CARSTENS LAKE

MANITOWOC COUNTY, WISCONSIN

ALUM TREATMENT FEASIBILITY STUDY

Prepared for the

Manitowoc County Lakes Association

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SUMMARY

The Carstens Lake Management Plan (Manitowoc County Lakes Association 2000) recommends the completion of an *alum treatment* to minimize the affects of *internal phosphorus loadings* on the lake. During 2002, a study was completed with two primary components; 1) to measure the amount of phosphorus entering Carstens Lake from its two primary inlets, and 2) determine if internal nutrient loadings were a significant source of phosphorus to the lake. These two components were then combined to determine if the completion of an alum treatment is appropriate for Carstens Lake. The study included field-collected data from the lake, and its two primary tributaries (referred to as the Carstens Road Site (CR) and the Boat Landing Site (BL) in this document) along with estimated values generated through modeling and predictive equations.

The major results of this study are outlined below:

- The data collected during the 2002 field season indicate that Carstens Lake is currently in a eutrophic state.
- FLUX Modeling (Walker 1999) estimated that 60,000 m^3 of water passed BL, loading approximately 10.9 kg of phosphorus to the lake and that approximately 420,000 m^3 of water had passed CR carrying approximately 40.9 kg of phosphorus.
- Modeling using data collected during the 2002 field season indicated that approximately 31.9 kg of phosphorus are internally loaded to Carstens Lake on an annual basis.
- Scenario development indicated that internal nutrient loading is a significant source of phosphorus to Carstens Lake. Furthermore, the scenarios indicate that due to the unnaturally high amount of phosphorus that enters the lake through the two primary tributaries, an alum treatment would not be feasible at this time.

Major recommendations presented to the Manitowoc County Lakes Association as a result of the findings described above, include the following:

- To reduce phosphorus loads from CR, recommendations were made for the installation of buffer strips between the tributary and agricultural lands and the possible creation of detention basins within the tributary's watershed.
- The creation of a detention basin to minimize loadings from BL and those entering the lake through surface flows was recommended.
- Septic system inspections and necessary updates/replacements were recommended to further reduce phosphorus loads to the lake.
- Creation of shoreland buffer areas between Carstens Lake and its developed shorelands were recommended as a method to minimize phosphorus inputs from those areas.

INTRODUCTION

Carstens Lake, located in southeast Manitowoc County, is a 21-acre seepage lake with a maximum depth of 28-feet and a mean depth of 12-feet. Approximately 690 acres drain to the lake with almost 79% of that area entering through a single tributary (Figure 2). Other water sources include overland flow, groundwater, and drain tile outfalls. Carstens Lake's sole outlet forms the headwaters to Pine Creek, which eventually flows to Lake Michigan. The Manitowoc County Lakes Classification study determined that only 35% of Carstens Lake's shoreline is developed; therefore, if the proposed zoning scheme is accepted, Carstens Lake will be protected under the County's zoning ordinances for semi-developed lakes. This classification assures that the undeveloped land around the lake would be developed in a conservative manner aimed to protect the lake. Also, that any additions or changes occurring on existing developed land would be mitigated with shoreland buffers and/or other shoreland improvement measures.

Although Carstens Lake does not have a lake association, the Manitowoc County Lakes Association (MCLA) and the Manitowoc County Soil and Water Conservation Department (Manitowoc County SWCD) have cooperated in the management of Carstens Lake including the setup and maintenance of the lake's aeration system. Together they completed a lake management plan for Carstens Lake in 2000 that outlined the lake's current and historical problems along with management alternatives to correct them. The plan determined that the lake's occasional fishkills were caused by anoxic conditions resulting from the decomposition of macrophytic and algal plant material during the winter months. It also determined that the growth of these aquatic plants is likely fueled by internal loads of phosphorus. Based upon excessive surface phosphorus levels (104 µg/l) that are much higher than regional averages (79 µg/l) (Lillie and Mason 1983) and limited sampling of the two primary inlets, the plan recommends an alum treatment to reduce internal phosphorus loading. However, an alum treatment for Carstens Lake would be very expensive (approximately $25,000-$45,000); therefore, this study was completed to determine if an alum treatment is feasible by determining if external phosphorus loads have been minimized and if internal loading is truly a significant source of phosphorus to the lake.

Notes on the Format of this Document

The primary goal of this document is to deliver the findings of the studies carried out at Carstens Lake. Many of the recommendations made within the document are presented in more detail with the Carstens Lake Management Plan (Manitowoc County Lakes Association 2002), including steps to implementation and the parties responsible for the implementation.

Care has been taken to keep the technical aspects of the document on laymen's terms as much as possible. To facilitate the ease of reading, certain topics are expanded upon and technical terms are defined in a glossary. Furthermore, the reporting of specific data is kept to a minimum within the text, but is wholly contained within the appendices. The appendices also contain the glossary mentioned above (terms contained in the glossary are italicized within the text).

For ease of reading and document compilation, the large format (11"x17") maps are contained near the end of this report.

RESULTS AND DISCUSSION

Water Quality and Lake Ecology

Judging the quality of lake water can be difficult because lakes display problems and benefits in many ways. However, focusing on specific aspects or parameters that are important to lake ecology, comparing those values to similar lakes within the same region, and historical data from the study lake provides an excellent method to evaluate the quality of a lake's water. To complete this task, three water quality parameters are focused upon:

1. **Phosphorus** is a nutrient that controls the growth of plants in the vast majority of Wisconsin lakes. It is important to remember that in lakes, the term "plants" includes both *algae* and *macrophytes*. Monitoring and evaluating concentrations of phosphorus within the lake helps to create a better understanding of the growth rates of the plants within the lake.
2. **Chlorophyll-*a*** is the pigment in plants that is used during *photosynthesis*. Chlorophyll-*a* concentrations indicate algal abundance within a lake.
3. **Secchi disk transparency** is a measurement of water clarity. Of all limnological parameters, it is the most used and the easiest for non-professionals to understand. Furthermore, measuring Secchi disk transparency over long periods of time is one of the best methods of monitoring lake health. The measurement is conducted by lowering a weighted, 20-cm diameter disk with alternating black and white quadrates (a Secchi disk) into the water and recording the depth just before it disappears from sight.

The parameters described above are inter-related. Phosphorus controls algal abundance, which is measured by chlorophyll-*a* levels. Water clarity, as measured by Secchi disk transparency, is directly affected by the particulates that are suspended in the water. In the majority of natural, Wisconsin lakes, the primary particulate matter is algae; therefore, algal abundance directly affects water clarity. In addition, studies have shown that water clarity is used by most lake users to judge water quality – in the layperson's mind, clear water equals clean water.

Each of these parameters is also directly related to the *trophic state* of the lake. As nutrients, primarily phosphorus, accumulate within a lake, its productivity increases and the lake progresses through three trophic states: *oligotrophic*, *mesotrophic*, and finally *eutrophic*. Every lake will naturally progress through these states; however, under natural conditions (i.e. not influenced by the activities of humans) this progress can take tens of thousands of years. Unfortunately, human influence has accelerated this natural aging process in most Wisconsin lakes. Monitoring the trophic state of a lake gives stakeholders a method by which to gauge the health of their lake over time. Yet, classifying a lake into one of three trophic states does not give clear indication of where a lake really exists in its trophic progression. To solve this problem, the parameters measured above can be used in an index that will indicate a lake's trophic state more clearly and provide a means for which to track it over time.

The main focus of this study is phosphorus, particularly, the loading of phosphorus from external and internal sources; therefore, throughout the text, we have used the relationships described above to estimate what the chlorphyll-*a* and Secchi disk transparencies would be for the given phosphorus levels. Furthermore, the estimated levels are used to calculate the trophic state index values for those parameters. Specifically, we have used the Wisconsin Trophic State Index (WTSI) (Lillie, et al. 1993) to index these values. The WTSI is based upon the widely used Carlson Trophic State Index (TSI) (Carlson 1977), but is specific to Wisconsin lakes. The WTSI is used extensively by the WDNR and is reported along with lake data collected by Self-Help

Volunteers. The WTSI values for the scenarios that we present within this document are displayed in Figure 3 by "Scenario" and each scenario is listed in the text and referenced in the figure's description.

Comparisons with regional and statewide data are also presented within the text and in the WTSI. These data are derived from Lillie and Mason (1983), an excellent source for comparing lakes within specific regions of Wisconsin. They divided the state's lakes into five regions each having lakes of similar nature or apparent characteristics. Manitowoc County lakes are included within the study's Southeast Region and are among 61 lakes randomly picked from the region that were analyzed for water clarity (Secchi disk), chlorophyll-*a*, and total phosphorus.

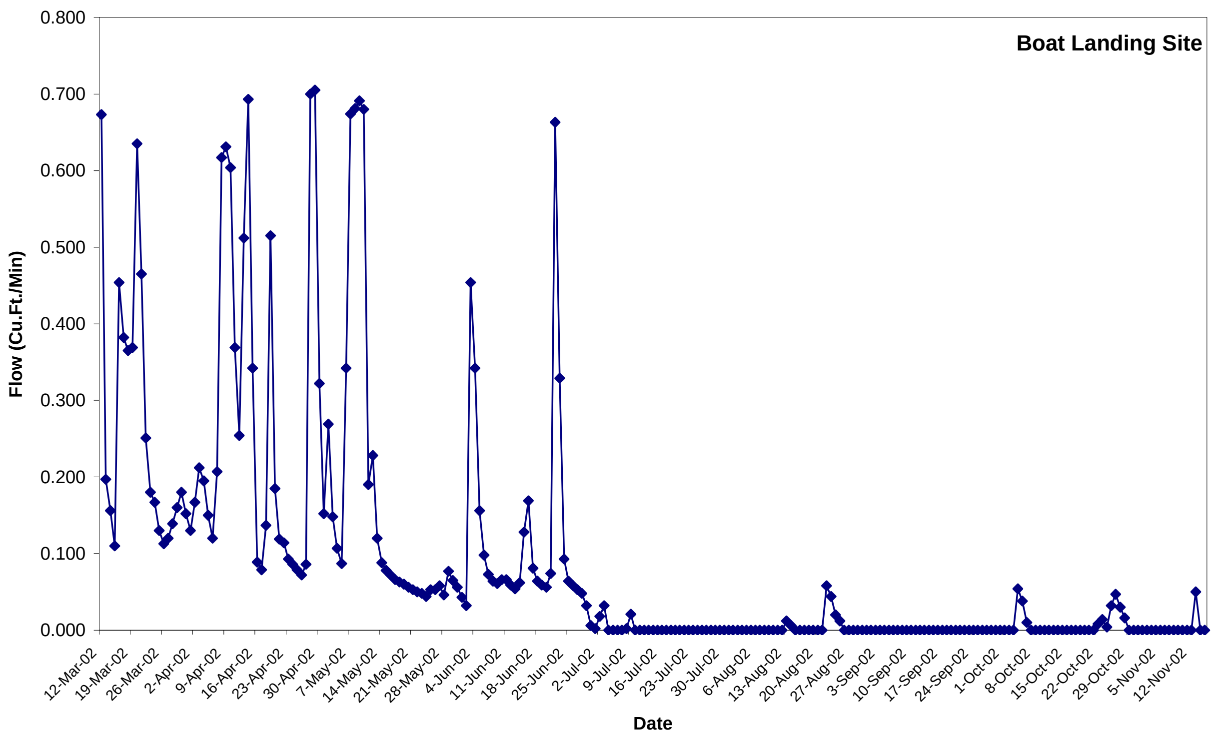
Finally, when classifying lakes into trophic levels, it must be remembered that values that fall into the mesotrophic or eutrophic categories are not indicative of poor lake health. There are benefits associated with the higher rates of productivity found in these lakes. For instance, lakes that are not as productive are unable to support a large fishery.

Tributary Flows and Phosphorus Loading

There are two primary inlet sites that supply water to Carstens Lake; a tile outfall located near the lake's boat landing (BL) and an intermittent stream that crosses Carstens Road (CR) and enters the lake on its north end (Figure 2). Flows were collected at both sites from mid May to mid November, 2002 (Figure 4); however, both had zero or nearly zero flow after the second week in July, 2002. The intermittent nature of both inlets confounded the sample retrieval for phosphorus analysis; however, sufficient samples were collected to complete the modeling (BL=17, CR=14) (Appendix B).

The FLUX modeling estimated that 60,000 m^3 of water passed BL, loading approximately 10.9 kg of phosphorus to the lake. The modeling also indicated that approximately 420,000 m^3 of water had passed CR carrying about 40.9 kg of phosphorus. On there own, the loading estimates do not mean much because their affect is dependent on the volume of water they are entering. For instance, adding 51.8 kg of phosphorus to Lake Winnebago (≈ 2.6 billion m^3) would only equate to an average concentration of approximately 0.02 mg/m^3- a very low concentration considering the eutrophic nature of the lake (Scenario 1, Figure 3). However, adding 51.8 kg of phosphorus to a small lake with a relatively low volume like Carstens Lake (≈ 322,000 m^3) could have a profound affect. In fact, if that amount of phosphorus were added to Carstens Lake and then utilized by the lake's algae population the lake would have an average phosphorus concentration of approximately 161 mg/m^3, which equates to a chlorphyll-*a* concentration of 122.3 mg/m^3 and a Secchi disk transparency of 1.7-feet (Scenario 2, Figure 3).

It must be stated that the scenarios described above are not truly realistic because they do not account for the natural process that occur when phosphorus enters a lake. In reality, the phosphorus that enters a lake is not fully utilized by its plants (in the cases above, algae). For example, portions of it are flushed out of the lake and some is settled to the bottom as it is precipitated by marl, iron, and other compounds. Through modeling, we can account for these natural losses and estimate how much phosphorus is actually available to the algae; and in turn, predict more realistic estimates of chlorophyll-*a* concentrations and Secchi disk depths. To complete this task the Wisconsin Lake Modeling Suite (WiLMS), a lake management tool developed by the WDNR, was utilized to create additional, comparative, scenarios. Basically, WiLMS is a suite of models that estimates how much phosphorus would typically be loaded to the lake from classified land use types within the lake's watershed. The user can then use the estimated phosphorus inputs to predict annual and spring overturn phosphorus concentrations for specific types of lakes.



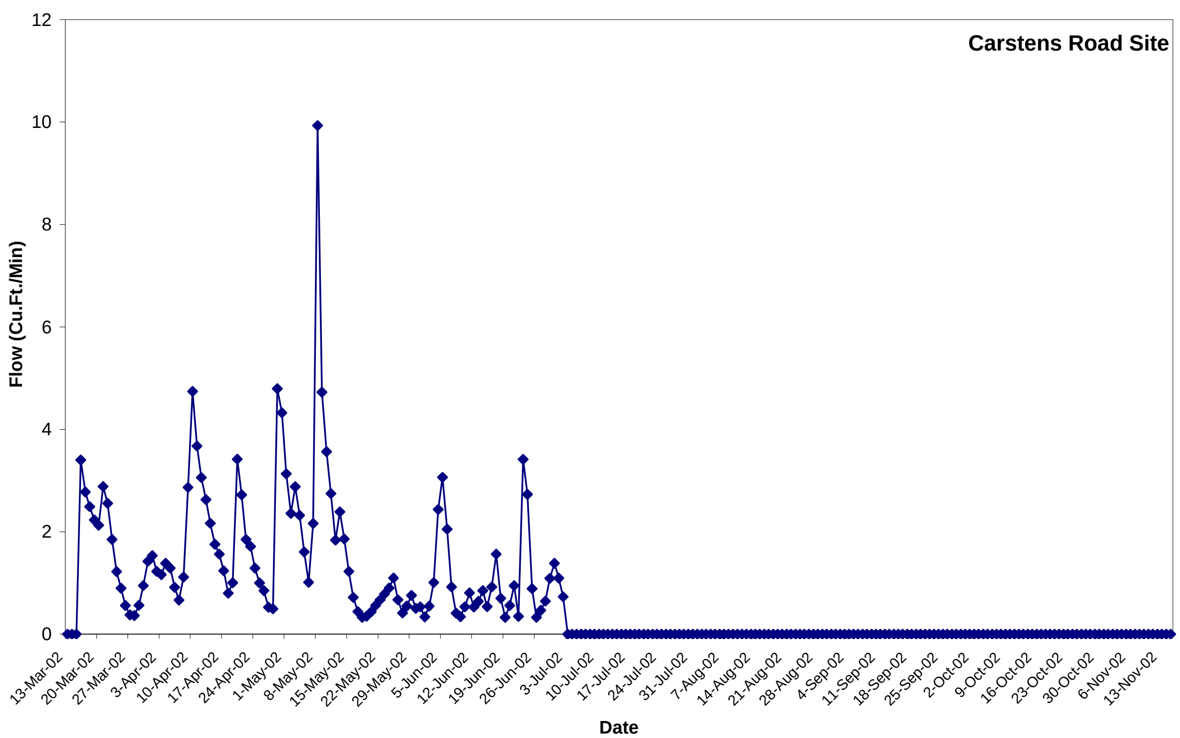


Figure 4. Average daily flows for Carstens Lake tributaries at the Boat Landing Site and Carstens Road Site during 2002.

Carstens Lake is a seepage lake with approximately 686-acres of land draining to it. Before the area was settled, developed, and much of the land converted for agricultural use, the watershed of Carstens Lake was likely dominated by woodlands. Forested areas contribute the least amount of phosphorus to lakes because they minimize surface runoff and maximize absorption of precipitation to the ground. By doing this, forested areas loose little soil through erosion and as a result, contribute very little phosphorus to lakes.

To demonstrate the affects of a forested watershed, modeling was completed to predict the phosphorus concentrations that would result if the watershed of Carstens Lake was in its original, forested state (Scenario 3, Figure 3). The results indicate that even though the watershed is contributing a minimal amount of phosphorus to the lake (roughly 27.7 kg), it would still be considered mesotrophic/eutrophic. The results are attributable to the size of Carstens Lake in relation to its watershed. This relationship is expressed in the watershed to lake area ratio, which for Carstens Lake is approximately 31:1. In general, lakes with a ratio greater than 10:1 tend to have management problems that revolve around excessive amounts of phosphorus and/or sediments that enter the lake from its drainage basin. This is true because as the drainage area increases, so does the amount of nutrients and sediments that are delivered to the lake. This is not to say that every lake with a watershed to lake area ratio greater than 10:1 experiences problems, because the amount of pollutants (nutrients, sediment, toxins, etc.) depends greatly on how the land within the watershed is used. However, in this case, it shows that even with the entire watershed being forested, we could expect that the watershed would influence the lake greatly.

To show the affects of the estimated loadings determined through the FLUX modeling, we added the tributary flows and loadings, described above, to Scenario 3 (Scenario 4, Figure 3). Naturally, these added loads increased the trophic state of the lake well above Scenario 3, indicating the loadings realistic results with the affects of flushing and phosphorus precipitation taken into consideration.

Scenario 5 (Figure 3) is the results of using the current land use data for the Carstens Lake watershed minus the watershed area CR. The watershed of CR is indicated in Figure 2 by the dotted line. The tributary inputs of water and phosphorus were added to the model as point-sources to give the most accurate results. Essentially, this scenario is a combination of results from modeling the remaining watershed outside of CR and those estimated through the FLUX procedure. Please note that the watershed of BL was not excluded as with CR because there would still be surface flow that would add water and phosphorus to Carstens; that surface flow contribution was included in the WiLMS analysis.

As indicated in Figure 3, the WTSI for Scenario 5 is lower than that of the WTSI values calculated for the data collected at Carstens Lake during 2002 (Scenario 8, Figure 3). This is especially true for the WTSI values calculated using total phosphorus and chlorphyll-*a*. The reason for this, as described below, is likely internal loading.

In the end, the scenarios described above indicate the profound affects that the loadings from CR and BL have on Carstens Lake. As indicated by Scenario 3, Carstens Lake would likely be eutrophic even if the watershed was left in its original forested state. Adding the loads estimated though the work of this study (i.e. inputs of BL and CR) to that undisturbed watershed (Scenario 4) pushes the lake into an even higher eutrophic state. Combining the current land use with the inputs determined through the study (Scenario 5) pushes it even higher and gives the most accurate representation of the watershed's phosphorus loadings to the lake.

Through these scenarios we can tell that completing a alum treatment at Carstens Lake is not appropriate at this time because there is too much phosphorus entering the lake from its watershed. If the treatment were to be completed, these findings indicate that the effects would be short-lived because external sources would likely over-ride them and still keep the lake at an elevated eutrophic level. Methods to minimize the watershed inputs are discussed in the Recommendations Section.

Internal Phosphorus Loading

In lakes that support strong stratification, the *hypolimnion*, can become devoid of oxygen both in the water column and within the sediment. When this occurs, iron changes from a form that normally binds phosphorus within the sediment to a form that releases it to the overlaying water. This can result in very high concentrations of phosphorus in the hypolimnion. Then, during the spring and fall turnover events, these high concentrations of phosphorus are mixed within the lake and utilized by algae. This cycle continues year after year and is termed "internal phosphorus loading;" a phenomenon that can support nuisance algae blooms decades after external sources are controlled.

A main component of this study was to discover if internal loading was a significant source of phosphorus in Carstens Lake. To determine this, the Wisconsin Internal Load Estimator (WINTLOAD) module of WiLMS was used to estimate the amount of phosphorus that is added to the lake on an annual basis through internal loading. The WINTLOAD results indicate that approximately 31.9 kg of phosphorus are internally loaded to the lake. As described in the section above, the effects of adding this much phosphorus to the lake must be demonstrated through modeling.

The WTSI values displayed as Scenario 6 (Figure 3) were calculated by adding 31.9 kg of phosphorus directly to Carstens Lake and excluded the affects of precipitation and flushing (see discussion above). As expected, the relatively small volume of Carstens Lake cannot dilute that much phosphorus and as Scenario 6 indicates, the lake would be in an elevated, eutrophic state. As outlined above, this scenario is unrealistically high because it does not take into the account the natural processes that prevent algae from using all the phosphorus. To account for these processes, WiLMS was used to estimate a more realistic affect of the internal load by adding it to the modeling setup of Scenario 5. The results of this analysis are displayed as Scenario 7 in Figure 3. Interestingly, the results of this analysis are very close to those found by using the actual data collected during 2002 (Scenario 8), which indicates the accuracy of the WiLMS modeling. This is particularly true for the phosphorus levels as the estimated value and the field-collected data only differ by 3 mg/m^3.

The results of these analyses indicate that internal loading is a significant source of phosphorus within Carstens Lake. It further indicates, that if the external sources of phosphorus can be minimized, Carstens Lake would likely benefit from an alum treatment.

Current and Desired Water Quality in Carstens Lake

The water quality data collected during 2002 are displayed as Scenario 8 in Figure 3 and contained in their entirety in Appendix C. Comparisons of these data with regional and statewide data (Scenarios 9 and 10, respectively, Figure 3) indicate that the eutrophic level of Carstens Lake is higher than other lakes found in the same region and within Wisconsin. Again, this shows the profound affects that internal and external loads have on Carstens Lake.

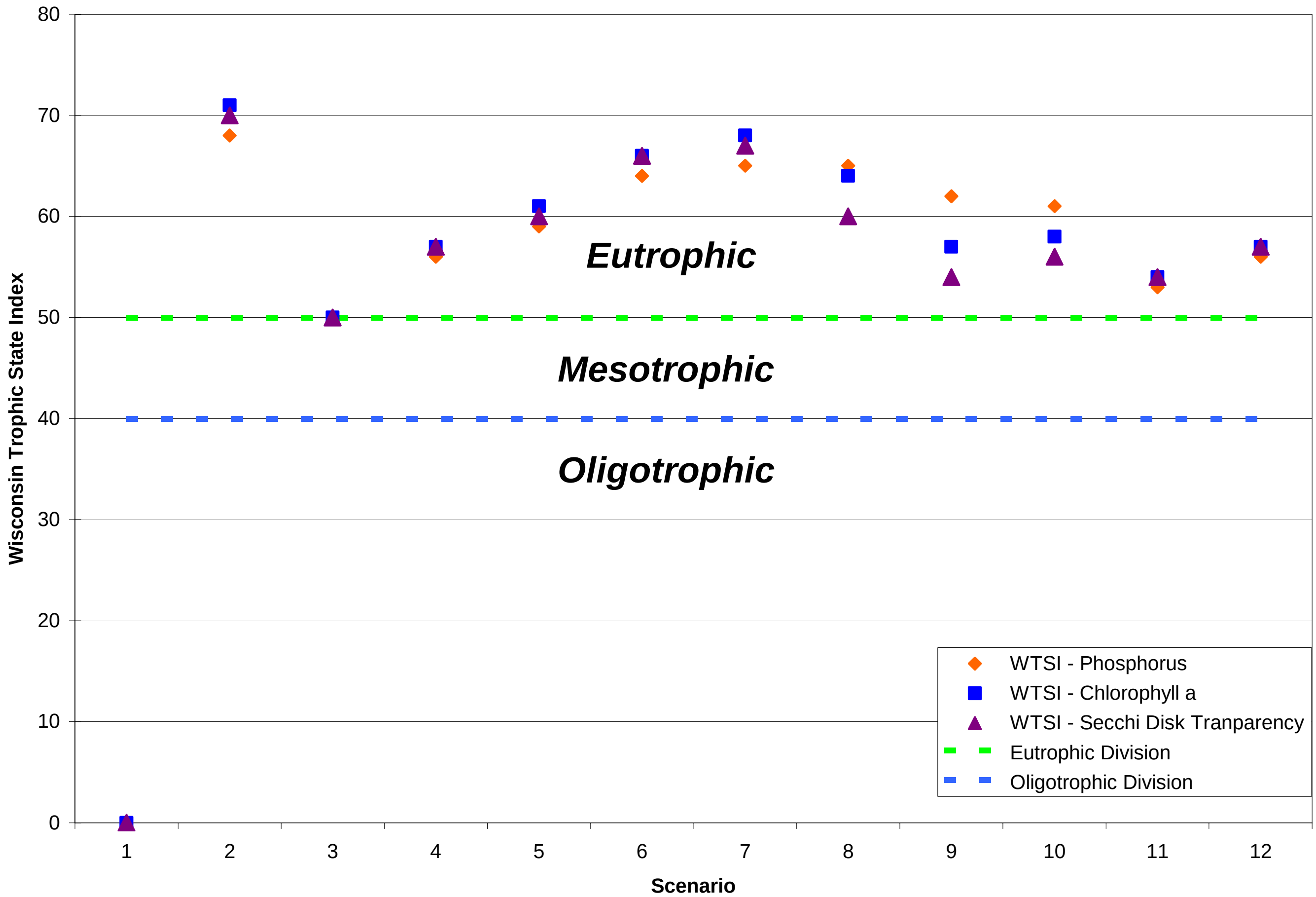


Figure 3. Wisconsin Trophic State Index values calculated for 12 scenarios developed to demonstrate the affects of tributary, watershed, and internal phosphorus loads to Carstens Lake. Key to scenarios:

Scenario	Description	Notes
1	Lake Winnebago with 51.8 kg of phosphorus (tributary load of Carstens Lake) added to it	Does not include affects of flushing and precipitation of phosphorus
2	Carstens Lake with 51.8 kg of phosphorus (tributary load of Carstens Lake) added to it.	Does not include affects of flushing and precipitation of phosphorus
3	Carstens watershed in a completely forested condition.	
4	Scenario 3 with tributary loads added.	
5	Current Carstens Lake watershed with tributary loads added as point sources	This is an accurate model of the external phosphorus loads to Carstens Lake
6	Carstens Lake with 31.9 kg of phosphorus (internal load of Carstens Lake) added to it.	Does not include affects of flushing and precipitation of phosphorus
7	Current Carstens Lake with internal and tributary loads added.	This is the most accurate model of phosphorus loading to Carstens Lake.
8	Actual values from 2002.	
9	Southeast regional averages.	After Lillie and Mason (1983)
10	Statewide averages	After Lillie and Mason (1983)
11	Desired phosphorus level as indicated in Carstens Lake Management Plan	Based upon a concentration of 25 mg/m^3
12	Eliminating BL load and reducing CR load by two-thirds.	

RECOMMENDATIONS

There were two primary goals for completing this study; 1) to measure the amount of phosphorus entering Carstens Lake from its two primary inlets, and 2) determine if internal nutrient loadings were a significant source of phosphorus to the lake. These two components were then combined to determine if the completion of an alum treatment is appropriate for Carstens Lake. The internal loading analysis indicates that internal loading is a significant source of phosphorus to Carstens Lake and, in turn, that the lake would likely benefit from having an alum treatment completed. However, the tributary load modeling indicates that the completion of an alum treatment is not appropriate at this time because of the elevated phosphorus loads that are entering the lake through these tributaries.

The lake management plan for Carstens Lake (Manitowoc County Lakes Association, 2000) states as one of it goals (GOAL II) that it would like to reduce the current, elevated phosphorus levels in Carstens Lake to 25 mg/m^3. This level along with predicted values of chlorophyll-*a* and water transparency were used to calculate the WTSI values displayed as Scenario 11 in Figure 3. To discover if this goal is obtainable, back calculations using WiLMS were completed. The modeling indicates that in order to obtain this goal, the external loads of phosphorus currently entering the lake would need to be cut from approximately 92.6 kg/yr to 44 kg/yr, or roughly in half. This would be a difficult goal to obtain if attention were only given to the two external sources that were studied here. In fact, completely removing the inputs from BL (10.9 kg/yr) combined with a two-third reduction in the loads coming from CR (51.8 kg/yr to 17.3 kg/yr) would still result in an average, estimated phosphorus concentration of 34 mg/m^3 (Scenario 12, Figure 3). Although this may be acceptable, it would not meet the goals of the Carstens Lake Management Plan. To obtain the goal, additional attention would need to be given to other sources of phosphorus to the lake, like those from the surrounding developed properties, septic tanks, and the remaining agricultural areas of the watershed. Recommendations to minimize these loads along with those of the two tributaries studied here are outlined below.

Carstens Road Tributary

The Carstens Lake Management Plan already outlines one of the steps that should be taken to minimize these loads. Specifically, the plan indicates the need for the creation of buffer strips to minimize phosphorus loadings to the tributary from existing agricultural lands (Figure 5). As of this writing, the Manitowoc County Soil and Water Conservation Department (Manitowoc County SWCD) is attempting to implement the installation of buffers in these locations. This work should continue until the buffers and necessary easements are created. The Manitowoc County SWCD has experience in utilizing state and federal funds for the implementation of these types of projects. If additional funds are needed, the MCLA may consider applying for a WDNR Lake Protection Grant to supply those funds.

Additionally, the creation of detention basins within the tributary's watershed would further reduce loadings to the lake. To complete this task, the MCLA should work with the WDNR, the Manitowoc County SWCD, and the U.S. Fish and Wildlife Service to obtain information on suitable locations, engineering designs, and permitting needs. Again, the WDNR Lake Protection Grant Program would be a feasible funding source for the initial designs and construction of these basins.

Boat Landing Drain Tile Tributary

Destruction of this drain tile would be the best course of action in eliminating its affects on the lake. This is unlikely because the drain tile functions to drain lands that are currently being used for agriculture and it also functions as an outlet for a small detention pond located between the lake and State Highway 42. A more implemental plan would be to create a detention basin to treat the tile's flow before it enters Carstens Lake (Figure 5). A detention basin was constructed east of English Lake (Figure 5) to treat surface flows from 37-acres of agricultural lands before they enter the lake. Studies conducted by NES Ecological Services (English Lake Protection and Rehabilitation District 2001) indicated that the detention basin removed over 70% of the phosphorus, sediment, and nitrogen contained within inflowing water before it entered English Lake. The implementation of this recommendation would not only treat the water entering the basin from the existing drain tile, but would also treat the water entering through surface flows. Combined, the reduction of these inputs could have a profound affect on the overall phosphorus loadings entering Carstens Lake.

It is recommended that the MCLA partner with the WDNR, the Manitowoc County SWCD, and the U.S. Fish and Wildlife Service to implement this plan. Again, the WDNR Lake Protection Grant Program would be an appropriate funding source to complete the engineering designs, and provide cost-sharing for the purchase of necessary easements and the construction of the basin.

Septic Systems

To minimize this source all septic systems around the lake should be professionally inspected. By state law, a septic system is considered to be failing if untreated wastewater is backed up into the building, seeps to the soil surface, enters surface or groundwater, or moves into the soil's saturated zone. With the exception of being backed up into the building, all of these failures could potentially increase nutrient loading to Carstens Lake. The Wisconsin Department of Commerce estimates that nearly 1-in-5 septic systems are failing in Wisconsin. Inspections should include soil test and possibly ground water monitoring to determine if the soils are truly retaining phosphorus and other contaminants or just passing them through to the groundwater and on to the lake. If systems are found to be failing, they may be required by county or state regulations to be corrected. The Wisconsin Department of Commerce partially funds private sewage system replacements through their Wisconsin Fund, Private Sewage System Replacement and Rehabilitation Grant Program, but the requirements are stringent and include that the system must be serving the owner's principal residence and that the owners not make in excess of a specified annual income. More information about this grant program can be found on the Dept. of Commerce website or by calling (608) 267-7113. Furthermore, many lake groups have successfully applied for WDNR Planning Grants to pay for 75% of these inspection costs.

Residential Shoreland Properties

Fortunately, minimizing these phosphorus loads is relatively simple. Many of the residential properties located around the lake do not contain a natural, functioning buffer between the lake and the maintained landscapes of the properties. Creation of a least a 35-foot wide buffer strip, consisting of native trees, shrubs, and herbaceous plants would greatly reduce the loadings of sediment and phosphorus from these shoreland properties. Additional benefits include the increased aesthetic value that would be added to each property and the increased wildlife habitat that would be created. As with the shoreland restoration projects the MCLA are currently completing, MCLA should seek professional advice concerning the creation of buffer strips from the WDNR and/or a qualified consultant. Furthermore, partial funding for these types of projects is available through WDNR Lake Protection Grant program.

Finally, it is strongly recommended that only phosphate-free fertilizers be used on shoreland properties and back lots. This type of fertilizer is readily available for retail purchase. The local UW-Extension may be contacted for a list of suppliers.

METHODS

Tributary Phosphorus Load Determination

Phosphorus loadings for the two tributaries (Figure 1) were estimated using FLUX, a model developed by William Walker of the US Army Corps of Engineers Waterways Experiment Station (Walker 1999). FLUX is an interactive program designed for use in estimating the loadings of nutrients or other water quality components passing a tributary sampling station over a given period of time. Using six calculation techniques, the model maps the flow/concentration relationship developed from the sample record onto the entire flow record to calculate total mass discharge and associated error statistics.

FLUX requires three sets of data for loading estimations; 1) continuous, daily flows spanning the time period of interest, 2) periodic grab samples analyzed for the parameter of concern and collected over a range of flows, and 3) instantaneous flows corresponding to the time the grab samples were collected (Appendix B) Daily and instantaneous flows were determined using Isco Model 4300, bubble-type flowmeters that were installed at the two inlets and programmed to record stream stage (feet) every quarter hour. Flows were calculated from stage using rating curves (Appendix C). Flows used in the construction of the rating curve were calculated using the .2, .4, .8 of Depth Method (Marsh-McBirney, Inc. 1995) and velocities recorded with a Marsh-McBirney Flo-mate Model 2000 electromagnetic flowmeter.

Grab samples were collected by volunteers from the MCLA and NES staff. Samples were fixed with sulfuric acid and refrigerated prior to shipping on ice to the Wisconsin State Laboratory of Hygiene for analysis,. To maintain data consistency, time and stage information were recorded from the ISCO equipment during the collection of grab samples.

Lake Water Quality

Lake water quality samples were collected seven times throughout the duration of the project and included analysis of samples collected with a 3-liter Van Dorn bottle from 3-feet below the water surface and 3-feet above the lake bottom. Table 1 lists the parameters that were monitored and the approximate timing of sample collection. Furthermore, Secchi disk transparencies and dissolved oxygen/temperature profiles were determined on a biweekly basis. All nutrient samples collected were preserved as described above for the tributary phosphorus samples and shipped on ice with the chlorophyll *a* samples to the Wisconsin State Laboratory of Hygiene for analysis.

Table 1. Carstens Lake water quality sampling parameters and approximate schedule.

Parameter	Winter		Spring Turnover		June		July		Fall Turnover		Post-Fall Turnover	
	S	B	S	B	S	B	S	B	S	B	S	B
Total Phosphorus	●	●	●	●	●	●	●	●	●	●	●	●
Chlorophyll a	●		●	●	●		●		●	●	●	
Total Kjeldahl Nitrogen	●	●	●	●	●	●	●	●	●	●	●	●
Nitrate-Nitrite Nitrogen	●	●	●	●	●	●	●	●	●	●	●	●

Data Analysis and Modeling

Watershed modeling was completed using the Wisconsin Lake Modeling Suite v. 3.3(WiLMS) (Panuska and Kreider 2003). Internal phosphorus loading estimates were calculated using the Internal Load Estimator Module (WINTLOAD) of WiLMS. The Prediction and Uncertainty Analysis Module of WiLMS was used to support watershed modeling and the internal nutrient loading estimated in WINTLOAD. Predictive equations presented in Lillie et. al (1993) were used to estimate chlorophyll-*a* and Secchi disk clarities from total phosphorus levels.

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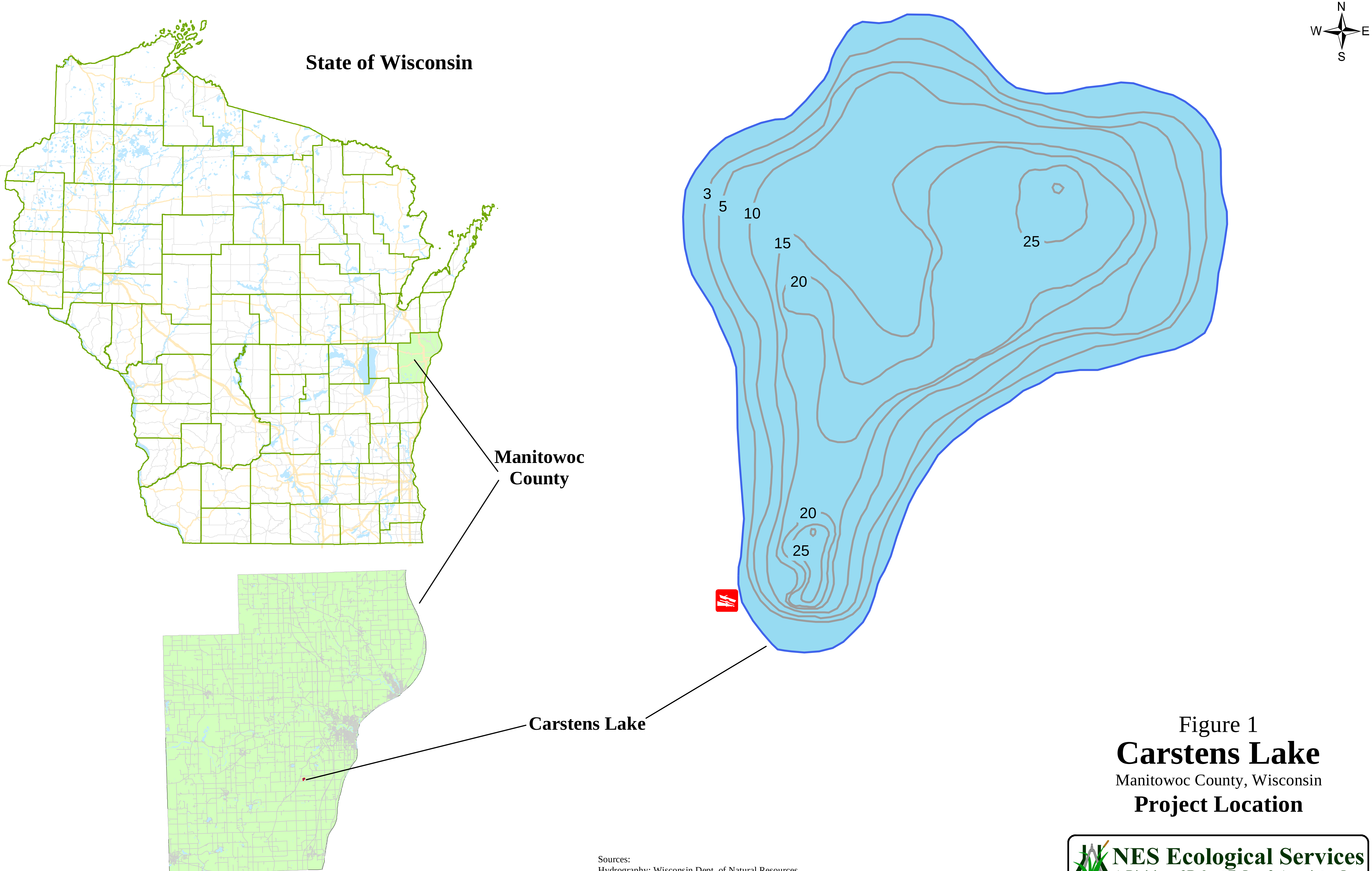

Figure 1
Carstens Lake
Manitowoc County, Wisconsin
Project Location

Sources:
Hydrography: Wisconsin Dept. of Natural Resources
Base Data: Wisconsin Dept. of Natural Resources
Carstens Lake Bathemetry: NES Ecological Services after Wisconsin Dept. of Natural Resources

NES Ecological Services
A Division of Robert E. Lee & Associates, Inc.

Figure 2

Carstens Lake

Manitowoc County, Wisconsin

Project Monitoring Sites

Legend

Carstens Lake Watershed

Carstens Road Site Watershed

N
W E
S

1 inch equals 1,000 feet

0 750 1,500 3,000 Feet

Sources:
Orthophotography: Manitowoc County
Carstens Lake Watershed: Manitowoc County
Hydrography: Wisconsin Dept. of Natural Resources
Carstens Road Site Watershed: NES Ecological Services
Monitoring Site Locations: NES Ecological Services

NES Ecological Services
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Figure 5

Carstens Lake

Manitowoc County, Wisconsin

Recommended Conservation Practices for the Carstens Lake Watershed

Legend

- Proposed Drain Tile Detention Basin
- Buffer Needs
- Carstens Lake Watershed
- Carstens Road Site Watershed

N
W E
S

1 inch equals 1,000 feet

0 750 1,500 3,000 Feet

Sources:
Orthophotography: Manitowoc County
Carstens Lake Watershed: Manitowoc County
Hydrography: Wisconsin Dept. of Natural Resources
Carstens Road Site Watershed: NES Ecological Services
Buffer and Detention Basin Locations: Manitowoc County

NES Ecological Services
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A

APPENDIX A

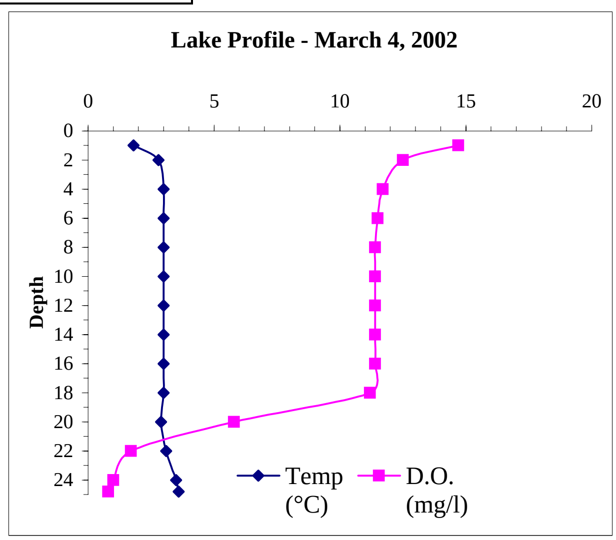
Water Quality Dataset Collected During 2002 & 2003

Carstens Lake

Date:	**03-04-02**	**Max Depth (ft):**	25.5
Time:	14:45	**CARLS Depth (ft):**	3.0
Weather:	Partly Sunny, 10	**CARLB Depth (ft):**	22.0
Ent:	tsn **Verf:** TAH/TSN	**Secchi Depth (ft):**	3.8

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	1.8	14.7	7.8	507
2.0	2.8	12.5	7.8	552
4.0	3.0	11.7	7.7	552
6.0	3.0	11.5	7.8	552
8.0	3.0	11.4	7.8	552
10.0	3.0	11.4	7.8	551
12.0	3.0	11.4	7.8	551
14.0	3.0	11.4	7.8	551
16.0	3.0	11.4	7.8	551
18.0	3.0	11.2	7.8	552
20.0	2.9	5.8	7.6	593
22.0	3.1	1.7	7.4	628
24.0	3.5	1.0	7.3	677
24.8	3.6	0.8	7.3	698

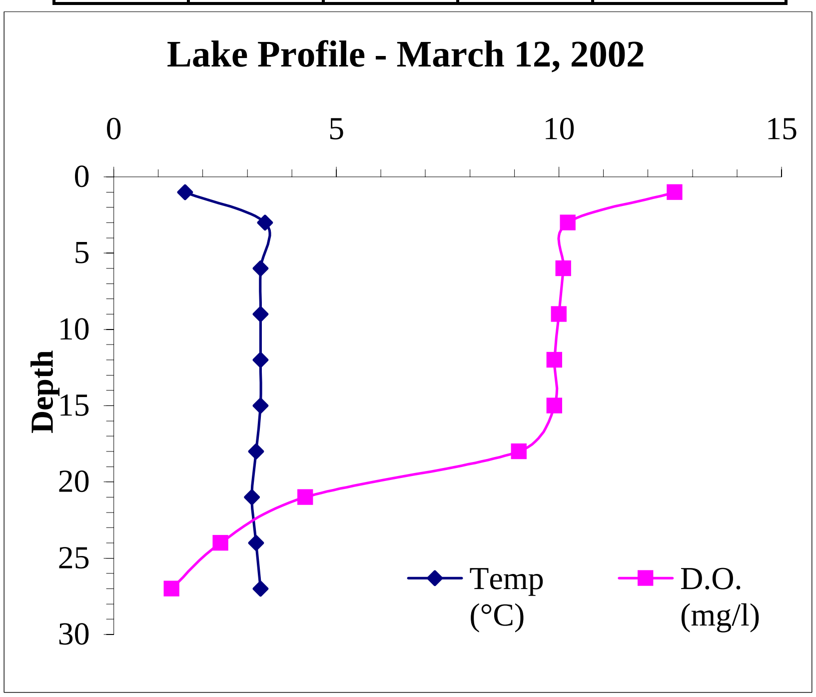
Parameter	CARLS	CARLB
Total P (mg/l)	0.194	0.281
Dissolved P (mg/l)		
Chl a (µg/l)	25	
TKN (mg/l)	2.600	2.990
NO2+NO3-N (mg/l)	1.180	1.030
NH3-N (mg/l)		
Total N (mg/l)	3.780	4.020
Lab Cond. (µS/cm)		
Lab pH		
Alkal (mg/l CaCO3)		
Total Susp Sol (mg/l)		
Calcium (mg/l)		



Carstens Lake

Date: 03-12-02 **Max Depth (ft):** 28.4
Time: 12:15 ***Profile Only***
Weather: Partly cloudy, no wind, 36F
Ent: TSN **Verf:** TAH/TSN **Secchi Depth (ft):** 3.8 .

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	1.6	12.6	7.1	387
3.0	3.4	10.2	7.5	550
6.0	3.3	10.1	7.6	552
9.0	3.3	10.0	7.6	553
12.0	3.3	9.9	7.6	553
15.0	3.3	9.9	7.6	553
18.0	3.2	9.1	7.6	557
21.0	3.1	4.3	7.4	628
24.0	3.2	2.4	7.3	653
27.0	3.3	1.3	7.3	674



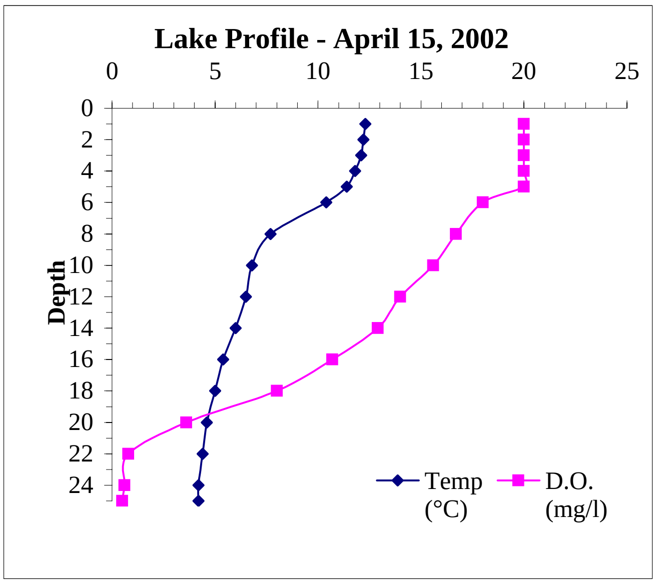
Carstens Lake

Date: **04-15-02**
Time: 13:15
Weather: Partly Cloudy, Breezy, 78
Ent: tsn **Verf:** TAH/TSN

Max Depth (ft): 25.6
CARLS Depth (ft): 3.0
CARLB Depth (ft): 22.0
Secchi Depth (ft): 2.0

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	12.3	20.0	8.8	491
2.0	12.2	20.0	8.8	491
3.0	12.1	20.0	8.9	492
4.0	11.8	20.0	8.9	492
5.0	11.4	20.0	8.9	494
6.0	10.4	18.0	8.7	503
8.0	7.7	16.7	8.4	507
10.0	6.8	15.6	8.2	516
12.0	6.5	14.0	8.2	518
14.0	6.0	12.9	8.1	524
16.0	5.4	10.7	7.8	540
18.0	5.0	8.0	7.7	560
20.0	4.6	3.6	7.5	583
22.0	4.4	0.8	7.4	614
24.0	4.2	0.6	7.4	634
25.0	4.2	0.5	7.4	638

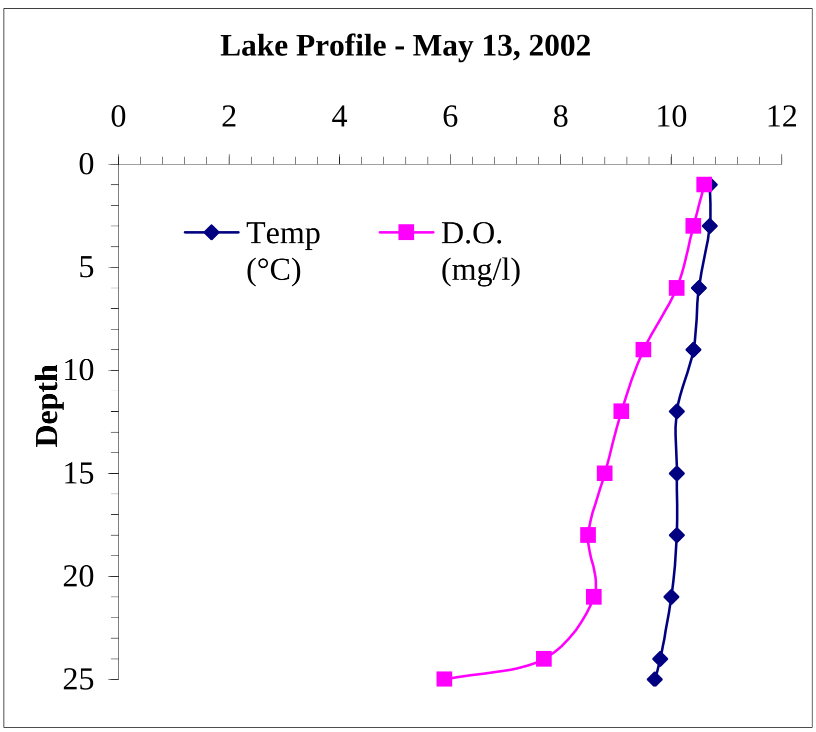
Parameter	CARLS	CARLB
Total P (mg/l)	0.203	0.373
Dissolved P (mg/l)		
Chl a (µg/l)	133	2
TKN (mg/l)	3.130	3.480
NO_2+NO_3-N (mg/l)	0.784	0.817
NH_3-N (mg/l)		
Total N (mg/l)	3.914	4.297
Lab Cond. (µS/cm)		
Lab pH		
Alkal (mg/l $CaCO_3$)		
Total Susp Sol (mg/l)		
Calcium (mg/l)		



Carstens Lake

Date: **05-13-02** **Max Depth (ft):** 25.6
Time: 12:41 ***Profile Only***
Weather: Overcast
Ent: TSN **Verf:** TAH/TSN **Secchi Depth (ft):** 2.2 .

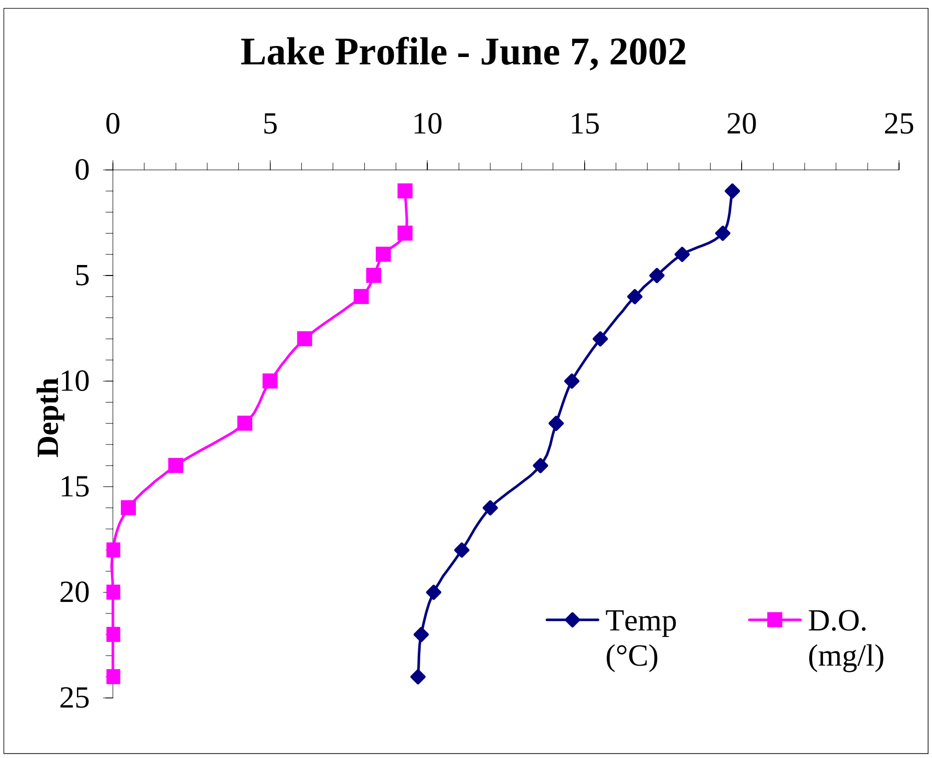
Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	10.7	10.6	8.4	469
3.0	10.7	10.4	8.4	470
6.0	10.5	10.1	8.4	470
9.0	10.4	9.5	8.3	471
12.0	10.1	9.1	8.3	472
15.0	10.1	8.8	8.3	472
18.0	10.1	8.5	8.2	472
21.0	10.0	8.6	8.3	473
24.0	9.8	7.7	8.2	475
25.0	9.7	5.9	8.0	479



Carstens Lake

Date: **06-07-02** **Max Depth (ft):** 25.2
Time: ***Profile Only***
Weather: Breezy and Clear
Ent: TSN **Verf:** TAH/TSN **Secchi Depth (ft):** 8.6 .

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	19.7	9.3	8.6	540
3.0	19.4	9.3	8.6	540
4.0	18.1	8.6	8.6	542
5.0	17.3	8.3	8.6	540
6.0	16.6	7.9	8.6	542
8.0	15.5	6.1	8.3	551
10.0	14.6	5.0	8.2	550
12.0	14.1	4.2	8.2	553
14.0	13.6	2.0	8.2	554
16.0	12.0	0.5	8.0	553
18.0	11.1	0.0	7.9	550
20.0	10.2	0.0	7.6	553
22.0	9.8	0.0	7.7	560
24.0	9.7	0.0	7.6	563

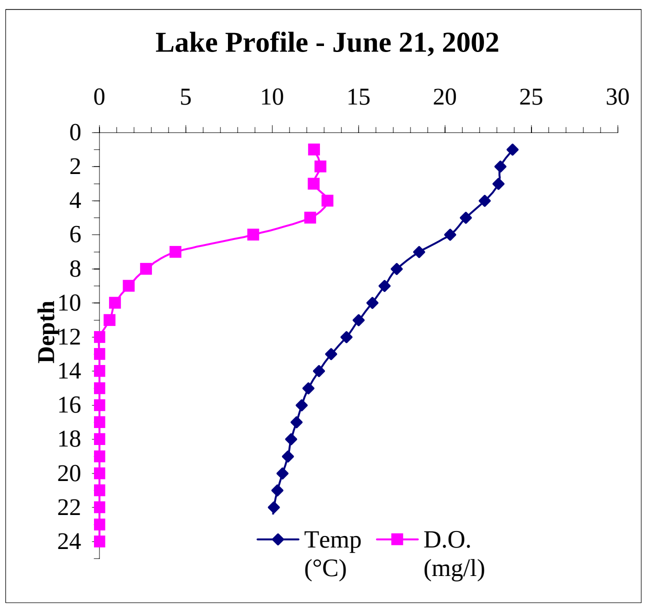


ırstens Lake

Date:	**06-21-02**		**Max Depth (ft):**	25.1
Time:	14:50	CARLS	**CARLS Depth (ft):**	3.0
Weather:	partly cloudy 75 rain earlier		**CARLB Depth (ft):**	22.0
Ent:	BGN	**Verf:** BN/JE	**Secchi Depth (ft):**	3.7

Depth (ft)	**Temp (°C)**	**D.O. (mg/l)**	**pH**	**Sp. Cond (µS/cm)**
1.0	23.9	12.4	8.8	512
2.0	23.2	12.8	8.9	515
3.0	23.1	12.4	8.8	517
4.0	22.3	13.2	8.8	523
5.0	21.2	12.2	8.8	528
6.0	20.3	8.9	8.5	549
7.0	18.5	4.4	8.1	567
8.0	17.2	2.7	8.0	568
9.0	16.5	1.7	7.9	563
10.0	15.8	0.9	7.9	559
11.0	15.0	0.6	7.9	558
12.0	14.3	0.0	8.0	556
13.0	13.4	0.0	8.1	554
14.0	12.7	0.0	8.1	558
15.0	12.1	0.0	9.2	560
16.0	11.7	0.0	9.4	560
17.0	11.4	0.0	9.4	561
18.0	11.1	0.0	9.4	560
19.0	10.9	0.0	9.4	563
20.0	10.6	0.0	9.4	566
21.0	10.3	0.0	9.3	570
22.0	10.1	0.0	9.2	574
23.0	10.0	0.0	8.3	576
24.0	9.9	0.0	8.1	576

Parameter		**CARLS**	**CARLB**
Total P (mg/l)		0.069	0.484
Dissolved P (mg/l)			
Chl a (µg/l)		10.5	
TKN (mg/l)		1.880	4.550
NO_4+NO_3-N (mg/l)		0.646	0.020
NH_3-N (mg/l)			
Total N (mg/l)		2.526	4.570
Lab Cond. (µS/cm)			
Lab pH			
Alkal (mg/l $CaCO_3$)			
Total Susp Sol (mg/l)			
Calcium (mg/l)			

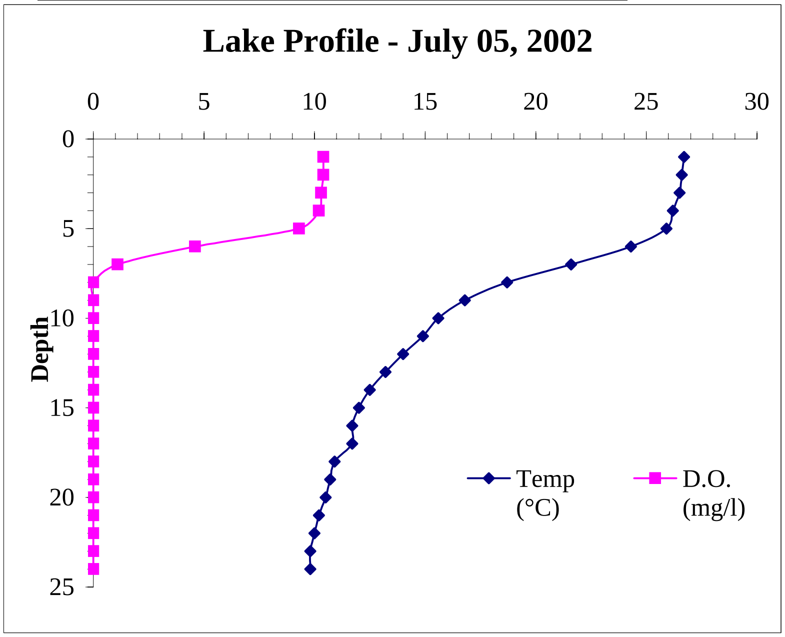


Carstens Lake

Date: 07-05-02
Time: 11:20
Weather: partly cloudy 70
Ent: BGN **Verf:** BN/JE

Max Depth (ft): 25.2
Profile Only
Secchi Depth (ft): 2.6 .

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	26.7	10.4	8.4	492
2.0	26.6	10.4	8.4	492
3.0	26.5	10.3	8.4	491
4.0	26.2	10.2	8.4	491
5.0	25.9	9.3	8.4	493
6.0	24.3	4.6	8.0	540
7.0	21.6	1.1	7.8	567
8.0	18.7	0.0	7.8	564
9.0	16.8	0.0	7.8	558
10.0	15.6	0.0	7.9	555
11.0	14.9	0.0	7.9	555
12.0	14.0	0.0	8.3	557
13.0	13.2	0.0	9.0	556
14.0	12.5	0.0	9.4	557
15.0	12.0	0.0	9.6	563
16.0	11.7	0.0	9.8	565
17.0	11.7	0.0	9.8	568
18.0	10.9	0.0	9.8	568
19.0	10.7	0.0	9.8	570
20.0	10.5	0.0	9.8	573
21.0	10.2	0.0	8.8	580
22.0	10.0	0.0	8.3	590
23.0	9.8	0.0	8.0	617
24.0	9.8	0.0	7.6	640



Carstens Lake

Date: 07-23-02
Time: 16:00
Weather: 71, breezy clear
Ent: BGN **Verf:** BN/JE

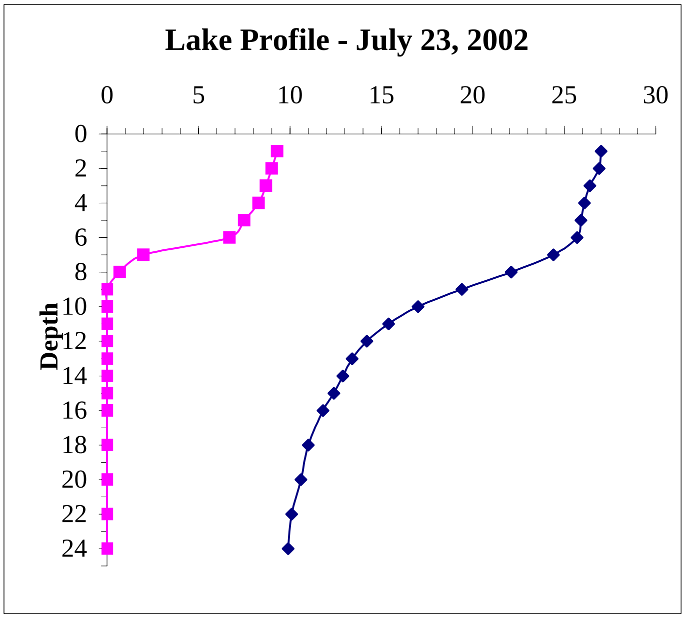
CARLS

Max Depth (ft): 25.2
CARSLS 3.0
CARSLB 22.0
Secchi Depth (ft): 1.7

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	27.0	9.3	9.3	453
2.0	26.9	9.0	9.4	453
3.0	26.4	8.7	9.4	455
4.0	26.1	8.3	9.4	456
5.0	25.9	7.5	9.4	461
6.0	25.7	6.7	9.4	463
7.0	24.4	2.0	EM	498
8.0	22.1	0.7	EM	550
9.0	19.4	0.0	EM	566
10.0	17.0	0.0	EM	561
11.0	15.4	0.0	EM	567
12.0	14.2	0.0	EM	565
13.0	13.4	0.0	EM	563
14.0	12.9	0.0	EM	565
15.0	12.4	0.0	EM	567
16.0	11.8	0.0	EM	575
18.0	11.0	0.0	EM	581
20.0	10.6	0.0	EM	599
22.0	10.1	0.0	EM	618
24.0	9.9	0.0	EM	639

EM = Equipment Malfunction

Parameter	CARLS	CARLB
Total P (mg/l)	0.079	0.632
Dissolved P (mg/l)		
Chl a (µg/l)	14.6	
TKN (mg/l)	1.950	6.640
NO_4+NO_3-N (mg/l)	0.013	0.013
NH_3-N (mg/l)		
Total N (mg/l)	1.963	6.653
Lab Cond. (µS/cm)		
Lab pH		
Alkal (mg/l $CaCO_3$)		
Total Susp Sol (mg/l)		
Calcium (mg/l)		

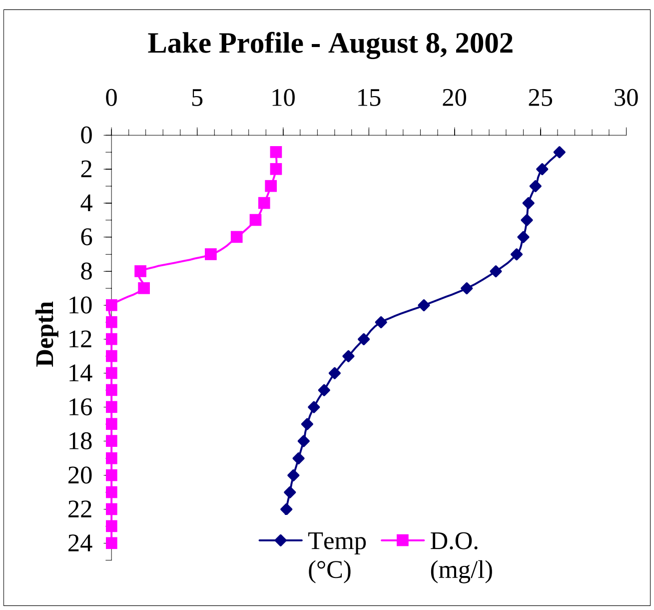


Carstens Lake

Date: **08-08-02** **Max Depth (ft):** 24.9
Time: 13:47 ***Profile only***
Weather: Clear, slight breeze 79
Ent: BGN **Verf:** TAH/TSN **Secchi Depth (ft):** 2.2

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	26.1	9.6	6.3	462
2.0	25.1	9.6	6.2	461
3.0	24.7	9.3	6.2	462
4.0	24.3	8.9	6.3	463
5.0	24.2	8.4	6.4	463
6.0	24.0	7.3	6.5	467
7.0	23.6	5.8	6.6	469
8.0	22.4	1.7	6.4	514
9.0	20.7	1.9	6.0	555
10.0	18.2	0.0	EM	568
11.0	15.7	0.0	EM	568
12.0	14.7	0.0	EM	572
13.0	13.8	0.0	EM	574
14.0	13.0	0.0	EM	574
15.0	12.4	0.0	EM	581
16.0	11.8	0.0	EM	590
17.0	11.4	0.0	EM	592
18.0	11.2	0.0	EM	600
19.0	10.9	0.0	EM	607
20.0	10.6	0.0	EM	613
21.0	10.4	0.0	EM	621
22.0	10.2	0.0	EM	637
23.0	10.1	0.0	EM	651
24.0	10.0	0.0	EM	689

EM = Equipment Malfunction



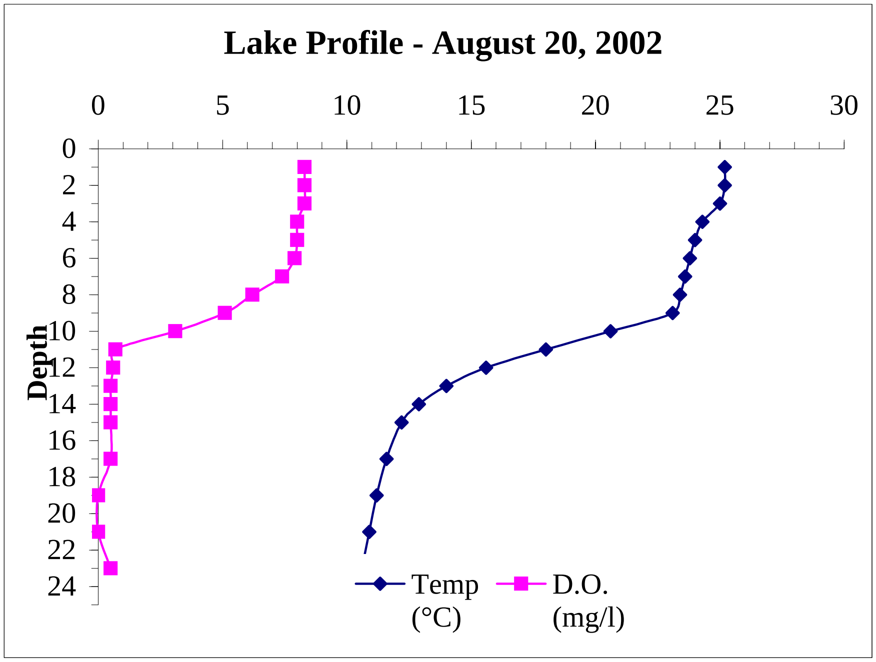
Carstens Lake

Date: **08-20-02**
Time: 14:30
Weather: Mostly Sunny, 76
Ent: BGN **Verf:** BN/JE

Max Depth (ft): 24.1
Profile only

Secchi Depth (ft): 2.8

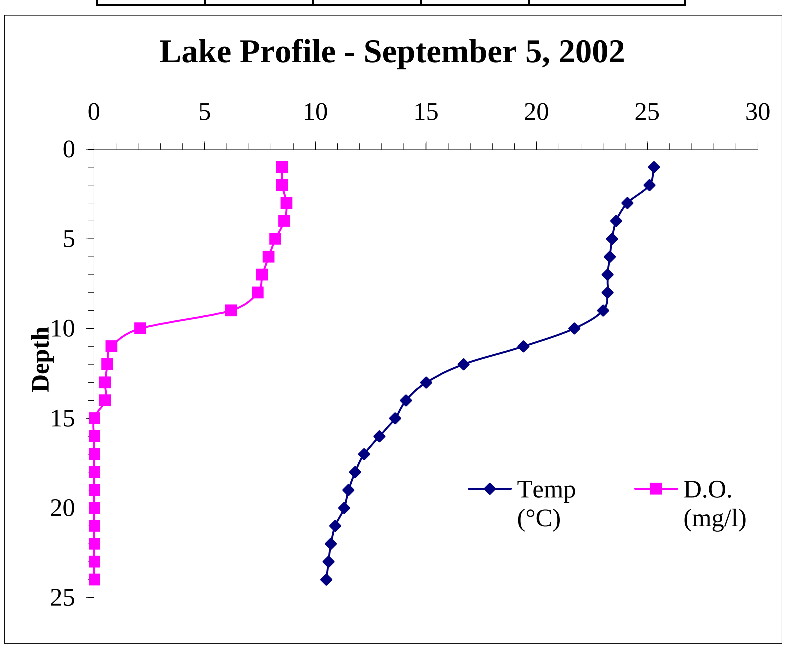
Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	25.2	8.3	9.1	470
2.0	25.2	8.3	9.2	470
3.0	25.0	8.3	9.2	470
4.0	24.3	8.0	9.2	470
5.0	24.0	8.0	9.2	469
6.0	23.8	7.9	9.1	469
7.0	23.6	7.4	9.0	473
8.0	23.4	6.2	8.9	474
9.0	23.1	5.1	8.8	485
10.0	20.6	3.1	8.1	544
11.0	18.0	0.7	7.5	474
12.0	15.6	0.6	7.4	579
13.0	14.0	0.5	7.4	588
14.0	12.9	0.5	7.3	597
15.0	12.2	0.5	7.3	603
17.0	11.6	0.5	7.2	613
19.0	11.2	0.0	7.2	623
21.0	10.9	0.0	7.2	628
23.0	10.6	0.5	7.1	644



Carstens Lake

Date: **09-05-02** | **Max Depth (ft):** 24.4
Time: 15:31 | ***Profile Only***
Weather: Clear, light Breeze, 72F
Ent: TSN **Verf:** TAH/TSN | **Secchi Depth (ft):** 2.8 .

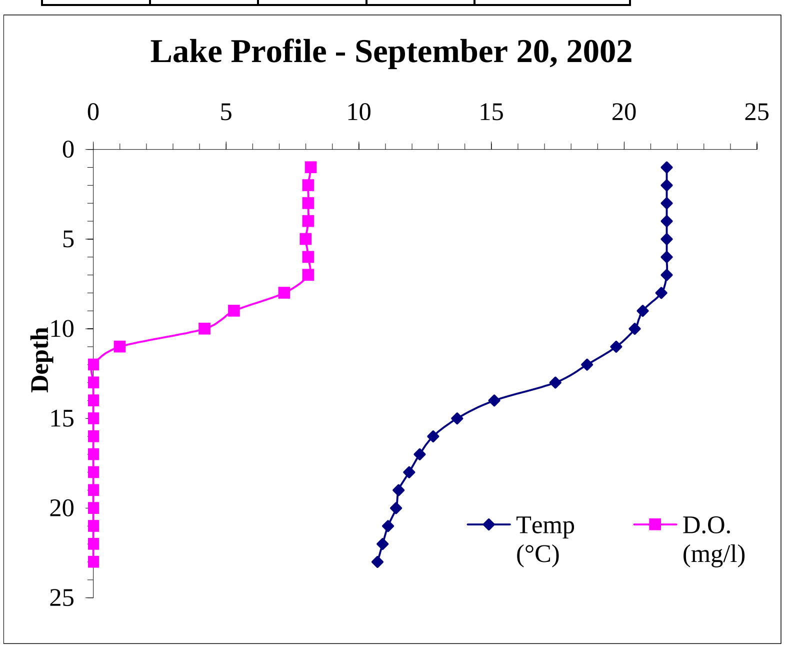
Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	25.3	8.5	9.0	472
2.0	25.1	8.5	9.1	474
3.0	24.1	8.7	9.0	472
4.0	23.6	8.6	9.0	472
5.0	23.4	8.2	8.9	473
6.0	23.3	7.9	8.9	473
7.0	23.2	7.6	8.9	474
8.0	23.2	7.4	8.8	475
9.0	23.0	6.2	8.7	478
10.0	21.7	2.1	8.2	507
11.0	19.4	0.8	7.9	551
12.0	16.7	0.6	7.4	588
13.0	15.0	0.5	7.3	596
14.0	14.1	0.5	7.3	597
15.0	13.6	0.0	7.3	602
16.0	12.9	0.0	7.2	608
17.0	12.2	0.0	7.2	613
18.0	11.8	0.0	7.2	618
19.0	11.5	0.0	7.2	622
20.0	11.3	0.0	7.2	627
21.0	10.9	0.0	7.1	640
22.0	10.7	0.0	7.1	649
23.0	10.6	0.0	7.1	654
24.0	10.5	0.0	7.0	664



Carstens Lake

Date: **09-20-02** **Max Depth (ft):** 24.2
Time: ***Profile Only***
Weather: Overcast, Showers, 68F
Ent: TSN **Verf:** TAH/TSN **Secchi Depth (ft):** 3.4 .

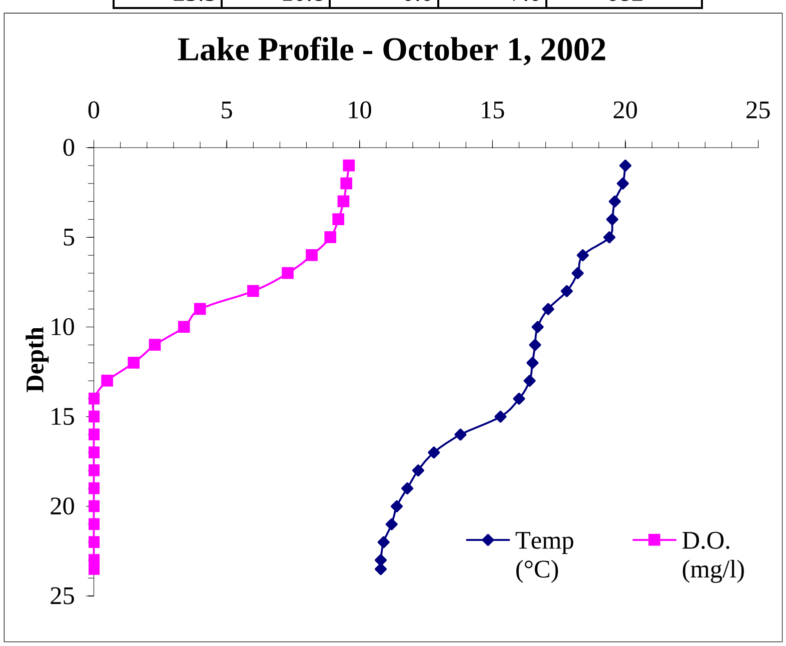
Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	21.6	8.2	9.1	472
2.0	21.6	8.1	9.2	472
3.0	21.6	8.1	9.1	472
4.0	21.6	8.1	9.1	472
5.0	21.6	8.0	9.1	472
6.0	21.6	8.1	9.0	472
7.0	21.6	8.1	9.0	472
8.0	21.4	7.2	8.9	474
9.0	20.7	5.3	8.7	485
10.0	20.4	4.2	8.6	491
11.0	19.7	1.0	8.2	507
12.0	18.6	0.0	7.7	542
13.0	17.4	0.0	7.4	575
14.0	15.1	0.0	7.3	601
15.0	13.7	0.0	7.3	611
16.0	12.8	0.0	7.2	622
17.0	12.3	0.0	7.2	625
18.0	11.9	0.0	7.2	632
19.0	11.5	0.0	7.2	637
20.0	11.4	0.0	7.2	641
21.0	11.1	0.0	7.1	650
22.0	10.9	0.0	7.1	658
23.0	10.7	0.0	7.1	669



Carstens Lake

Date: **10-01-02** **Max Depth (ft):** 23.5+
Time: ***Profile Only***
Weather: Clear, Breezy, 81F
Ent: TSN **Verf:** TAH/TSN **Secchi Depth (ft):** 3.7 .

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	20.0	9.6	9.0	494
2.0	19.9	9.5	8.9	495
3.0	19.6	9.4	8.9	495
4.0	19.5	9.2	8.9	495
5.0	19.4	8.9	8.8	494
6.0	18.4	8.2	8.8	497
7.0	18.2	7.3	8.7	498
8.0	17.8	6.0	8.6	501
9.0	17.1	4.0	8.4	504
10.0	16.7	3.4	8.3	505
11.0	16.6	2.3	8.2	508
12.0	16.5	1.5	8.2	510
13.0	16.4	0.5	8.1	513
14.0	16.0	0.0	8.0	530
15.0	15.3	0.0	7.4	566
16.0	13.8	0.0	7.2	630
17.0	12.8	0.0	7.2	639
18.0	12.2	0.0	7.1	644
19.0	11.8	0.0	7.1	652
20.0	11.4	0.0	7.1	656
21.0	11.2	0.0	7.0	667
22.0	10.9	0.0	7.0	676
23.0	10.8	0.0	7.0	682
23.5	10.8	0.0	7.0	682

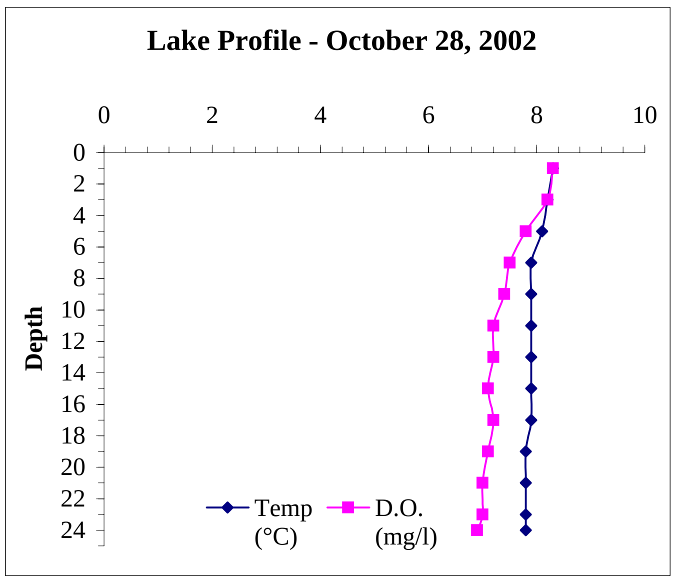


Carstens Lake

Date: **10-28-02** | **Max Depth (ft):** 24.8
Time: 13:00 | **CARLS Depth (ft):** 3.0
Weather: Clear, Breezy, 45 | **CARLB Depth (ft):** 21.0
Ent: tsn **Verf:** TAH/TSN | **Secchi Depth (ft):** 4.3

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	8.3	8.3	8.2	519
3.0	8.2	8.2	8.3	520
5.0	8.1	7.8	8.2	519
7.0	7.9	7.5	8.2	521
9.0	7.9	7.4	8.1	520
11.0	7.9	7.2	8.1	519
13.0	7.9	7.2	8.1	520
15.0	7.9	7.1	8.1	520
17.0	7.9	7.2	8.1	520
19.0	7.8	7.1	8.1	520
21.0	7.8	7.0	8.1	520
23.0	7.8	7.0	8.1	521
24.0	7.8	6.9	8.1	521

Parameter	CARLS	CARLB
Total P (mg/l)	0.120	0.085
Dissolved P (mg/l)		
Chl a (µg/l)	38.1	
TKN (mg/l)	2.820	2.690
NO_2+NO_3-N (mg/l)	0.000	0.000
NH_3-N (mg/l)		
Total N (mg/l)	2.820	2.690
Lab Cond. (µS/cm)		
Lab pH		
Alkal (mg/l $CaCO_3$)		
Total Susp Sol (mg/l)		
Calcium (mg/l)		

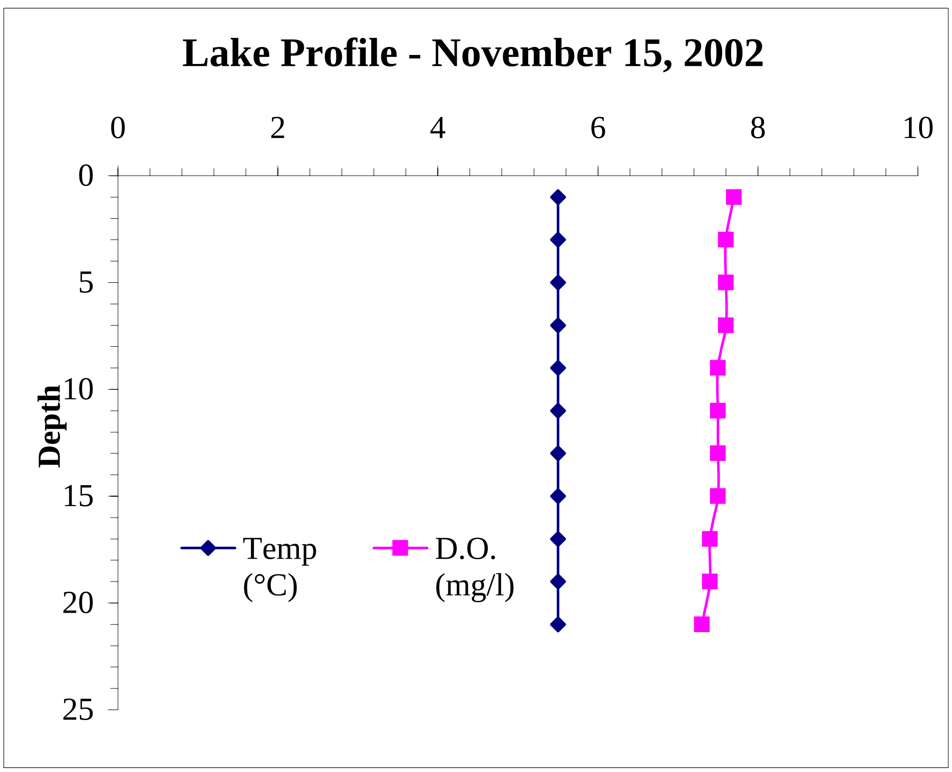


Carstens Lake

Date: **11-15-02**
Time: 10:30
Weather: Clear, 28F, Breezy
Ent: TSN **Verf:** TAH/TSN

Max Depth (ft): 22.2
Profile Only
Secchi Depth (ft): 12.2

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (μS/cm)
1.0	5.5	7.7	8.2	524
3.0	5.5	7.6	8.2	525
5.0	5.5	7.6	8.2	524
7.0	5.5	7.6	8.2	524
9.0	5.5	7.5	8.2	524
11.0	5.5	7.5	8.2	525
13.0	5.5	7.5	8.2	525
15.0	5.5	7.5	8.2	524
17.0	5.5	7.4	8.2	524
19.0	5.5	7.4	8.2	525
21.0	5.5	7.3	8.2	524



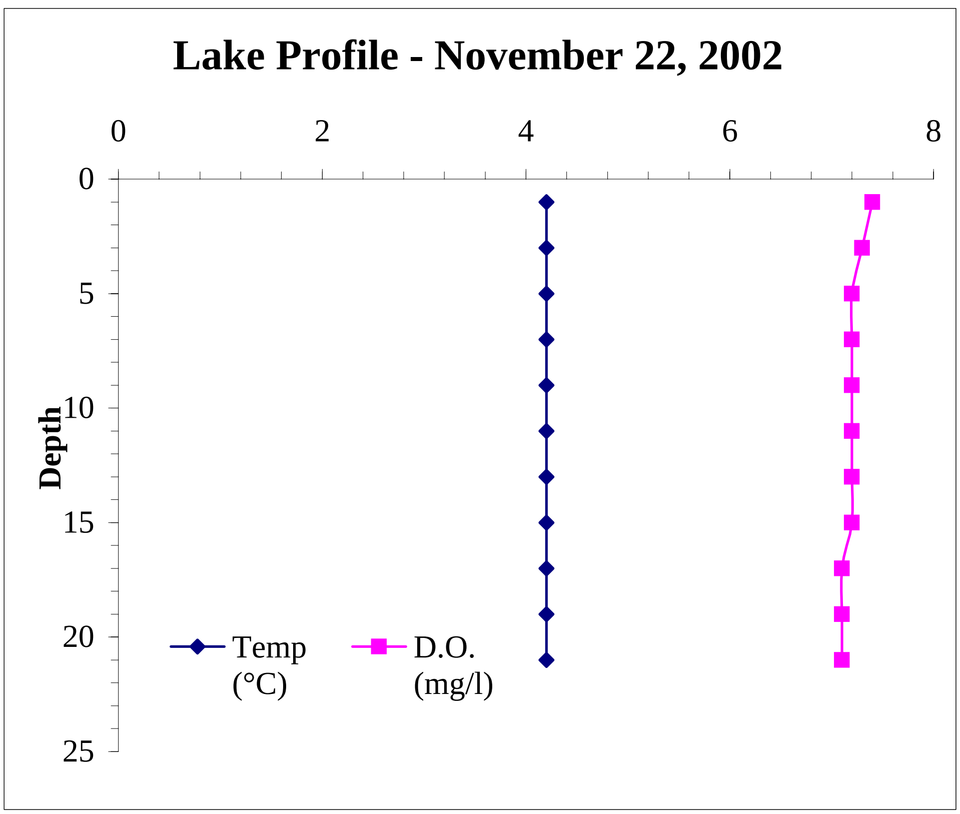
Carstens Lake

Date: **11-22-02**
Time: 12:39
Weather: Overcast, 34F
Ent: TSN **Verf:** TAH/TSN

Max Depth (ft): 21.8
Profile Only

Secchi Depth (ft): 9.6 .

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	4.2	7.4	7.8	523
3.0	4.2	7.3	7.8	523
5.0	4.2	7.2	7.8	524
7.0	4.2	7.2	7.8	524
9.0	4.2	7.2	7.8	524
11.0	4.2	7.2	7.8	525
13.0	4.2	7.2	7.8	524
15.0	4.2	7.2	7.8	525
17.0	4.2	7.1	7.8	525
19.0	4.2	7.1	7.8	525
21.0	4.2	7.1	7.8	525

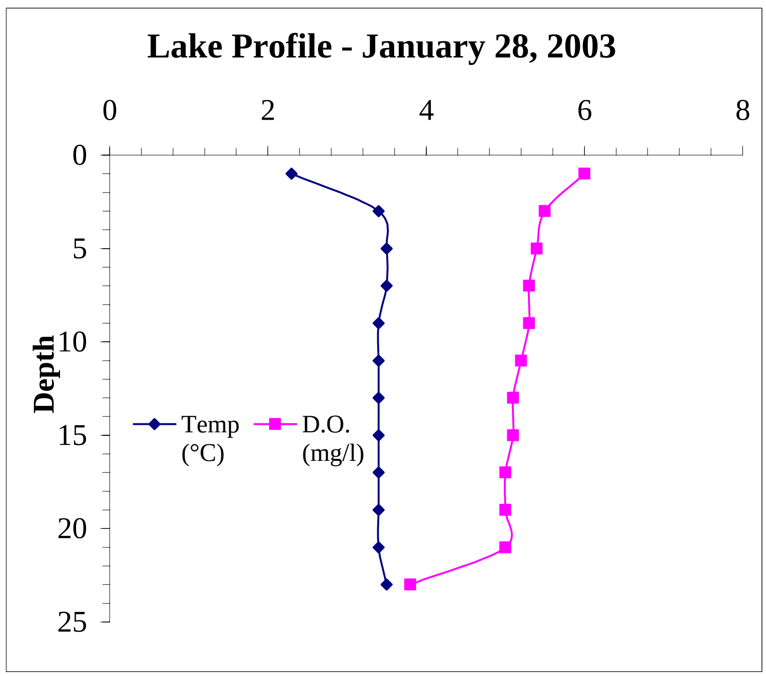


Carstens Lake

Date: **01-28-03** **Max Depth (ft):** 24.9 **Ice:** 1.3
Time: 14:30 **CarLS** 3.0
Weather: Cloudy, snow, 25F **CarLB** 22.0
Ent: TSN **Verf:** TAH/TSN **Secchi Depth (ft):** 10.5 .

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	2.3	6.0	7.6	575
3.0	3.4	5.5	7.6	581
5.0	3.5	5.4	7.6	581
7.0	3.5	5.3	7.6	581
9.0	3.4	5.3	7.6	583
11.0	3.4	5.2	7.6	582
13.0	3.4	5.1	7.6	582
15.0	3.4	5.1	7.6	583
17.0	3.4	5.0	7.6	582
19.0	3.4	5.0	7.6	582
21.0	3.4	5.0	7.6	583
23.0	3.5	3.8	7.6	584

Parameter	CARLS	CARLB
Total P (mg/l)	0.207	0.217
Dissolved P (mg/l)		
Chl a (µg/l)	1.23	
TKN (mg/l)	3.630	3.750
NO_2+NO_3-N (mg/l)	0.098	0.103
NH_3-N (mg/l)		
Total N (mg/l)	3.728	3.853
Lab Cond. (µS/cm)		
Lab pH		
Alkal (mg/l $CaCO_3$)		
Total Susp Sol (mg/l)		
Calcium (mg/l)		



Carstens Lake

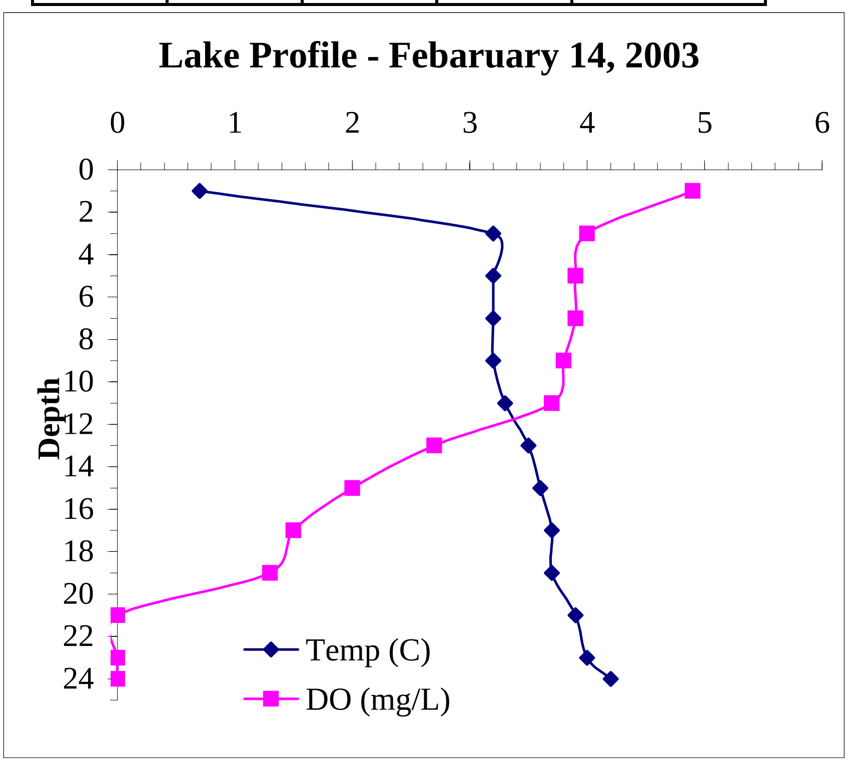
Date: **02-14-03** **Max Depth (ft):** 24.8 **Ice:** No Data

Time: 10:00 ***Profile Only***

Weather: 19F, Overcast

Ent: TSN **Verf:** TAH/TSN **Secchi Depth (ft):** 5.6 .

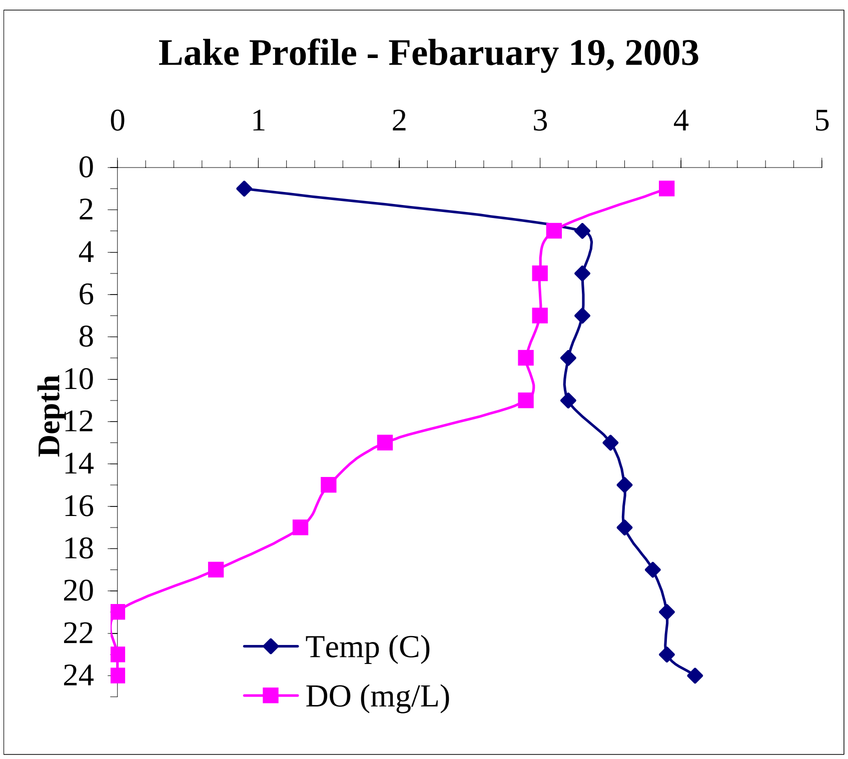
Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	0.7	4.9	7.5	593
3.0	3.2	4.0	7.5	588
5.0	3.2	3.9	7.5	588
7.0	3.2	3.9	7.5	589
9.0	3.2	3.8	7.5	589
11.0	3.3	3.7	7.5	589
13.0	3.5	2.7	7.5	588
15.0	3.6	2.0	7.5	589
17.0	3.7	1.5	7.5	590
19.0	3.7	1.3	7.4	590
21.0	3.9	0.0	7.4	593
23.0	4.0	0.0	7.4	594
24.0	4.2	0.0	7.1	663



Carstens Lake

Date: **02-19-03** **Max Depth (ft):** 24.8 **Ice:** 1.6
Time: 13:45 ***Profile Only*** **Snow:** ~1"
Weather: 25F, Clear, Windy
Ent: TSN **Verf:** TAH/TSN **Secchi Depth (ft):** 6.8 .

Depth (ft)	Temp (°C)	D.O. (mg/l)	pH	Sp. Cond (µS/cm)
1.0	0.9	3.9	7.6	585
3.0	3.3	3.1	7.6	586
5.0	3.3	3.0	7.6	586
7.0	3.3	3.0	7.6	587
9.0	3.2	2.9	7.6	588
11.0	3.2	2.9	7.6	588
13.0	3.5	1.9	7.5	588
15.0	3.6	1.5	7.5	588
17.0	3.6	1.3	7.5	590
19.0	3.8	0.7	7.5	590
21.0	3.9	0.0	7.4	594
23.0	3.9	0.0	7.4	600
24.0	4.1	0.0	7.0	670



B

APPENDIX B

Flow and Phosphorus Values Utilized in FLUX Modeling

Date	Flow (CFS)
03/12/2002	0.673
03/13/2002	0.197
03/14/2002	0.156
03/15/2002	0.11
03/16/2002	0.454
03/17/2002	0.382
03/18/2002	0.365
03/19/2002	0.369
03/20/2002	0.635
03/21/2002	0.465
03/22/2002	0.251
03/23/2002	0.18
03/24/2002	0.167
03/25/2002	0.13
03/26/2002	0.113
03/27/2002	0.12
03/28/2002	0.139
03/29/2002	0.16
03/30/2002	0.18
03/31/2002	0.152
04/01/2002	0.13
04/02/2002	0.167
04/03/2002	0.212
04/04/2002	0.195
04/05/2002	0.15
04/06/2002	0.12
04/07/2002	0.207
04/08/2002	0.617
04/09/2002	0.631
04/10/2002	0.604
04/11/2002	0.369
04/12/2002	0.254
04/13/2002	0.512
04/14/2002	0.693
04/15/2002	0.342
04/16/2002	0.089
04/17/2002	0.079
04/18/2002	0.137
04/19/2002	0.515
04/20/2002	0.185
04/21/2002	0.119
04/22/2002	0.114
04/23/2002	0.093
04/24/2002	0.086
04/25/2002	0.079
04/26/2002	0.072
04/27/2002	0.086
04/28/2002	0.7
04/29/2002	0.705
04/30/2002	0.322
05/01/2002	0.152
05/02/2002	0.269
05/03/2002	0.148
05/04/2002	0.107
05/05/2002	0.087
05/06/2002	0.342
05/07/2002	0.674
05/08/2002	0.681
05/09/2002	0.691
05/10/2002	0.68
05/11/2002	0.19
05/12/2002	0.228
05/13/2002	0.12
05/14/2002	0.088
05/15/2002	0.078
05/16/2002	0.072
05/17/2002	0.066
05/18/2002	0.063
05/19/2002	0.06
05/20/2002	0.056
05/21/2002	0.053
05/22/2002	0.05
05/23/2002	0.048
05/24/2002	0.044
05/25/2002	0.053
05/26/2002	0.053
05/27/2002	0.058
05/28/2002	0.046
05/29/2002	0.077
05/30/2002	0.065
05/31/2002	0.056
06/01/2002	0.043
06/02/2002	0.032

06/03/2002	0.454
06/04/2002	0.342
06/05/2002	0.156
06/06/2002	0.098
06/07/2002	0.073
06/08/2002	0.064
06/09/2002	0.061
06/10/2002	0.066
06/11/2002	0.066
06/12/2002	0.059
06/13/2002	0.054
06/14/2002	0.062
06/15/2002	0.128
06/16/2002	0.169
06/17/2002	0.081
06/18/2002	0.064
06/19/2002	0.059
06/20/2002	0.056
06/21/2002	0.074
06/22/2002	0.663
06/23/2002	0.329
06/24/2002	0.093
06/25/2002	0.064
06/26/2002	0.058
06/27/2002	0.053
06/28/2002	0.048
06/29/2002	0.032
06/30/2002	0.006
07/01/2002	0.002
07/02/2002	0.018
07/03/2002	0.032
07/04/2002	-0.063
07/05/2002	0
07/06/2002	0
07/07/2002	-0.063
07/08/2002	0.002
07/09/2002	0.021
07/10/2002	-0.022
07/11/2002	-0.028
07/12/2002	-0.051
07/13/2002	0
07/14/2002	0
07/15/2002	0
07/16/2002	0
07/17/2002	0
07/18/2002	0
07/19/2002	0
07/20/2002	0
07/21/2002	-0.01
07/22/2002	-0.028
07/23/2002	0
07/24/2002	0
07/25/2002	0
07/26/2002	0
07/27/2002	0
07/28/2002	0
07/29/2002	0
07/30/2002	0
07/31/2002	0
08/01/2002	0
08/02/2002	0
08/03/2002	0
08/04/2002	0
08/05/2002	0
08/06/2002	0
08/07/2002	0
08/08/2002	0
08/09/2002	0
08/10/2002	0
08/11/2002	0
08/12/2002	0
08/13/2002	0.012
08/14/2002	0.006
08/15/2002	-0.044
08/16/2002	0
08/17/2002	0
08/18/2002	0
08/19/2002	0
08/20/2002	0
08/21/2002	-0.01
08/22/2002	0.058
08/23/2002	0.044
08/24/2002	0.02
08/25/2002	0.012

08/26/2002	-0.031
08/27/2002	-0.063
08/28/2002	0
08/29/2002	0
08/30/2002	0
08/31/2002	0
09/01/2002	0
09/02/2002	0
09/03/2002	0
09/04/2002	0
09/05/2002	0
09/06/2002	0
09/07/2002	0
09/08/2002	0
09/09/2002	0
09/10/2002	0
09/11/2002	0
09/12/2002	0
09/13/2002	0
09/14/2002	0
09/15/2002	0
09/16/2002	0
09/17/2002	0
09/18/2002	0
09/19/2002	0
09/20/2002	0
09/21/2002	0
09/22/2002	0
09/23/2002	0
09/24/2002	0
09/25/2002	0
09/26/2002	0
09/27/2002	0
09/28/2002	0
09/29/2002	0
09/30/2002	0
10/01/2002	0
10/02/2002	0
10/03/2002	0
10/04/2002	0.054
10/05/2002	0.038
10/06/2002	0.01
10/07/2002	-0.048
10/08/2002	-0.063
10/09/2002	0
10/10/2002	0
10/11/2002	0
10/12/2002	0
10/13/2002	0
10/14/2002	0
10/15/2002	0
10/16/2002	0
10/17/2002	0
10/18/2002	0
10/19/2002	-0.048
10/20/2002	0
10/21/2002	-0.019
10/22/2002	0.008
10/23/2002	0.014
10/24/2002	0.004
10/25/2002	0.032
10/26/2002	0.047
10/27/2002	0.03
10/28/2002	0.016
10/29/2002	-0.005
10/30/2002	-0.037
10/31/2002	-0.063
11/01/2002	0
11/02/2002	0
11/03/2002	0
11/04/2002	0
11/05/2002	0
11/06/2002	0
11/07/2002	0
11/08/2002	0
11/09/2002	0
11/10/2002	0
11/11/2002	0
11/12/2002	0
11/13/2002	0.05
11/14/2002	0
11/15/2002	0

Appendix B Boat Landing Site Instantaneous Flows and Phosphorus Concentrations used in FLUX

Date	Flow (CFS)	mg/m^3 P
03/12/2002	0.48	149
03/19/2002	0.325	51
03/28/2002	0.14	50
04/08/2002	0.875	234
04/18/2002	0.08	54
04/19/2002	0.169	178
04/25/2002	0.08	45
04/28/2002	0.85	167
05/06/2002	0.061	894
05/07/2002	0.85	414
06/03/2002	0.627	132
06/05/2002	0.26	97
06/20/2002	0.04	69
07/09/2002	0.02	213
08/22/2002	0.06	240
10/21/2002	0.03	166
10/28/2002	0.02	87

Date	Flow (CFS)
03/13/2002	0
03/14/2002	0
03/15/2002	0
03/16/2002	3.401
03/17/2002	2.777
03/18/2002	2.489
03/19/2002	2.228
03/20/2002	2.127
03/21/2002	2.885
03/22/2002	2.554
03/23/2002	1.85
03/24/2002	1.22
03/25/2002	0.896
03/26/2002	0.56
03/27/2002	0.377
03/28/2002	0.363
03/29/2002	0.564
03/30/2002	0.947
03/31/2002	1.423
04/01/2002	1.534
04/02/2002	1.227
04/03/2002	1.163
04/04/2002	1.386
04/05/2002	1.292
04/06/2002	0.915
04/07/2002	0.665
04/08/2002	1.114
04/09/2002	2.865
04/10/2002	4.74
04/11/2002	3.675
04/12/2002	3.06
04/13/2002	2.629
04/14/2002	2.168
04/15/2002	1.755
04/16/2002	1.563
04/17/2002	1.241
04/18/2002	0.798
04/19/2002	1.006
04/20/2002	3.419
04/21/2002	2.723
04/22/2002	1.85
04/23/2002	1.711
04/24/2002	1.292
04/25/2002	0.999
04/26/2002	0.852
04/27/2002	0.525
04/28/2002	0.497
04/29/2002	4.794
04/30/2002	4.323
05/01/2002	3.13
05/02/2002	2.359
05/03/2002	2.88
05/04/2002	2.32
05/05/2002	1.608
05/06/2002	1.012
05/07/2002	2.161
05/08/2002	9.934
05/09/2002	4.723
05/10/2002	3.563
05/11/2002	2.745
05/12/2002	1.836
05/13/2002	2.39
05/14/2002	1.857
05/15/2002	1.227
05/16/2002	0.719
05/17/2002	0.438
05/18/2002	0.329
05/19/2002	0.35
05/20/2002	0.437
05/21/2002	0.561
05/22/2002	0.669
05/23/2002	0.785
05/24/2002	0.901
05/25/2002	1.096
05/26/2002	0.669
05/27/2002	0.413
05/28/2002	0.552
05/29/2002	0.758
05/30/2002	0.505
05/31/2002	0.534
06/01/2002	0.337
06/02/2002	0.548
06/03/2002	1.008

06/04/2002	2.434
06/05/2002	3.065
06/06/2002	2.05
06/07/2002	0.921
06/08/2002	0.408
06/09/2002	0.341
06/10/2002	0.535
06/11/2002	0.807
06/12/2002	0.531
06/13/2002	0.639
06/14/2002	0.851
06/15/2002	0.54
06/16/2002	0.921
06/17/2002	1.563
06/18/2002	0.702
06/19/2002	0.331
06/20/2002	0.561
06/21/2002	0.947
06/22/2002	0.345
06/23/2002	3.413
06/24/2002	2.728
06/25/2002	0.89
06/26/2002	0.327
06/27/2002	0.466
06/28/2002	0.644
06/29/2002	1.09
06/30/2002	1.383
07/01/2002	1.095
07/02/2002	0.73
07/03/2002	0
07/04/2002	0
07/05/2002	0
07/06/2002	0
07/07/2002	0
07/08/2002	0
07/09/2002	0
07/10/2002	0
07/11/2002	0
07/12/2002	0
07/13/2002	0
07/14/2002	0
07/15/2002	0
07/16/2002	0
07/17/2002	0
07/18/2002	0
07/19/2002	0
07/20/2002	0
07/21/2002	0
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11/15/2002	0

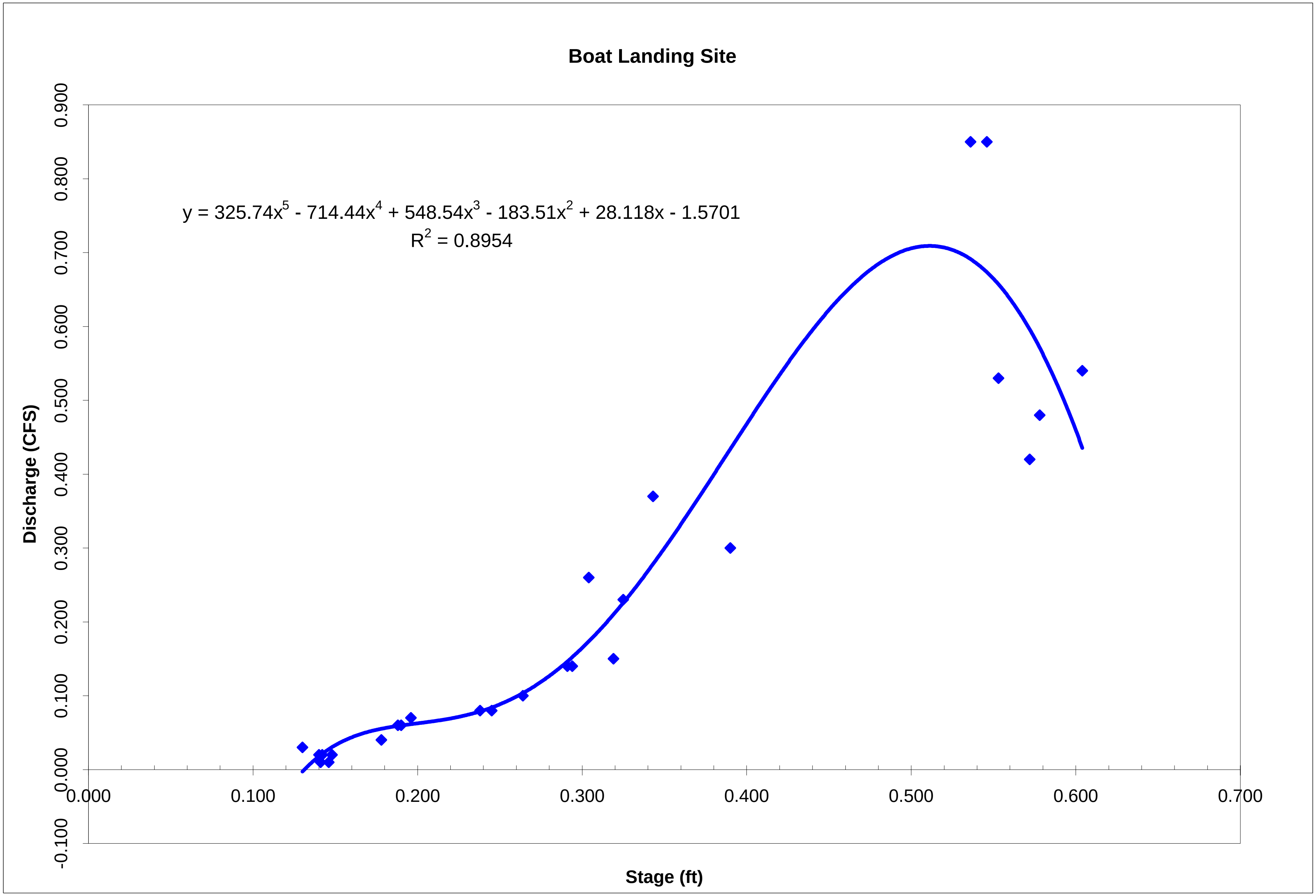
Appendix B Carstens Road Site Instantaneous Flows and Phosphorus Concentrations used in FLUX

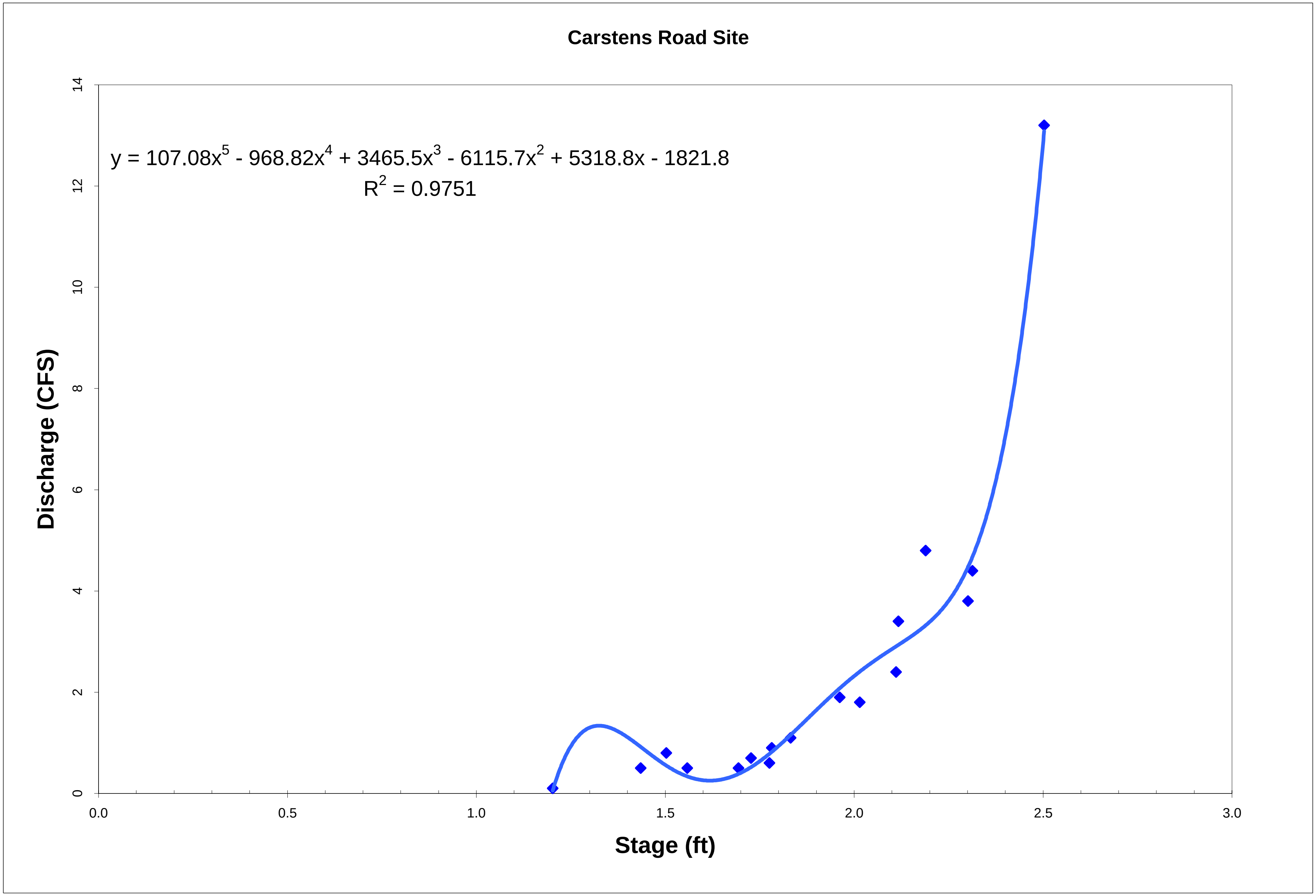
Date	Flow (CFS)	mg/m^3 P
03/12/2002	3.8	62
03/19/2002	2.099	29
03/28/2002	0.5	25
04/08/2002	3.196	29
04/18/2002	1.156	45
04/19/2002	3.535	58
04/25/2002	0.6	250
04/28/2002	6.278	106
05/06/2002	17.826	1570
05/07/2002	13.2	280
06/03/2002	3.27	131
06/20/2002	0.5	137
07/09/2002	0.1	457

C

APPENDIX C

Rating Curves Used to Relate Tributary Stage to Discharge


Boat Landing Site
y = 325.74x^5 - 714.44x^4 + 548.54x^3 - 183.51x^2 + 28.118x - 1.5701
R^2 = 0.8954
Discharge (CFS)
-0.100
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Stage (ft)



Carstens Road Site
y = 107.08x5 - 968.82x4 + 3465.5x3 - 6115.7x2 + 5318.8x - 1821.8
R2 = 0.9751
Discharge (CFS)
Stage (ft)
0
2
4
6
8
10
12
14
0.0
0.5
1.0
1.5
2.0
2.5
3.0

D

APPENDIX D

Lake Term Glossary

Algae	Microscopic plants that use sunlight as an energy source. Algae can be unicellular (Diatoms), filamentous (many green or blue-green species), colonies in a gelatinous mass (many blue-greens) or more complicated colonies like *Chara sp.*
Alum Treatment	An in-lake treatment used in reducing internal nutrient loading. The treatment includes the application of aluminum sulfate or other aluminum salt (alum) directly to the lake. Once added to the lake, the alum changes form and begins to form a floc. As the floc settles to the bottom, it pulls phosphorus and particulate matter down with it. Finally, the floc settles to the bottom creating a "blanket" or barrier that prevents phosphorus from entering the water column from the bottom sediments and as a result, reduces internal phosphorus loading significantly.
Anthropogenic	An occurrence caused or produced by the action of humans.
Anoxic	Devoid of dissolved oxygen.
Benthic	Pertaining to a river bed or lake floor
Contact Herbicide	A plant specific pesticide which causes extensive cellular damage exclusively to the areas of the target which come in contact with the herbicide (Affects contacted area only)
Ecosystem	The interaction of a community of organisms with each other and with the characteristics that make up their environment (Aquatic ecosystem, Northern Boreal Forest)
Emergent	An aquatic plant having most of its vegetative parts above the water surface (Cattail, Common Arrowhead)
Epilimnion	The upper most layer of water within a stratified lake. During the summer, this layer holds the warmest water and during the winter it holds the coldest water. This layer continuously circulates.
Exotic	A non-native organism that has been introduced into an area (Purple Loosestrife, Eurasian Water Milfoil)
Floating-leaf	Plants rooted in the sediment or free-floating with leaves lying flat on the water surface (Duckweed, White Water Lilly)
Hypolimnion	The deepest layer of water within a stratified lake. In the winter it holds the warmest water and in the summer it holds the coldest water.
Interspecific	Between two or more distinct species.
Invasive	An organism which readily colonizes a disturbed area and tends to take it over by out-competing other plants. These can be native (Cattail) or exotic species (Purple Loosestrife).
Limiting Nutrient	The nutrient, usually phosphorus, which is in shortest supply and controls the growth rate of algae and macrophytes.
Littoral Zone	Pertaining to the shallow water zone of a lake that has sufficient light penetration to support macrophytes.
Macrophyte	A multicelled plant, usually with roots, stems, and leaves. A vascular plant (Cattail, Eurasian water-milfoil, pondweeds)

Median Value	A value in a set which has an equal number of observations above it and below it
Metalimnion	This is the layer between the epilimnion and the hypolimnion that has the greatest range of temperature change with depth. The metalimnion contains the thermocline, but is not the same thing.
Native	An organism that is naturally occurring to an area (White Water Lilly, Northern Water-milfoil)
Nitrogen to Phosphorus Ratio	Results of this ratio indicate if algal growth within a lake is limited by nitrogen or phosphorus. If the ratio is greater than 16:1, the lake is considered phosphorus limited; if it is less than 16:1, it is considered nitrogen limited. The key ratio of 16:1 is related to the normal nitrogen to phosphorus ration found in most algae.
Non-Point Source Pollution	A source of pollution that comes from an indirect point of discharge (Overland flow)
Periphyton	A community of algae, and fragments of algae, which are attached to submerged objects such as plants and stones
Photosynthesis	The process in which chlorophyll producing organisms convert CO2 and water into sugar and oxygen, using sunlight as an energy source
Phytoplankton	Free-floating (not attached) algae.
Point Source Pollution	A source of pollution that comes from a direct point of discharge (Drain Tile Outfall)
Senesce	To complete a life cycle; to die off
Shoreland Buffer Zone	A buffer of native plants and habitat that occurs between the lake and developed property. The buffer zone serves to filter sediment and nutrients that wash off of a developed area before they reach the lake.
Species Diversity	An index that relates the number of species to their relative abundances. A community with many species with similar numbers (abundances) is more diverse than a community with the same number of species, but only a few of the species dominate the area with their abundances.
Species Richness	The total number of species occurring in a community
Submergent	An aquatic plant growing entirely under the water surface (Coontail, Large-leaf pondweed, Eurasian water-milfoil)
Systematic Herbicide	A plant specific pesticide which causes systematic cellular damage after coming in contact with the target. These herbicides spread through the entire plant.
Water Residence Time	The average amount of time water resides in a lake. Usually measured in years or days. A lake with a long residence time would have a slow flushing rate.
Zooplankton	Microscopic animals that are free-floating with in a water body. Many prey on algae and are an important food source for young fish.

E

APPENDIX E

Presentations to the Manitowoc County Lakes Association Concerning the Project

Carstens Lake
Alum Treatment Feasibility Study

Timothy A. Hoyman, CLM

NES Ecological Services
A Division of Robert E. Lee & Associates, Inc.

Presentation Outline

- Project Background
  - Lake Management Planning Grant Study
- Intro to Phosphorus and Alum Treatments
- Feasibility Study
  - Project Objectives
  - Project Activities
  - Volunteer Needs
- Future Activities

NES Ecological Services
A Division of Robert E. Lee & Associates, Inc.

Project Background

Carstens Lake

- **Lake Management Planning Grant Report**
  - **Project Findings**
    - *Lake is Eutrophic*
    - *High Phosphorus Levels*
    - *Nuisance Algal Blooms*
    - *Fishkills from Plant Decay*
    - *Most of the Water Enters Lake Through Two Inlets*

NES Ecological Services
A Division of Robert E. Lee & Associates, Inc.

Project Background

Carstens Lake

- **Lake Management Planning Grant Report**
  - **Recommendations**
    - *Reduce Phosphorus Entering the Lake*
    - *Investigate Alum Treatment for Lake*

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Phosphorus

Sources of Phosphorus

- **External Sources**
  - *Surface Runoff*
  - *Groundwater*
  - *Precipitation*
  - *Agricultural Drain Tiles*
  - *Sewage Plant Effluent*
  - *Lawn Runoff*
- **Internal Loading**

May be a significant source of phosphorus driving algae and other plant growth even after external source are minimized.

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Alum Treatment

Phosphorus Inactivation

- **Aluminum Sulfate Addition**
  - *Forms aluminum hydroxide floc*
  - *Floc settles to the bottom of lake "dragging" phosphorus with it.*
  - *Floc forms barrier to sediment phosphorus release.*

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Feasibility Study

Project Objectives

1. Determine how much phosphorus is entering Carstens Lake from its watershed via the lake’s two inlets.
2. Determine the extent of internal phosphorus loading in Carstens Lake.

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Feasibility Study

Project Activities

- Tributary Sampling
  - Continuous Flow
  - Water Quality Grab Samples
    - Storm and Base Flows
- Lake Water Quality
  - Nutrients
  - Chlorophyll (Algae)
  - D.O. / Temp Profiles

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Feasibility Study

Volunteer Needs

- Responsibilities:
  - Collect Grab Samples During Storm Events
  - Preserve Samples
  - Record Precipitation
  - Mail Samples to State Lab of Hygiene

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Future Activities

Future Management of Carstens Lake

- Eurasian Water-milfoil
  - Milfoil Weevil
- Restoration of Shoreland Buffers
  - Weevil Overwintering
  - Detains Residential Runoff
  - Scenic Beauty

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Wisconsin Lakes Partnership

UW Extension

Wisconsin Dept. of Natural Resources

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Carstens Lake
Alum Treatment Feasibility Study
December 3, 2003

Timothy A. Hoyman, CLM
NES Ecological Services
A Division of Robert E. Lee & Associates, Inc.

Presentation Outline

- Project Background
- Project Objectives
- Phosphorus & Lakes
- Results and Discussion
- Recommendations

NES Ecological Services
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Project Background

Carstens Lake

- **Lake Management Planning Grant Report**
  - **Project Findings**
    - *Lake is Eutrophic*
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Project Background

Carstens Lake

- **Lake Management Planning Grant Report**
  - **Recommendations**
    - *Reduce Phosphorus Entering the Lake*
    - *Investigate Alum Treatment for Lake*

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Project Objectives

- Investigate Internal Phosphorus Loadings
  - Phosphorus Concentrations
  - Temperature and Dissolved Oxygen Profiles
- Investigate Phosphorus Loads from Tributaries
  - Continuous Flow Monitoring
  - Grab Samples for Phosphorus Analysis

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Phosphorus & Lakes

Water Quality

↑ Phosphorus (Limiting Plant Nutrient)

↑ Chlorophyll-*a* (Algal Abundance)

↓ Water Clarity (Secchi Disk)

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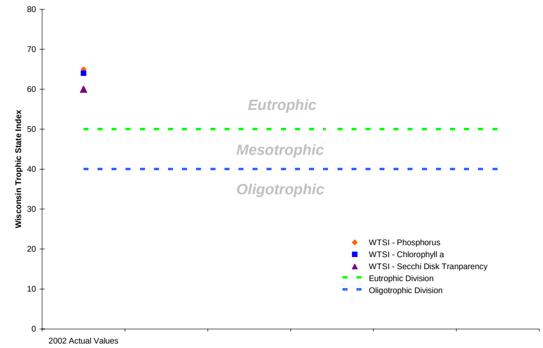
Results & Discussion



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Phosphorus & Lakes

Sources of Phosphorus

- **External Sources**
  - *Surface Runoff*
  - *Groundwater*
  - *Precipitation*
  - *Agricultural Drain Tiles*
  - *Faulty Septic Systems*
  - *Lawn Runoff*
- **Internal Loading**

May be a significant source of phosphorus driving algae and other plant growth even after external source are minimized.

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Phosphorus & Lakes

Phosphorus Inactivation

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Results & Discussion

Internal Phosphorus Loading

- **Water Quality Monitoring**
  - *High Volumes of Anoxic Water*
  - *High Concentrations of Phosphorus*

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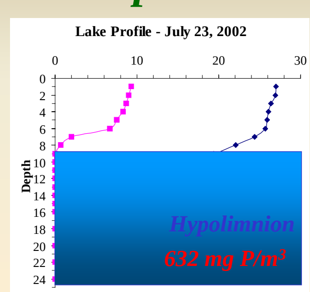
Results & Discussion

Internal Phosphorus Loading



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Results & Discussion

Internal Phosphorus Loading

- **Water Quality Monitoring**
  - *High Volumes of Anoxic Water*
  - *High Concentrations of Phosphorus*
- **Internal Load Estimation**
  - *Modeling Result: 32 kg/year*
  - *Turnover Concentration: **99 mg P/m3***
  - *Secchi Disk Depth of 2.2 feet.*

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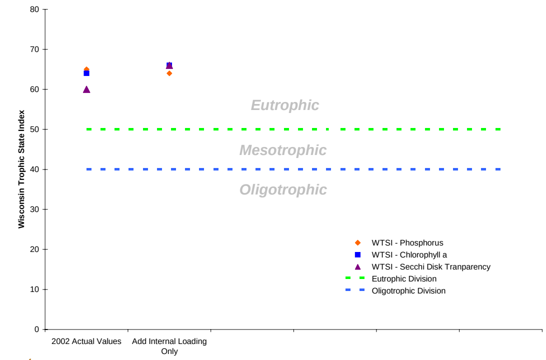
Results & Discussion



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Results & Discussion

Internal Phosphorus Loading

- **Water Quality Monitoring**
  - *High Volumes of Anoxic Water*
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- **Internal Load Estimation**
  - *Modeling Result: 32 kg/year*
  - *Turnover Concentration: **99 mg P/m3***
  - *Secchi Disk Depth of 2.2 feet.*

YES!

YES!

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Results & Discussion

Tributary Loading

Boat Landing Site (kg)	11.0
Carstens Road Site (kg)	40.9
TOTAL PHOSPHORUS LOAD (kg)	**51.9**

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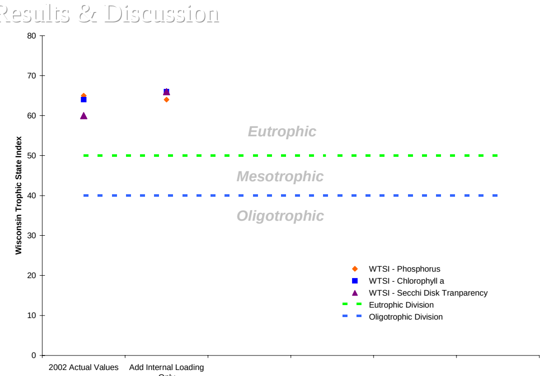
Results & Discussion



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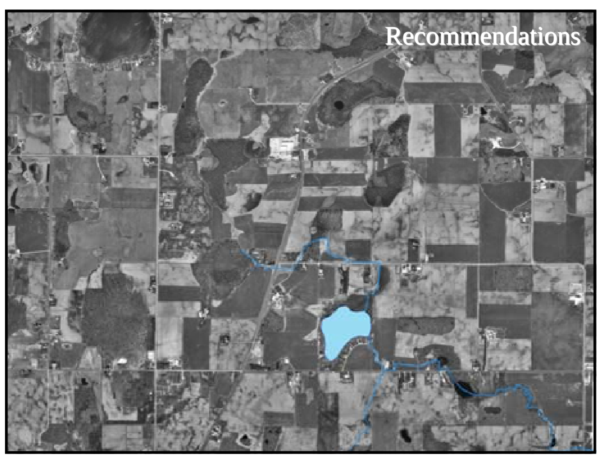
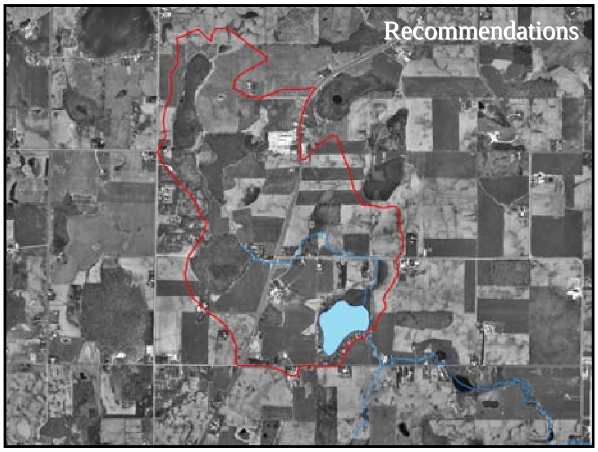
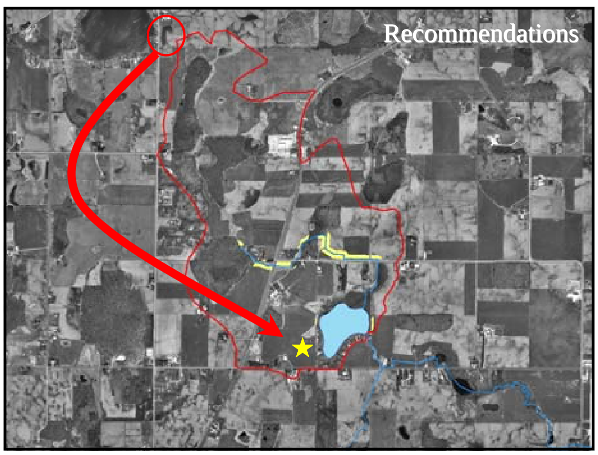



Recommendations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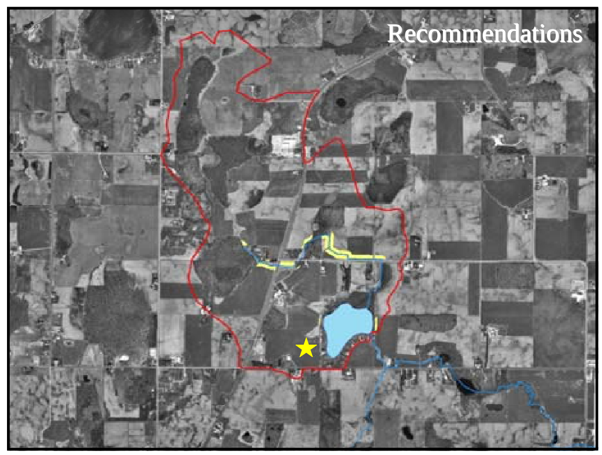
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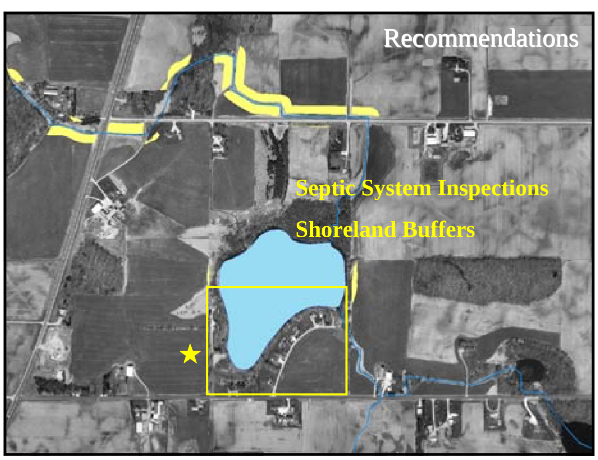
Recommendations
Septic System Inspections
Shoreland Buffers


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