the lake bottom that became anoxic and contributed to internal loading is not known. This makes it very diffucult to predict whether internal loading occurred during the years hypolimnetic samples were not collected.

Table 1. Evidence of internal loading.

Date	Total Phosphorus (ug/L)	
	Surface	Bottom
Jul-91	15	78
Sep-92	19	30
Jul-95	25	132

The months during which Secchi data were collected are highly variable from year to year and therefore the yearly averages are not directly comparable (Table 2). However, Secchi depths were somewhat similar in depth from 1990 to 2003 with only depths measured in 2003 considered eutrophic (Figure 2).

Table 2. Secchi depth data collection. Multiple readings in the same month occur from 2000 to 2003 and are represented by “XX”.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
May							X							
June					X	X					X	X	X	XX
July	X	X		X	X	X		X			XX	XX	X	XX
August	X	X	X	X					X	X	X	X	X	XX
September	X	X	X		X	X		X				X		X
October	X	X	X		X						X	X	X	X

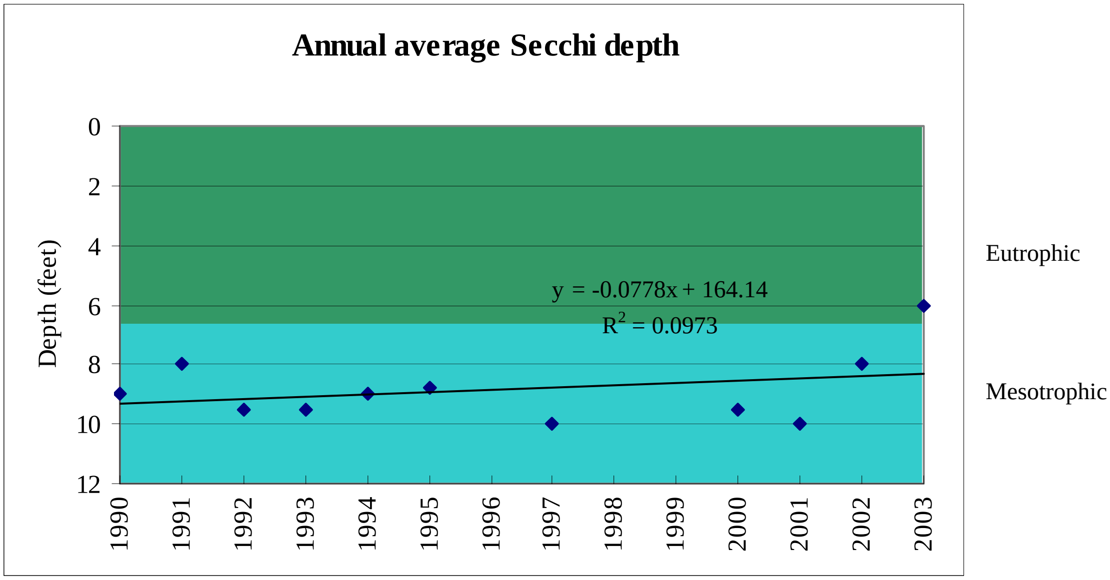

Figure 2. Average annual Secchi depths for Clear Lake (Rock County, WI) from 1990 to 2003. Data for years when only one measurement was collected were omitted to reduce the bias created when sampling at different times of the year.

The historical data shows that Clear Lake is generally mesotrophic with moderate water clarity impairment. Variability is not uncommon from year to year and many times lakes display an oscillating curve as seen in the 10-year period from 1991 to 2000 (Figure 1). Self-help Secchi data are designed to provide a "big picture" of the lake's trophic status. Comparing any one year to another can be misleading because environmental variables, like rainfall amounts, temperature, and etc, can change greatly from year to year. These factors play a major role in how nutrients are used by algae.

3.1 Water Sample Collection

A sample site was established at the deepest location (approximately 16.5 feet) at the East end of the lake. Ecologists from Aquatic Engineering, Inc. (AEI) performed all water measurements and collections from May through October in 2004. Surface samples were collected using a composite surface sampling device from zero to six feet deep. Bottom samples were collected by lowering a Van Dorn sampling device to approximately one foot above the sediment/water interface. Water samples were placed on ice and delivered to WSLOH located in Madison, WI according to WSLOH Lake Planning Grant Bottle, Preservation and Shipping Requirements (5/20/04). Samples were analyzed for total phosphorus, chlorophyll *a*, total Kjeldahl nitrogen, and total suspended solids.

3.2 On-Site Water Quality Measurements

Depth profiles were collected at the water quality monitoring sample site between 10:00 a.m. and 4:00 p.m. on day of sampling with sampling done monthly during the summer sampling periods *(May through October)*. Data points were collected at one meter intervals throughout the water column for dissolved oxygen, pH, conductivity, and temperature with a calibrated SONDE YSI probe. The dissolved oxygen probe was calibrated with oxygen saturated deionized water to 100% saturation. The pH probe was calibrated using a two-point bracketing standards method where the low standard was pH 7.0 and the upper standard was pH 10.0. The conductivity probe was calibrated using a diluted conductivity standard.

3.3 Bathymetric Survey

Transects were created with GIS software prior to conducting the bathymetric survey. Transects were generated 100 feet apart and traversed the lake from east to west (Figure 3). Navigation during the survey was conducted using a WASS enabled GPS connected to a laptop PC with GIS software which allowed the technician to follow the pre-determined transects. A Lowrance LCX18C recording sonar with WASS enabled GPS was used to digitally record the location of the boat and the depth to bottom as the boat traveled the transects. Position and depth data was recorded by the Lowrance sonar unit to a Secure Digital (SD) Card. The information on the SD card was transferred to a desktop computer and read using Lowrance Sonar Viewer v1.2.2. GPS coordinates were recorded for every change in depth of 2 feet from 0 to 16 feet deep (i.e. as the boat traveled a transect the depth would change continuously and the locations where the depth changed from 2' to 4', 4' to 6', 6' to 8', etc. were mapped in ArcMap). Those locations were used to create points which marked the edges of those depth zones. The outline of the lake was used as the zero depth line and points created in ArcMap for each depth zone were grouped to create the contour lines for the 2 through 16 foot depth zones. The surface area of each depth zone was multiplied by two feet to calculate the volume of water at that depth. All volumes from each depth zone were summed to obtain a total lake volume in acre-feet.

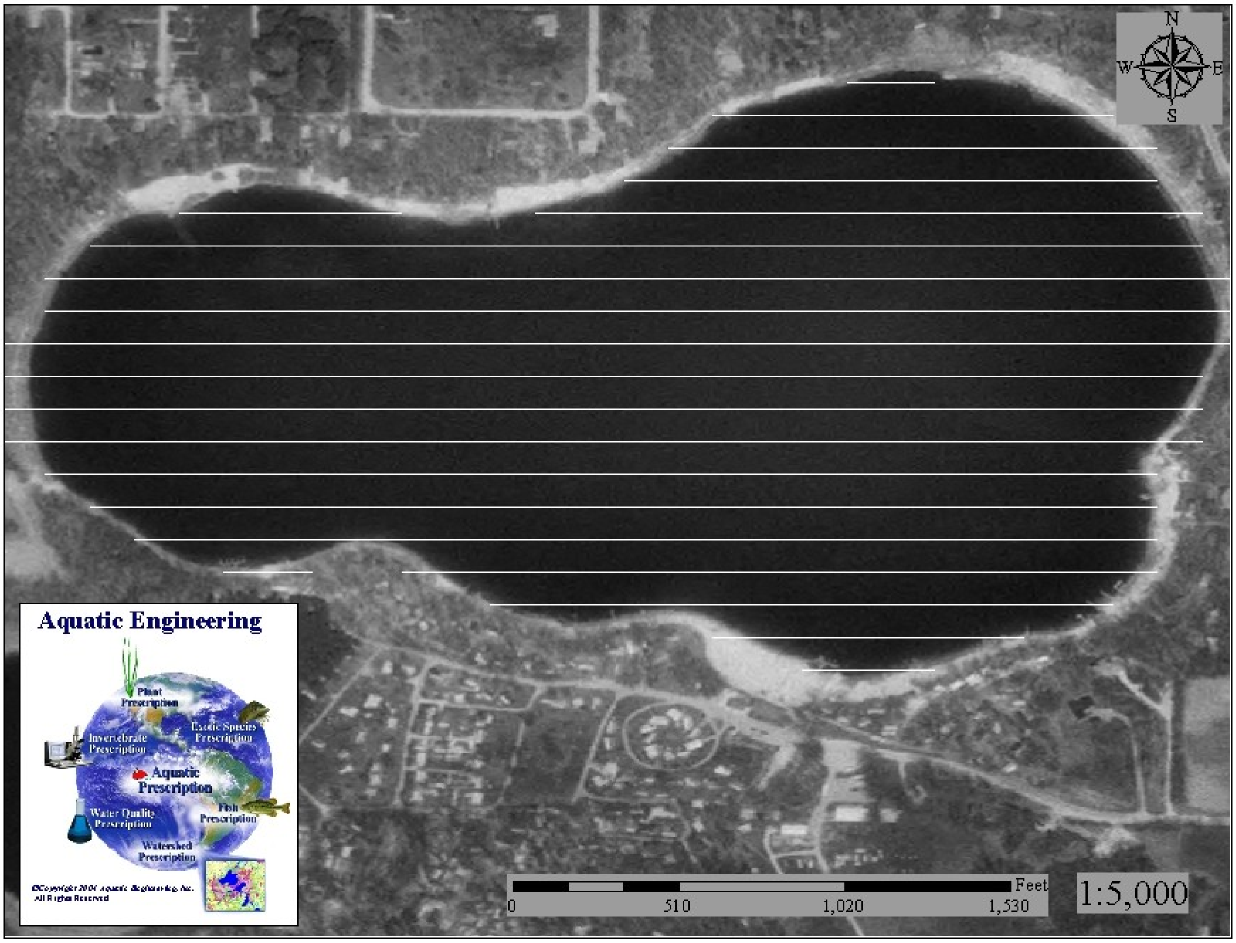

Figure 3. Pre-selected transects for the bathymetric survey of Clear Lake (Rock County, WI.)

3.4 Trophic Status Calculations

Trophic status was calculated for Clear Lake water samples using the following equations (the units of measurement required for each parameter are included as a subscript in the equation):

$TSI_{SD} = 60 – 14.41 * \ln (SD_m)$

$TSI_{chl} = 9.81 * \ln (chl_{\mu g}) + 30.6$

$TSI_{TP} = 14.42 * \ln (TP_{\mu g}) + 4.15$

The following scale is used to evaluate trophic status (Lillie and Mason 1983):

TSI < 40	oligotrophic
40 < TSI < 50	mesotrophic
TSI > 50	eutrophic

3.5 WiLMS Phosphorus Modeling

The WiLMS modeling program available through the WDNR was used to model the phosphorus load for Clear Lake. The watershed area was delineated using a 24k topographical map and land use coverage data was obtained from the county and imported to Arc GIS software for use with the WiLMS software non-point-source pollution estimates. Once in Arc GIS, individual land type coverages were selected and exported as individual shape files based on the functional categories within WiLMS software. Pasture and cropland land type coverages were combined in the land use map. The area was then split 50/50 in order to fulfill requirements for WiLMS analysis. The result was that both are 11 percent of the total watershed even though they are not separate on the coverage map. Land use areas were calculated using HGIS and the total area of each functional category were calculated (Table 3).

Table 3. Land use coverage data for Clear Lake watershed (Rock County, WI).

Land use Category	Area (acres)	Percent Coverage
Agriculture (row crop)	26.5	11
Pasture/Grassland	26.5	11
Urban (high development)	24.6	10
Medium Residential	65.3	26
Wetlands	0.0	0
Forest	22.1	9
Lake Surface	82.0	33
TOTAL	247.0	100

Data for modeling septic system contributions to phosphorus loading was estimated by representatives of the Clear Lake Improvement Association. Assumptions used to perform WiLMS modeling include:

1) 68 full-time residents occupy settlements for 365 days per year = **68 capita years**

2) 56 part-time residents occupy settlements for approximately 120 days per year = **18 capita years**

3) Assumed: for 2 months (8 weekends, 16 days total), weekend guests occupied 94 sites (20% capacity) averaging 2 guests per site = *3,008 guest-days* (16x94x2)

Assumed: for 3 months (90 days), week-long guests occupied 376 sites (80% capacity) averaging 3 guests per site = *101,520 guest-days* (90x376x3)

104,528 campground guest-days annually/365 days per year = **286 capita years**

Total = 68 + 18 + 286 = **372 capital years**

Gaps in background information necessary for a complete nutrient budget include:

1) Hydrological budget for the lake – ground water contributions are unknown

2) Affects of decaying CLP in early summer are not fully understood

3) Internal loading is questionable and hard to estimate when no thermocline is present

4.0 Results

4.1 Water Quality

The water quality measurements collected in 2004 show that Clear Lake is a eutrophic system which does not thermally stratify, has a retention time of approximately 5.25 years, and has physical parameters typical of seepage lakes of Wisconsin.

4.1.1 Phosphorous

Total phosphorus (TP) was reported for each sampling event (Figure 4, Figure 5, Table 4). The surface average monthly TP for Clear Lake in 2004 was 27.5 µg/L and ranged from 23 µg/L to 32 µg/L. The TSI_{TP} value for Clear Lake in 2004 was 51.9. The hypolimnetic phosphorus ranged from 31 µg/L to 118 µg/L in 2004 (Figure 5). The high hypolimnetic phosphorus was from the July 29th sample which was more than four times the surface concentration and suggests internal loading.

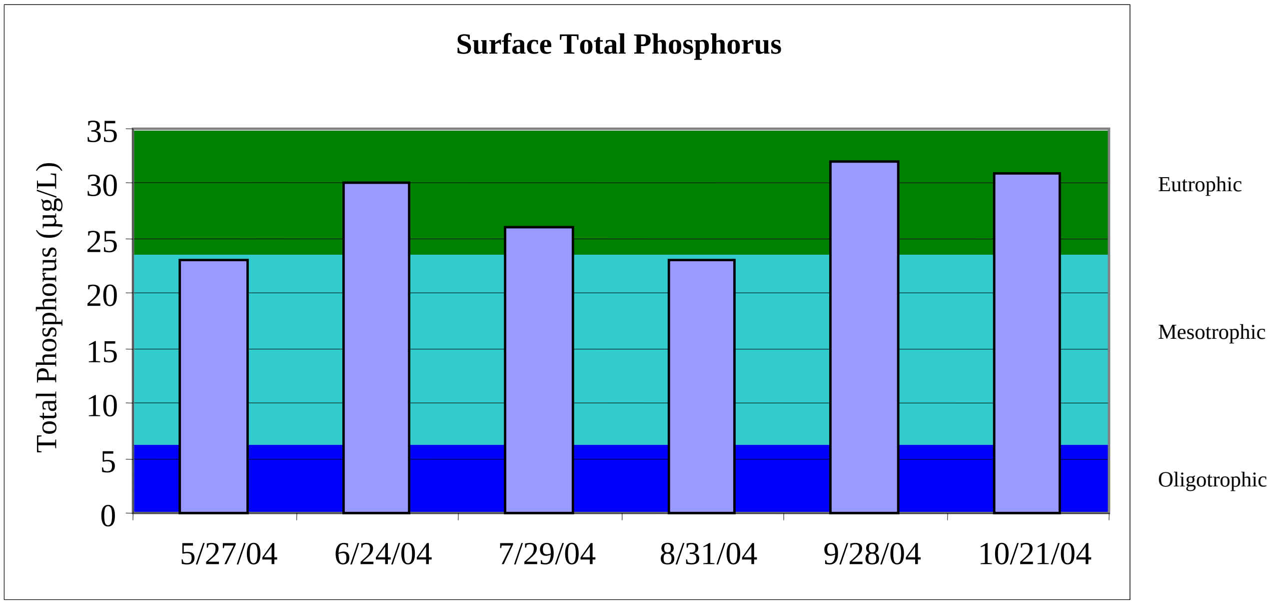

Figure 4. Total phosphorus measurements from the surface water of Clear Lake (Rock County, WI.) 2004.

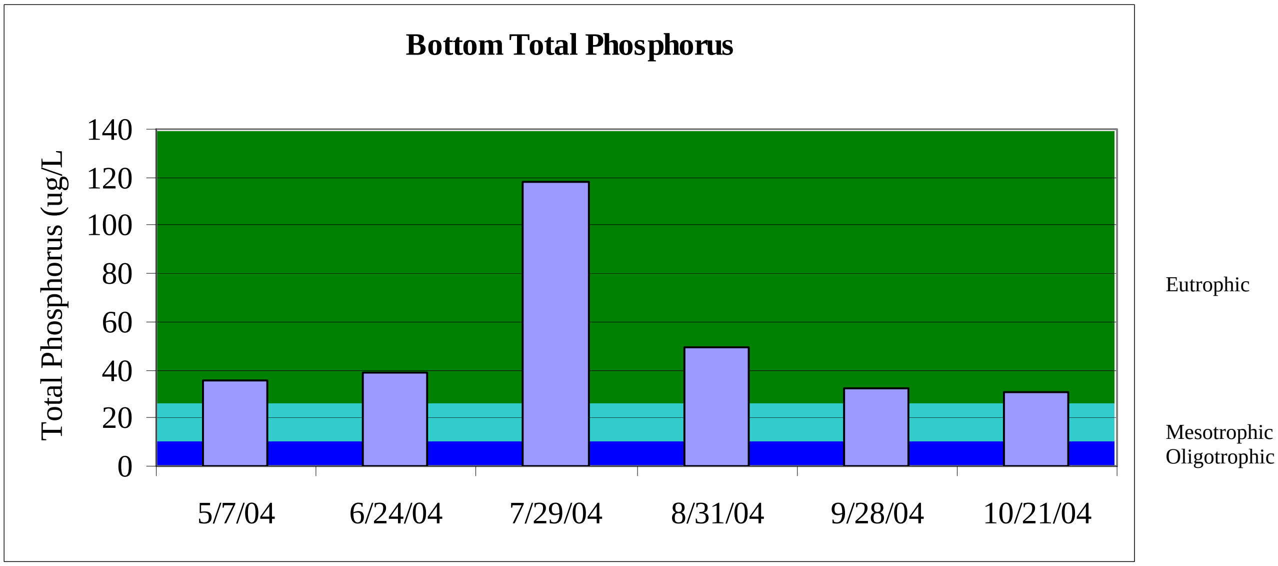

Figure 5. Total phosphorus of bottom samples at Clear Lake (Rock County, WI) 2004.

Table 4. Total phosphorus concentrations determined from surface and bottom water column samples in Clear Lake (Rock County, WI) 2004.

Date	Surface total phosphorus (µg/L)	Bottom total phosphorus (µg/L)
5/27/04	23[a]	36[b]
6/24/04	30	39
7/29/04	26	118
8/31/04	23	49
9/28/04	32	32
10/21/04	31	31

[a] duplicate quality control exceeded
[b] matrix duplicate quality control exceeded

4.1.2 Chlorophyll *a*

Chlorophyll *a* was also reported for the June through October sampling events (Figure 6, Table 5). The average chlorophyll *a* for Clear Lake in 2004 was 10.7 µg/L and ranged from 5.89 µg/L to 13.0 µg/L. The TSI_{chl} value for Clear Lake in 2004 is 53.9.

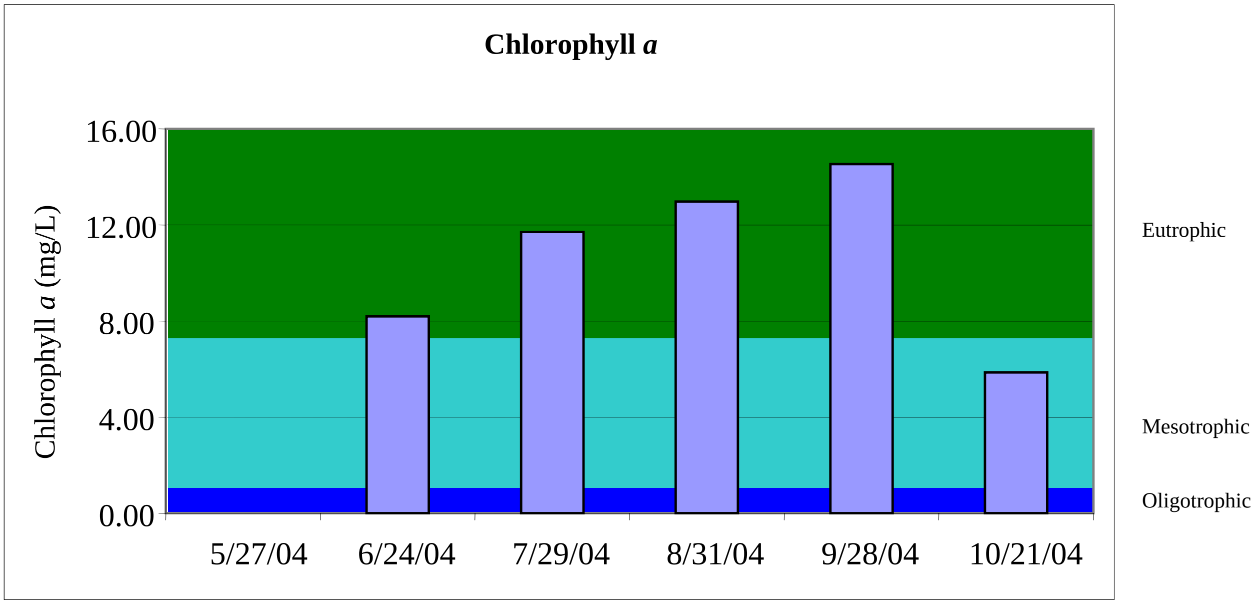

Figure 7. Chlorophyll *a* measurements for Clear Lake (Rock County, WI.) 2004.

Table 5. Chlorophyll *a* concentrations from Clear Lake (Rock County, WI) 2004.

Sample date	Chlorophyll *a* (µg/L)
5/27/04	Not sampled
6/24/04	8.15
7/29/04	11.7
8/31/04	13.0
9/28/04	14.5
10/21/04	5.89[a]

[a]Duplicate quality control exceeded

4.1.3 Secchi Depth

Secchi disk readings were collected six times in 2004 (Figure 7, Table 6) with an average reading of 6.0 feet. The maximum Secchi disk reading was 9.0 feet and the minimum was 3.75 feet. The TSI_{SD} for Clear Lake in 2004 is 51.3.

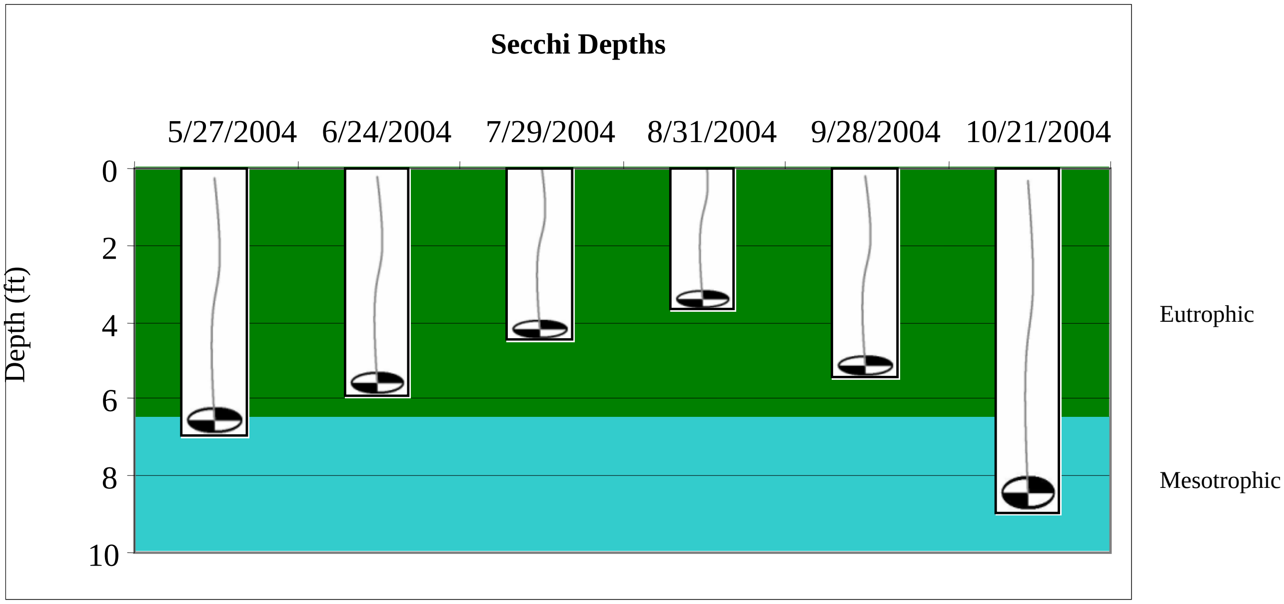

Figure 8. Secchi depth readings from the water quality sample location in Clear Lake (Rock County, WI.) 2004

Table 6. Secchi depths for Clear Lake (Rock County, WI) 2004.

Date	Secchi Depth (feet)
5/27/04	7.0
6/24/04	6.0
7/29/04	4.5
8/31/04	3.75
9/28/04	5.5
10/21/04	9.0

4.1.4 Other Parameters

Other parameters measured were total Kjeldahl nitrogen, soluble reactive phosphorus, temperature, conductivity, and pH. These chemical and physical parameters affect water quality differently and are discussed in the following sections.

Total Kjeldahl Nitrogen (TKN)

The Kjeldahl technique is a laboratory test for measuring the amount of organic nitrogen contained in water. The organic nitrogen can be either dissolved or suspended particulate matter and is calculated by the total Kjeldahl nitrogen concentration minus the ammonia concentration. High levels of organic nitrogen in water from animal and human waste, decaying organic matter, and live organic material like tiny algae cells can cause organic nitrogen enrichment of lake water (Tippecanoe Environmental Lake and Watershed Foundation 2005) and may indicate excessive production or organic pollution from the watershed. Nitrogen, like phosphorus, is an essential macronutrient needed for algal production. Most lakes, however, are phosphorus limited and attempts to reduce lake nitrogen levels may have little effect on algal biomass (Holdren 2001). The average TKN for Lake Clear in 2004 was 857 µg/L and had a N:P ratio of approximately 31 to 1 (by mass). The high N:P ratio supports the fact that Clear Lake is phosphorus limited in that a N:P ratio over 7:1 by weight is phosphorus limited.

Temperature

Temperature plays a major role in water quality, especially in lakes that become thermally stratified. Thermal stratification occurs when water in the top layer of a lake becomes heated by the sun and insufficient mixing action allows the warm water layer at the surface (epilimnion) to "float" on top of a cooler, more dense layer of water near the bottom (hypolimnion). As the summer progresses, the difference in density between the two layers increase, and, when the difference becomes too great for wind energy to mix, the lake becomes stratified (Holdren et al. 2001). The region between the epilimnion and hypolimnion is called the metalimnion. The particular depth within the metalimnion where the rate of change in temperature is greatest is called the thermocline (Holdren et al. 2001). In 2004 Clear Lake weakly stratified with the greatest temperature difference, from surface to bottom, of 5.83 degrees Celsius recorded during the July 29th sampling date (Figure 8).

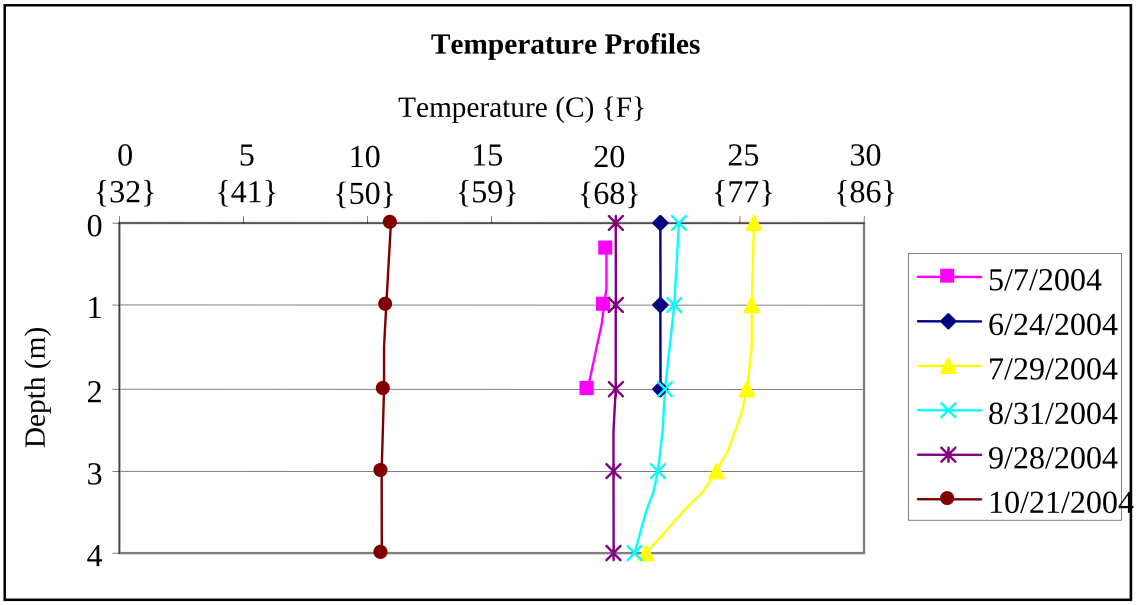

Figure 9. Temperature profiles for Clear Lake (Rock County, WI.) 2004.

Conductivity

Conductivity in lake water comes from a variety of sources like agricultural and industrial runoffs that contribute large amounts of dissolved salts, and sewage from septic tanks and treatment facilities which raises the conductive properties in water. Another source of conductive properties comes from the hypolimnion of thermally stratified lakes. As planktonic algae die throughout the summer, a "rain" of dead algal cells is constantly falling to the lake sediments. Bacteria in or near sediments aide in decomposition of algal cells by breaking high energy bonds stored in the algal cell wall. This decomposition produces CO_2 that is released into the water where it rapidly dissolves into carbonic acid, bicarbonate and carbonate ions that add to the conductive properties of the lake water. The average conductivity at a depth of two meters for Clear Lake in 2004 was 248 µS/cm which is typical of freshwater lakes.

Dissolved Oxygen

Dissolved oxygen plays an important role in both the biology and chemical properties of a lake. Anoxic conditions make certain compounds more soluble in water. The chemical and biological properties are most affected during summer stratification when the hypolimnion does not mix with the oxygen rich epilimnion. Clear Lake briefly and weakly stratified in 2004, and there was a concurrent oxygen gradient present from July to August (Figure 9). Readings from July and August show that dissolved oxygen levels dropped sharply between the two and three meter sample points. The oxygen saturation in July at the surface was 114% while at three meters deep it was only 15%. A similar, but less dramatic decrease in oxygen saturation was present during the August sampling period. This oxygen depletion is likely due to a high biological oxygen demand of algae, plankton and bacteria. Decomposition of organic waste near the sediment consumes oxygen faster than it can be replaced by photosynthesis and natural mixing of the lake water. One potential result of oxygen depletion is phosphorus release at the sediment surface.

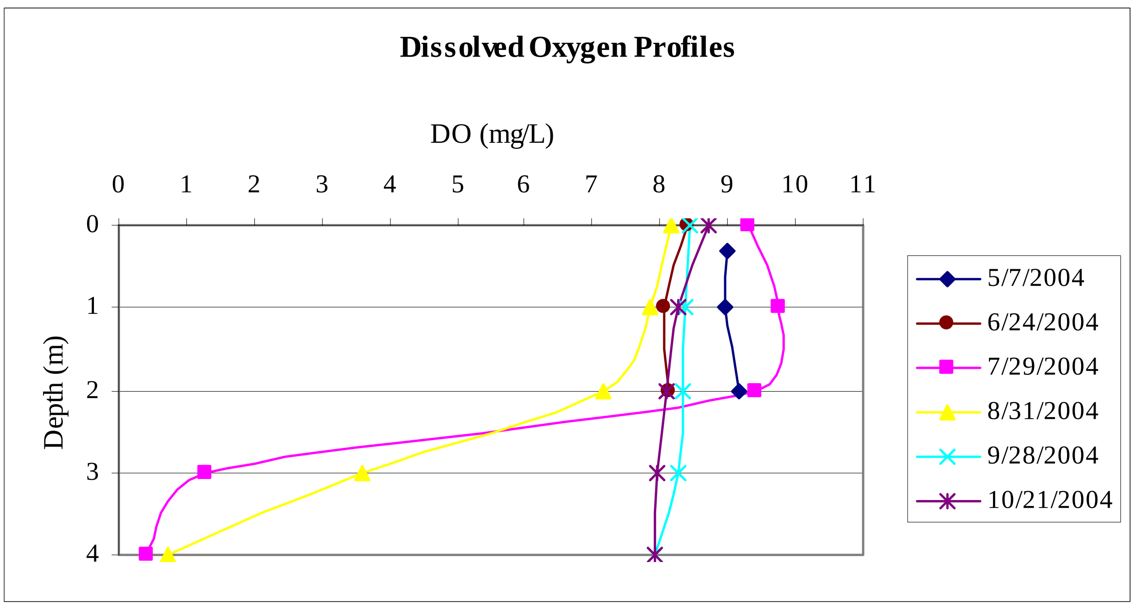

Figure 10. Dissolved oxygen profiles for Clear Lake (Rock County, WI.) 2004.

pH

pH is an important measurement to measure because many chemical compound form are caused by pH is a measurement of hydrogen ions in a solution that results in the solution being acidic, basic, or neutral. A neutral pH is a pH of 7 with a lower pH being acidic and a higher pH resulting in a basic solution. If the pH gets too high or too low, adverse affects of an ecosystem likely will result. Clear Lake data indicate that the pH was fairly consistent for the first part of the 2004 summer. However, for the July and August samplings, there was a decrease in pH starting at two meters and continued to decrease to the bottom of the lake (Figure 10). This is trend is similar to that of the temperature profiles and indicate that Clear Lake weakly stratified.

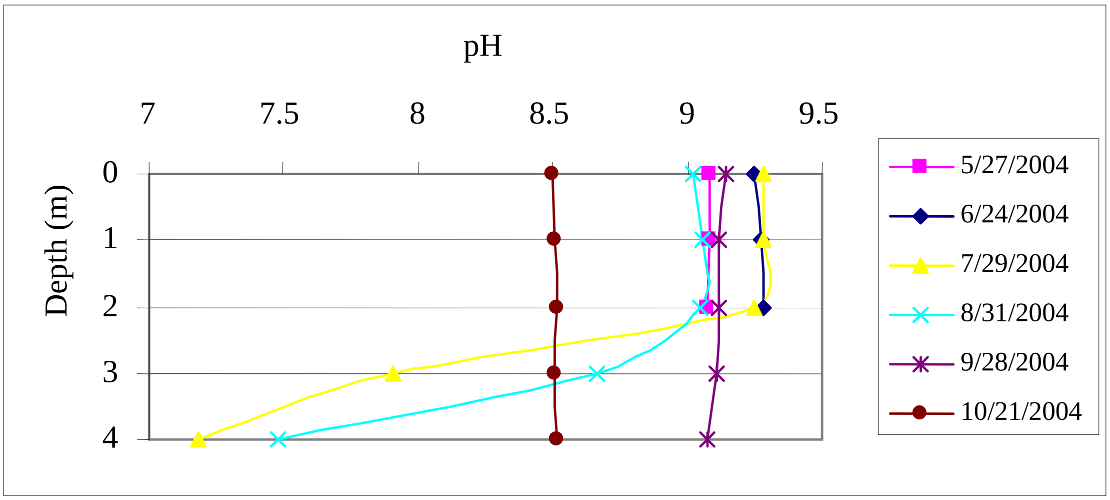

Figure 11. pH profiles for Clear Lake (Rock County, WI) 2004

4.2 Bathymetric Survey

The bathymetric survey conducted in the spring of 2005 revealed that the current bathymetric map on file with the WDNR was outdated. The maximum depth listed on the current DNR map was 10 feet where the actual maximum depth is 16.5 feet (Figure 11). The current map shows a 10-feet-deep area that stretches north and south on the east end of the lake. This survey revealed that the 10-feet-deep and greater area of the lake stretches westward more than previously recorded. Also noted in the most recent survey is a 10-foot deep area in the north-west corner of the lake not present on past maps. Based on this survey, the lake contains 700 acre-feet of water. The 700 acre-feet of water is broken down in two foot intervals in Table 7.

Table 7. Depth volumes for Clear Lake (Rock County, WI) in 2004.

Depth (feet)	Acres	Acre feet
0-2	82	164
2-4	77.3	155
4-6	71.4	143
6-8	59.2	118
8-10	37.3	74.6
10-12	13.5	27.0
12-14	6.5	13.0
14-16	2.5	5.0
16+	0.1	0.2

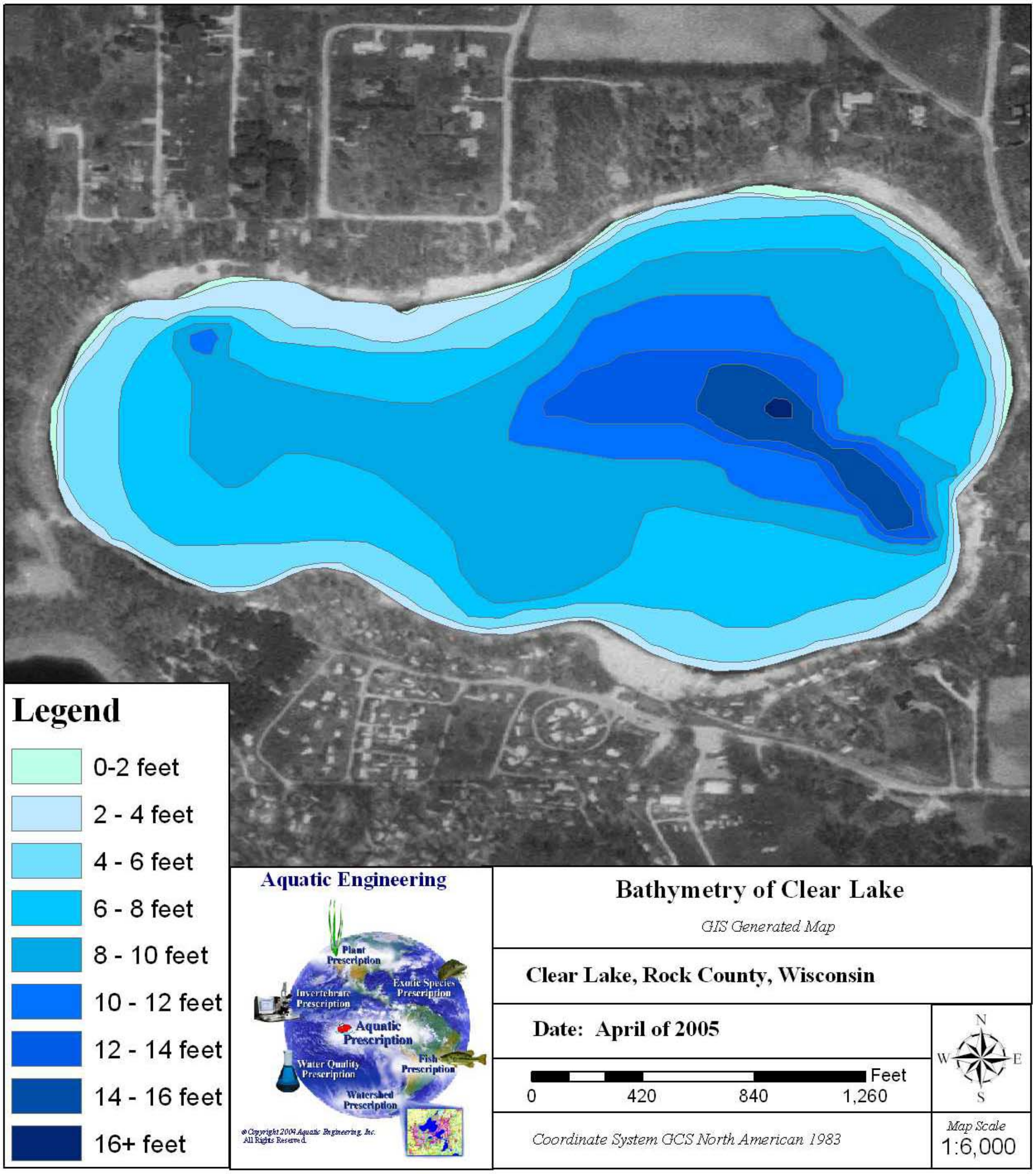

Figure 12. Bathymetry of Clear Lake (Rock County, WI.)

4.3 Watershed Analysis and Phosphorus Budget

The WiLMS program produced the most likely non-point source phosphorus load which illustrates the major source of phosphorus to Clear Lake is septic systems (Figure 12). However, if septic systems are not a source, high and medium urban densities result in the majority of phosphorus sources (Figure 13). Residential and commercial development also plays a large role in phosphorus contributions. If residential contributions from high and medium urban densities were both reduced by half, the septic systems become the major point source of phosphorus (Figure 14). The watershed of Clear Lake was delineated with the most current topographical data (Figure 15). It is recommended that the watershed be redelineated when topographical data is updated. By doing this, the delineated watershed will be more accurate. Land use coverage was derived within the watershed from the WDNR webview. The result is that phosphorus loading from the Clear Lake watershed is split into seven different categories with the majority of loading originating from residential and cropland/pasture (Figure 16).

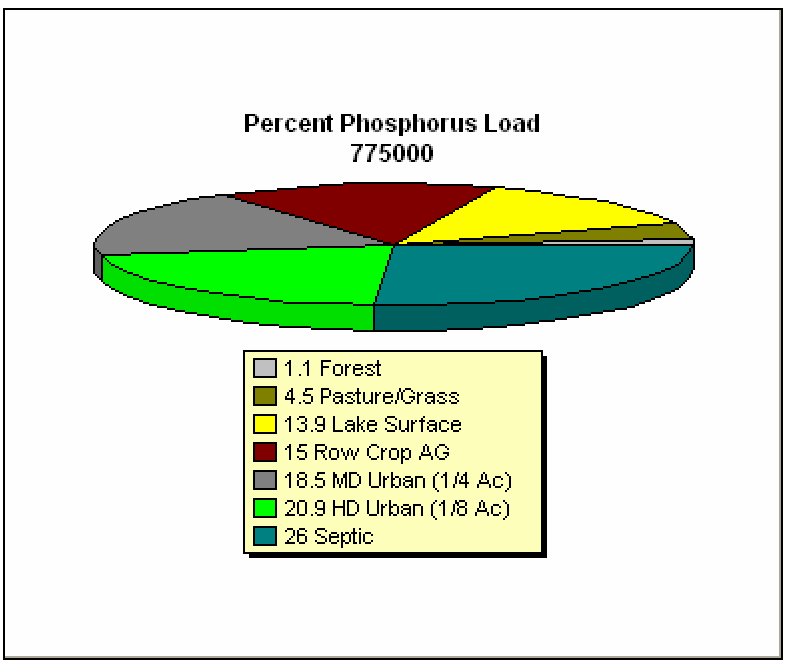

Figure 13. Sources of phosphorus for Clear Lake (Rock County, WI.). Legend definitions: AG = agriculture, MD = medium density, HD = high density.

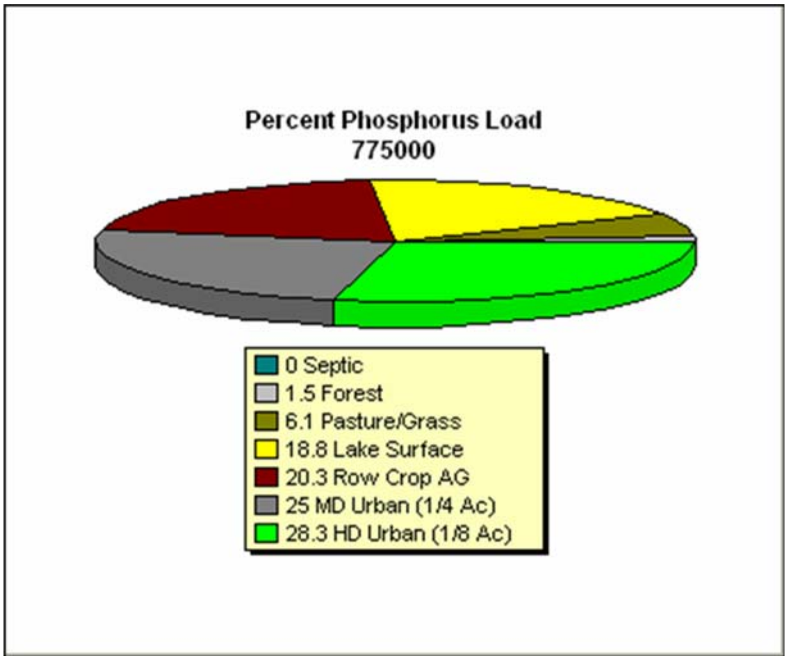

Figure 14. WiLMS phosphorus load without any septic contributions to Clear Lake (Rock County, WI). Legend definitions: AG = agriculture, MD = medium density, HD = high density.

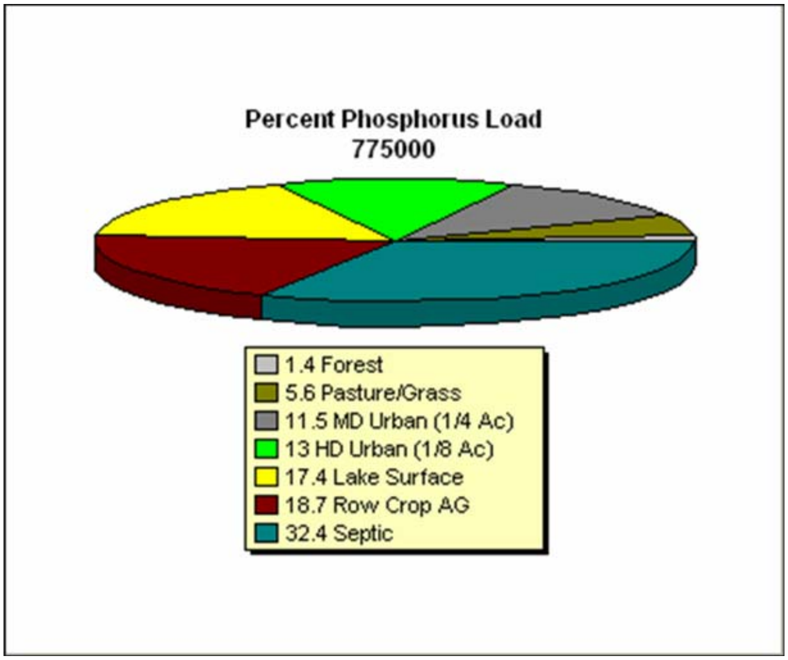

Figure 15. WiLMS phosphorus load with half the amount of urban contributions to Clear Lake (Rock County, WI). Legend definitions: AG = agriculture, MD = medium density, HD = high density.

There are critical sites that can lead to additional phosphorus loading to Clear Lake. These critical sites are locations where phosphorus inputs can occur and possibly lead to adverse effects to Clear Lake's ecosystem. There are four main types of sites that can lead to problems in Clear Lake which are nonbuffered shoreline, cattle travel, campground, and unmaintained septic systems. Nonbuffered shoreline sites do not allow ample absorption time for runoff resulting in a high volume of runoff entering Clear Lake. If nonbuffered shorelines where replaced with buffered shorelines, less direct runoff would enter Clear Lake because the buffer zone would absorb the majority of the runoff. The second listed critical site is cattle sites where cattle are in close proximity to Clear Lake where their feces can be either directly or indirectly be deposited in Clear Lake. Another critical phosphorus loading site is at the campground located on the lake. Up until 2006, gray water dumping was still allowed at the camp ground and with the camp ground averaging 104,528 guests per year, this likely is a major contribution of phosphorus. The last group of critical sites is locations where there are unmaintained septic systems. Unmaintained septic systems may have unknown leaks that likely would drain into Clear Lake causing phosphorus loading. Improving any or all of these critical sites of phosphorus loading would help prevent further degradation of Clear Lake's water quality.

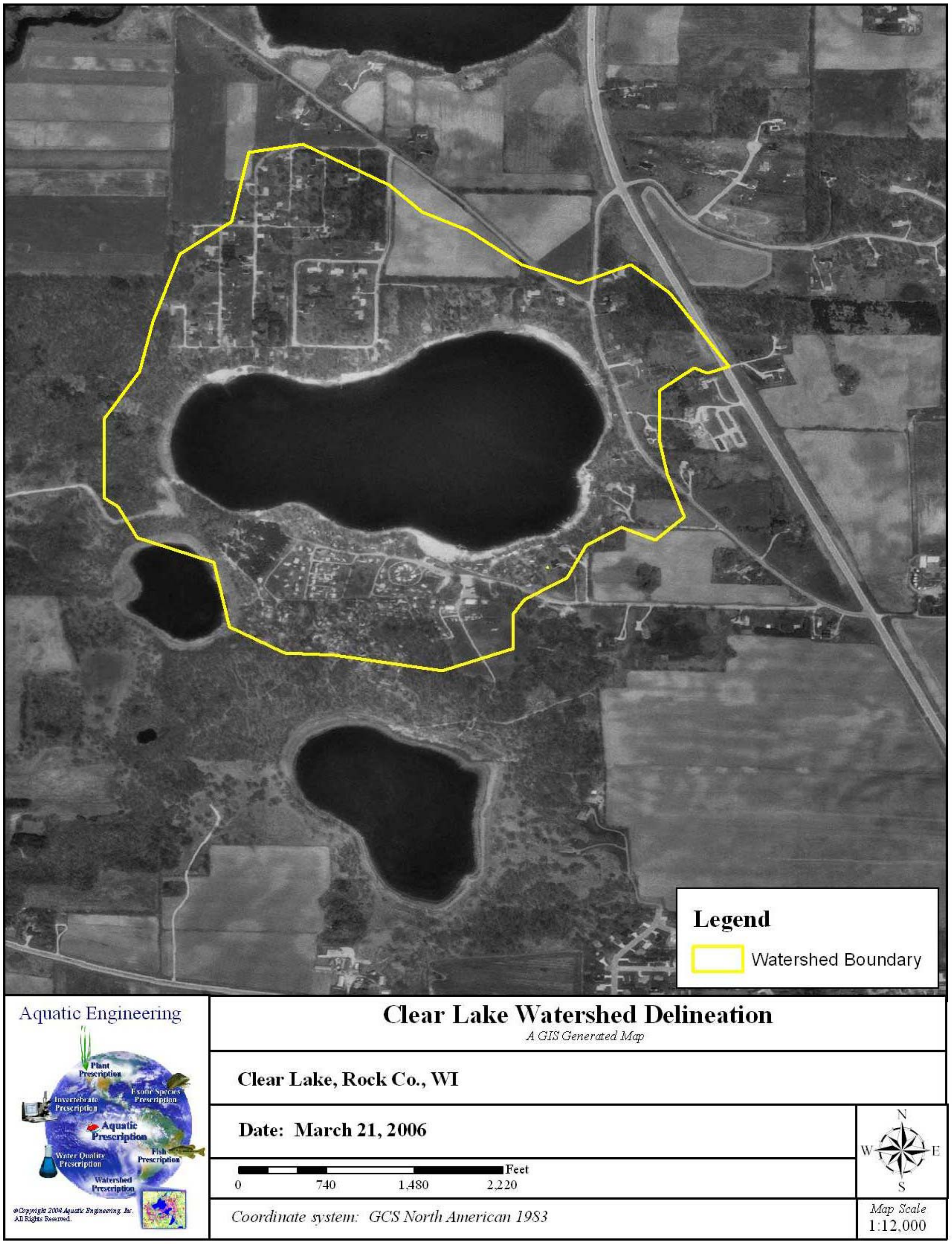

Figure 16. Watershed of Clear Lake (Rock County, WI.)

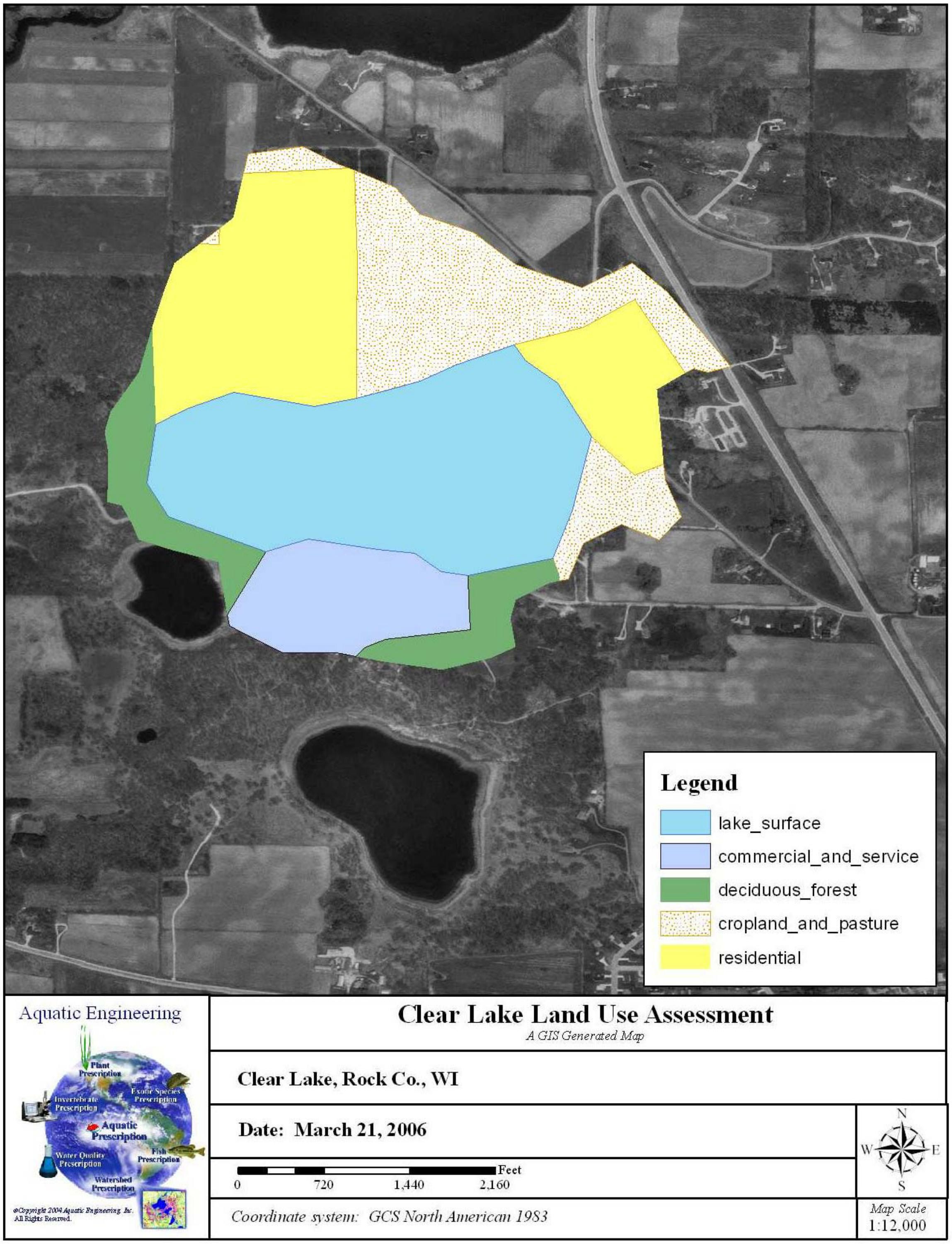

Figure 17. Land use assessment for Clear Lake (Rock County, WI.) Note: cropland and pasture land use coverage were combined in order to fulfill requirements of WiLMS.

5.0 Discussion

5.1 Trophic Status Index

Trophic status indices used in the evaluation of the 2004 water quality data for Clear Lake are one-dimensional analyses of the actual productivity (or nutrient status) of the lake. For a true understanding of trophic status, one has to consider the total biological processes within the body of water. The total processes would consider aquatic macrophytes, zooplankton, macroinvertebrates and wildlife activity within the lake. The amount of resources required to monitor each parameter are substantial and a true trophic status analysis would not be financially practical. For this reason, many scientists use the method developed by Carlson in 1977 which focuses on algal production.

Algal production can be measured directly by measuring the amount of chlorophyll *a* in the water column. The Carlson method also allows users to calculate the TSI of a lake by considering total phosphorus and Secchi depth. Total phosphorus and Secchi depths can be used to estimate TSI because there is a good understanding of how to relate algal productivity (chlorophyll *a*) to either value. Since chlorophyll *a* concentrations are most directly related to algal production, TSI_{Chl} is the most accurate value. Averaging the three TSI values really provides no better estimate of trophic status because it averages a good predictor with two lesser predictors (Lillie and Mason, 1983).

To interpret the results of the three TSI values you need to consider how each measurement is related to algal production and what factors affect those measurements. For example, if a lake has equally low TSI_{SD} and TSI_{Chl} values but the TSI_{TP} is much higher, you can conclude that some external factor is limiting algal growth (e.g. zooplankton predation, toxins, or the lake is nitrogen limited).

The TSI values for Clear Lake in 2004 show that Clear Lake was a eutrophic lake in 2004. Secchi depth, chlorophyll *a* and total phosphorus all support this interpretation. Clear Lake has qualities expected of the eutrophic status that seasonally occur with phosphorus and chlorophyll *a* levels. Compared to past data, Clear Lake has been gradually in increasing in TSI values and in 2004 Clear Lake had a TSI value high enough to be considered eutrophic. As part of a future monitoring strategy, future TSI values can be calculated and annually compared to historical data. This will indicate whether the eutrophication process is increasing, decreasing, or remaining constant. The TSI value of a lake can change dramatically from year to year when environmental conditions are significantly different so use caution when evaluating trends. The more samples collected per year, up to bi-weekly, improves trends and identification according to a data evaluation study by Susan Knight of the WDNR. In addition, the more years samples are collected, the better one will be able to determine long-term trends.

5.2 Phosphorus Budget

The phosphorus budget created using WiLMS modeling did not account for every source of phosphorus entering the lake. Only non-point source pollution calculations are considered in this budget therefore, other potential sources of phosphorus include ground water, CLP, and internal loading. A complete hydrologic budget would indicate the amount of ground water entering the lake. However, ground water interactions have not been well documented for Clear Lake. Samples of the nearby ground water would indicate that phosphorus concentration and a volume weighted calculation could be performed to determine the annual contribution of phosphorus made by ground water interactions.

Another potential source not included in the WiLMS analysis is internal loading. The WiLMS software has the capability of calculating internal loading but was designed to do so for thermally stratified lakes and not for lakes that do not thermally stratify like Clear Lake in 2004. However, oxygen depletion did occur near the sediment at the water quality monitoring station which was most likely due to a high biological oxygen demand created by microbacteria metabolizing organic matter found in the sediment. The oxygen depletion, even in the absence of a thermocline, could cause conditions favorable for internal loading of phosphorus. The data collected in 2004 shows more than four-fold increase in TP concentrations near the sediment and suggests a source of phosphorus is present. The source could be internal loading from the sediments, ground water interactions, or a combination of the two.

A third source of phosphorus unaccounted for is decaying CLP. A single acre of monotypic CLP is capable of releasing 5.5 pounds of phosphorus (McComas, 2000). In 2004, CLP was mapped where it was present, regardless of its density and not just in monotypic stands. Therefore, we can not estimate phosphorus release from CLP based on the 2004 distribution data. Besides CLP, other plants take up nutrients from the sediment which are later released into the lake water during annual die-off.

6.0 Recommendations

Our study revealed the water quality of Clear Lake is impacted by three components – surface runoff, internal loading/ground water interaction, and aquatic plant decomposition. Only surface runoff can be estimated based on information collected during this monitoring.

The Clear Lake Improvement Association is currently developing an aquatic plant management plan. The lake experiences some dense patches of curly-leaf pondweed (CLP) growth in the spring but the extent of growth has not been formally documented. The lake also suffers from dense stands of nuisance native plants. Managing major curly-leaf pondweed (CLP) populations and nuisance native plants will be addressed within the aquatic plant management plan. Managing the plant community may help reduce algal bloom frequency and severity by changing the way the nutrients and energy are used within the lake.

The Clear Lake Association should take the following prioritized steps to at least maintain, if not improve, the quality of water within Clear Lake.

Short-term priorities

- 1º Public education and implementation of buffer strips and shoreline restoration
- 1º Take semi-monthly surface and bottom water samples from May to October one year out of every three and have them analyzed for TP, and Chl *a*. If large manipulation, 10 acres or 10% of the littoral zone, are warranted, TKN will have to be determined.
- 1º Continue annual participation in WDNR's Self-help Secchi depth monitoring. Secchi depth should be recorded bi-weekly from May to October
- 1º Promote rain gardens to reduce roof runoff
- 2º Control CLP growth in the spring to reduce mid-summer phosphorus inputs
- 2º Remove nuisance plant material to reduce the amount of nutrients cycled each year

- 3º Have a complete hydrologic budget for the lake performed

Long-term

- Work towards creating rules to lessen the impact of the three culverts located on the lake and minimize the effects of current and future development
- Consider an Association “savings account” for future management activities
- Evaluate the implementation of physical control devices such as aerators or circulators
- Evaluate the applicability of a whole-lake alum treatment

7.0 References

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Appendix A
WSLOH Water Quality Lab Reports

Field #	Sample Description	Sample Collector	DNR Parameter Description	Result value	Units
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	CONDUCTIVITY AT 25C	214	UMHOS/CM
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	TOTAL DISSOLVED SOLIDS 180 C	120	MG/L
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	TEMPERATURE AT LAB	ICED	C
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	PH LAB	9.89	SU
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	ALKALINITY TOTAL CACO3	91	MG/L
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	NITROGEN NH3-N DISS	0.11	MG/L
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	NITROGEN KJELDAHL TOTAL	1.64	MG/L
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	NITROGEN NO3+NO2 DISS (AS N)	ND	MG/L
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	PHOSPHORUS TOTAL	*0.168	MG/L
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	PHOSPHORUS TOTAL DISS	0.108	MG/L
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	PHOSPHATE ORTHO DISS	**	MG/L
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	SAMPLE SIZE LITERS	200	ML
TOP-52704	MID-LAKE - 2M INTEGRATED SURFACE WATER	OSMON	CHLOROPHYLL A, FLUORESCENCE (WELSCHMAYER 1994)	19.4	UG/L
BOT	MID-LAKE - VAN DORN	OSMON	CONDUCTIVITY AT 25C	214	UMHOS/CM
BOT	MID-LAKE - VAN DORN	OSMON	TOTAL DISSOLVED SOLIDS 180 C	128	MG/L
BOT	MID-LAKE - VAN DORN	OSMON	TEMPERATURE AT LAB	ICED	C
BOT	MID-LAKE - VAN DORN	OSMON	PH LAB	9.87	SU
BOT	MID-LAKE - VAN DORN	OSMON	ALKALINITY TOTAL CACO3	92	MG/L
BOT	MID-LAKE - VAN DORN	OSMON	NITROGEN NH3-N DISS	ND	MG/L
BOT	MID-LAKE - VAN DORN	OSMON	PHOSPHORUS TOTAL	*0.091	MG/L
BOT-62404	MID-LAKE - VAN DORN	OSMON	CONDUCTIVITY AT 25C	238	UMHOS/CM
BOT-62404	MID-LAKE - VAN DORN	OSMON	TOTAL DISSOLVED SOLIDS 180 C	146	MG/L
BOT-62404	MID-LAKE - VAN DORN	OSMON	TEMPERATURE AT LAB	ICED	C
BOT-62404	MID-LAKE - VAN DORN	OSMON	PH LAB	9.18	SU
BOT-62404	MID-LAKE - VAN DORN	OSMON	ALKALINITY TOTAL CACO3	102	MG/L
BOT-62404	MID-LAKE - VAN DORN	OSMON	NITROGEN NH3-N DISS	*ND	MG/L
BOT-62404	MID-LAKE - VAN DORN	OSMON	PHOSPHORUS TOTAL	*0.078	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	CONDUCTIVITY AT 25C	241	UMHOS/CM
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	TOTAL DISSOLVED SOLIDS 180 C	150	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	TEMPERATURE AT LAB	ICED	C
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	PH LAB	9.11	SU
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	ALKALINITY TOTAL CACO3	104	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	NITROGEN NH3-N DISS	*ND	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	NITROGEN KJELDAHL TOTAL	*1.28	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	NITROGEN NO3+NO2 DISS (AS N)	*ND	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	PHOSPHORUS TOTAL	*0.077	MG/L

Field #	Sample Description	Sample Collector	DNR Parameter Description	Result value	Units
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	PHOSPHATE ORTHO DISS	0.024	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	CHLOROPHYLL A, FLUORESCENCE (WELSCHMAYER 1994)	**	UG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	CONDUCTIVITY AT 25C	241	UMHOS/CM
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	TOTAL DISSOLVED SOLIDS 180 C	150	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	TEMPERATURE AT LAB	ICED	C
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	PH LAB	9.11	SU
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	ALKALINITY TOTAL CACO3	104	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	NITROGEN NH3-N DISS	*ND	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	NITROGEN KJELDAHL TOTAL	*1.28	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	NITROGEN NO3+NO2 DISS (AS N)	*ND	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	PHOSPHORUS TOTAL	*0.077	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	PHOSPHATE ORTHO DISS	0.024	MG/L
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	SAMPLE SIZE LITERS	200	ML
TOP-62404	MID-LAKE - INTEGRATED SURFACE	OSMON	CHLOROPHYLL A, FLUORESCENCE (WELSCHMAYER 1994)	*25.6	UG/L
TOP-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	CONDUCTIVITY AT 25C	257	UMHOS/CM
TOP-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	TOTAL DISSOLVED SOLIDS 180 C	154	MG/L
TOP-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	TEMPERATURE AT LAB	ICED	C
TOP-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	PH LAB	8.56	SU
TOP-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	ALKALINITY TOTAL CACO3	*106	MG/L
TOP-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	NITROGEN NH3-N DISS	*ND	MG/L
TOP-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	NITROGEN KJELDAHL TOTAL	*1.15	MG/L
TOP-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	NITROGEN NO3+NO2 DISS (AS N)	*ND	MG/L
TOP-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	PHOSPHORUS TOTAL	*0.072	MG/L
TOP-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	PHOSPHATE ORTHO DISS	0.017	MG/L
TOP-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	SAMPLE SIZE LITERS	200	ML
TOP-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	CHLOROPHYLL A, FLUORESCENCE (WELSCHMAYER 1994)	30.8	UG/L
BOT-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	CONDUCTIVITY AT 25C	271	UMHOS/CM
BOT-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	TOTAL DISSOLVED SOLIDS 180 C	164	MG/L
BOT-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	TEMPERATURE AT LAB	ICED	C
BOT-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	PH LAB	8.1	SU
BOT-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	ALKALINITY TOTAL CACO3	*113	MG/L
BOT-072904	MID-LAKE - INTEGRATED SURFACE SAMPLER	STRASSER	NITROGEN NH3-N DISS	*0.030	MG/L

Appendix B
Onsite chemical and physical characteristics

On-site chemical and physical characteristics for Clear Lake

Date	Depth (m)	DO (mg/L)	DO (%)	Cond (ms/cm)	pH	Temp (C)	Turb top (NTU)	Turb bot (NTU)	Secchi (ft)
5/27/2004	0.32	8.99	98.2	0.239	9.08	19.62	4.09	4.4	7
5/27/2004	1	8.97	97.8	0.239	9.08	19.53			
5/27/2004	2	9.18	98.6	0.24	9.07	18.88			
5/27/2004	0.28	8.93	97.6	0.239	9.09	19.62			
6/24/2004	0	8.4	95.6	0.241	9.25	21.75	nc	nc	6
6/24/2004	1	8.07	92.1	0.242	9.27	21.77			
6/24/2004	2	8.14	92.7	0.241	9.28	21.77			
6/24/2004	0	8.24	93.8	0.241	9.29	21.77			
7/29/2004	0	9.31	114	0.24	9.28	25.53	nc	nc	4.5
7/29/2004	1	9.76	119	0.239	9.28	25.47			
7/29/2004	2	9.42	115	0.241	9.25	25.31			
7/29/2004	3	1.27	15	0.27	7.91	24.01			
7/29/2004	4	0.42	4.5	0.322	7.18	21.23			
7/29/2004	bottom	0.26	2.9	0.358	7.37	19.7			
8/31/2004	0	8.17	94.5	0.227	9.02	22.54	5.05	8.23	3.75
8/31/2004	1	7.84	90.3	0.226	9.06	22.33			
8/31/2004	2	7.15	81.8	0.226	9.05	21.96			
8/31/2004	3	3.6	40.8	0.233	8.66	21.71			
8/31/2004	4	0.72	8.6	0.279	7.48	20.8			
8/31/2004	botom	0.36	4	0.308	7.52	19.96			
9/28/2004	0	8.44	93	0.263	9.14	19.98	4.52	11.9	5.5
9/28/2004	1	8.37	92	0.263	9.12	20.01			
9/28/2004	2	8.35	92	0.263	9.12	20			
9/28/2004	3	8.27	91	0.263	9.11	19.95			
9/28/2004	4	7.93	87	0.263	9.07	19.88			
9/28/2004	bottom	7.51	82	0.263	9.06	19.46			
10/21/2004	0	8.73	79	0.276	8.5	10.91	5.26	3.32	9
10/21/2004	1	8.25	74	0.275	8.51	10.72			
10/21/2004	2	8.09	73	0.275	8.52	10.65			
10/21/2004	3	7.97	72	0.275	8.51	10.61			
10/21/2004	4	7.91	71	0.276	8.52	10.6			
10/21/2004	bottom	7.8	70	0.276	8.5	10.6			