Report

Phase II Lake Study Report

Archibald Lake, Oconto County

Scope I.D.: 00A017

May 2004

Foth & Van Dyke

Archibald Lake
Phase II – Lake Study Report
Executive Summary

Foth & Van Dyke was retained by the Archibald Lake Association to conduct a water quality evaluation of Archibald Lake. The Lake Association received a Lake Management Planning Grant from the Wisconsin Department of Natural Resources (WDNR) in October 2002 for a Phase II study. The WDNR provided funding of up to $10,000 for this project. The lake association has provided in-kind services and matching funds of 25%.

The Phase II project addressed the following areas:

- Water quality evaluation of both lake basins.
- Water quality and quantity data collection from the inlet stream.
- Evaluate groundwater levels around the lake to assess the impact of groundwater on the lake.
- Conduct shoreline monitoring to locate local areas of groundwater impact

Water Quality

A sampling program was implemented focusing on the trophic status of the east and west lobe of the lake. The water quality in 2003 showed the east lobe to be oligotrophic and the west lobe to be mesotrophic. The results in 2003 showed little change from test results from 2001.

Inlet Stream

The flow from the inlet stream was measured and determined to range from 1.5 to 3.3 cfs. The phosphorus load to the lake was determined to be 62 pounds per year.

Groundwater Elevation

Groundwater elevations were measured at eight locations around the lake. Groundwater enters the lake mainly in the west lobe and exits the lake in the east lobe. The groundwater direction fluctuates throughout the year and can vary at each site.

Shoreline Monitoring

Specific conductivity readings were taken along the entire lake shoreline. Conductivity readings were generally higher in the west lobe and significantly higher in the area around the mouth of the inlet stream.

Recommendations

The Phase II report provides new information on the lake hydrology. The information should be combined with the previous Phase 1 report and the upcoming Phase III report to complete a lake management plan.

Archibald Lake
Phase II – Lake Study Report

Contents

Page

Page

Tables

Figures

Appendices

1. Introduction

Archibald Lake is located in the Section 1, 2, and 3, T32N, R15E in the Town of Townsend, Oconto County, Wisconsin. The lake covers an area of 430 acres as referenced on the website www.dnr.state.wi.us/org/water/fhp/lakes/lakemap/oconto.htm, with approximately 10% of the lake area less than 3 feet in depth and approximately 42% of the lake area exhibiting a depth of over 20 feet. The maximum depth of the lake is approximately 50 feet. The lake has 7.47 miles of shoreline.

In October 2002, the Archibald Lake Association was awarded a Lake Management Planning Grant from the Wisconsin Department of Natural Resources (WDNR) to conduct a Phase II study of the water quality in Archibald Lake.

1.1 Authorization

The Archibald Lake Association authorized Foth & Van Dyke and Associates Inc. to complete the Phase II study for Archibald Lake, and to prepare a report identifying the results. The study was completed through a collaborative effort between Foth & Van Dyke, the Archibald Lake Association volunteers, and WDNR personnel.

1.2 Purpose

The purpose of the Phase II lake study was to address the following areas.

- Obtain additional water quality data to establish the existing water quality of both basins of Archibald Lake.
- Obtain water quality data from the inlet stream to aid in assessing water quality flowing into the Archibald Lake.
- Evaluate groundwater levels at eight sand points and two groundwater wells and two lake gauges around the lake to assess if groundwater is an important contributing source of water to the lake.
- Complete shoreline monitoring for water quality parameters to locate differences in water chemistry and possible sources of influence from groundwater, and potential areas of localized groundwater input to the lake and possible correlation to failing septic systems

The results of this study will be used to provide the Archibald Lake Association with an understanding of the water quality of Archibald Lake and the potential sources of nutrients. This report may be used in conjunction with the Phase III study to develop a long term lake management plan for Archibald Lake.

1.3 Project Study Area

Figure 1-1 illustrates the project study area, including the water quality sampling locations, inlet stream gauging and sand point locations

2. Water Quality

The water quality of a lake is dependent upon a number of factors and lake characteristics. Every lake possesses a unique set of physical and chemical characteristics that may change over time. The chemical changes occur on a daily basis, while physical changes (such as plant and algae growth) occur on a seasonal basis. Seasonal changes in the physical characteristics of a lake are common because factors such as surface runoff, groundwater inflow, precipitation, temperature and sunlight are variable. A lakes water quality will vary with the seasonal changes, therefore data must be gathered over a period of time to accurately determine if a lake is experiencing significant changes in water quality and to distinguish between natural variability and impacts due to human activity.

To determine the water quality and trophic status of Archibald Lake, a sampling program was devised which included testing numerous characteristics of the lake over a one-year time period. The following section explains the sampling program and its components, presents the results and analysis of the collected data, and provides conclusions about the water quality of the lake. First, however, it is important to identify the natural aging process experienced by lakes (eutrophication), and the source of the lake's water supply as this contributes to the resulting water quality of the lake. In addition, identification of the water source allows for sound management practices to be selected consistent with the specific characteristics of the lake.

2.1 Eutrophication -The Aging Process

This process was discussed in Phase I and will only be referenced in Phase II

2.2 Watershed Analysis

As reported in Phase I, forested land use is the largest category in the watershed and makes up 60% of the total land use. Rural residential land use makes up 18%. Wetland areas comprise 5% of the total watershed. Agricultural land use totals 0.5% of the total watershed. Archibald Lake is 16% of the total watershed. The watershed to Archibald Lake is approximately 2,491 acres.

To determine the trophic state of the lake, the Wisconsin Trophic State Index (WTSI) can be applied to each of the above noted factors. The WTSI converts the actual measurement into a value which is representative of one of the trophic states. Values less than or equal to 39 indicate oligotrophic conditions, values from 40-49 indicate mesotrophic conditions, and values equal to or greater than 50 represent eutrophic conditions.

This report will compare the 2001 data collected in the Phase I grant with the data collected in the 2003 Phase II grant.

2.3 General Characteristics of Archibald Lake

Archibald Lake is classified as a seepage lake: a seepage lake is a lake without a significant inlet or outlet, is fed by rainfall and may be fed by groundwater. Seepage lakes lose water through evaporation and water moving out of the lake over a portion or entire basin of the lake. Runoff is also a source of water to the lake. Seepage lake water quality typically is most influenced by runoff, which is impacted by the drainage basin, the land use in that basin, and use of land on the shoreline. Concentrated populations of livestock or waterfowl within the drainage basin may also impact the water quality of a seepage lake.

Archibald covers an area of 430 acres, with approximately 10% of the lake area less than 3 feet of water depth and approximately 42% over a depth of 20 feet. The maximum lake is about 50 feet. The lake has 7.47 miles of shoreline.

2.4 Sampling Program

Weekly groundwater measurements were collected by Archibald Lake Association members for the Phase II Lake Grant, at two sandpoint locations from May 2003 through August 2003. Weekly measurements were also taken at a lake gauge that was installed near each sandpoint in April 2001. Weekly measurements of the lake stage were taken from May 2003 through August 2003 from the eight lake bed sandpoints that were installed in May 2003. These weekly measurements included measurements of water levels both inside and outside of the sandpoints, and were taken from May 2003 through October 2003.

The sampling programs for Phase II used to evaluate the water quality of Archibald Lake was conducted over approximately a five month time period, beginning in April of 2003, and concluding in August 2003. This sampling program provided information to evaluate the current water quality of the lake and the small inlet stream. Surface water sampling was conducted on four separate occasions including for the West and East Basins and five separate occasions for stream gauging:

	West Basin	East Basin	Inlet Stream
April 2003	X	X	X
May 2003			X
June 2003	X	X	X
July 2003	X	X	X
August 2003	X	X	X

Archibald Lake Association members and Foth & Van Dyke personnel performed the water quality sampling, while laboratory analysis of the samples was completed by the State Laboratory of Hygiene. An important aspect of the sampling plan was to collect samples in early spring and in summer months to assess seasonal changes which can affect water quality. Also there is a Self – Help monitoring program occurring on Archibald Lake with help from the WDNR and the data collected from this program was also used where ever possible.

Numerous parameters were included in the sampling program, including:

Dissolved Oxygen (D.O.)	Total Phosphorus	Ammonia Nitrogen
Total Kjeldahl Nitrogen	Total Suspended Solid	Chloride
Potassium	Temperature	pH
Ortho-phosphate (dissolved/reactive)	Nitrate plus Nitrite Nitrogen	Redox
Secchi Disc Readings	Calcium	Magnesium
Specific Conductivity	Chlorophyll a	Sulfate
Sulfate	Alkalinity Total	Total Hardness

These parameters were measured at a single sample location in each basin. Temperature, D.O., pH, redox, and specific conductivity were measured at various depths in the lake in each basin ranging from surface to lake bottom. As the primary objective of this study was to determine the trophic status of Archibald Lake, the parameters which contribute to making this determination were sampled more frequently than most other parameters. These parameters include total phosphorus (Total P), Chlorophyll a, and Secchi Disc readings. For the purposes of this study, dissolved oxygen, pH, temperature, specific conductivity, and redox were also sampled on all sample dates. Table 2-1 summarizes the sampling program that was collected in the Phase II Lake Grant Study and data that was used in this study and collected by the self-help monitoring program for a year by year comparison.

The Inlet Stream was sampled for the same parameters listed above for comparison to the lake data

The following sections provide the results of the 2003 Phase II Grant sampling program, highlighting the factors which contribute to the determination of the lake's trophic state and comparison to previous sampling years using data collected from the Phase II Grant and the Self Help Monitoring program database.

Table 2-1
Archibald Lake Phase II Sampling Plan

	West Lobe				East Lobe				Inlet Stream				
Parameters	Apr	Jun	Jul	Aug	Apr	Jun	Jul	Aug	Apr	May	Jun	Jul	Aug
Dissolved Oxygen	X	X	X	X	X	X	X	X	X	X	X	X	X
PH	X	X	X	X	X	X	X	X	X	X	X	X	X
Specific Conductivity	X	X	X	X	X	X	X	X	X	X	X	X	X
Temperature	X	X	X	X	X	X	X	X	X	X	X	X	X
Redox	X	X	X	X	X	X	X	X	X	X	X	X	X
Total Phosphorus	X	X	X	X					X	X		X	X
Ortho- Phosphate	X	X	X	X					X	X		X	X
Total Kjedahl Nitrogen	X	X	X	X					X	X		X	X
Nitrate+Nitrite Nitrogen	X	X	X	X					X	X		X	X
Ammonia Nitrogen	X	X	X	X					X	X		X	X
Chlorophyll a	X	X	X	X					X	X		X	X
Sulfate	X	X	X	X					X	X		X	X
Chloride	X	X	X	X					X	X		X	X
Total Alkalinity	X	X	X	X					X	X		X	X
Total Hardness	X	X	X	X					X	X		X	X
Total Suspended Solids	X	X	X	X					X	X		X	X

Parameters	West Lobe Apr	Jun	Jul	Aug	East Lobe Apr	Jun	Jul	Aug	Inlet Stream Apr	May	Jun	Jul	Aug
Velocit Gauging									X	X	X	X	X
Secci Disc Readings	X	X	X	X	X	X	X	X					
BOD_5									X				
Iron									X				
Calcium									X				
Manganese									X				
Magnesium									X				
Potassium									X				
Volatile Organic Solids									X				

2.4.1 Lake Bed Sand Point

Lakebed sand point locations are illustrated in Fig 1-1. The eight lake bed sand points consisted of a stainless Campbell well point, 1 ¼" diameter, 30" length, 60 gauze size screen with a galvanized coupling and a 5-foot galvanized riser pipe with a vented screw cap. These sand points were installed using a post hole driver to drive the point into the lake bed. It was driven to an adequate depth so that the screen interval was approximately 1-2 feet below the lakebed. A copy of the label for the sand point construction is provide in Appendix A.

Sand point construction logs are contained in Appendix A. The names and address of the owners of the property adjacent to lake where the sand points were installed near their docks are also listed in Appendix A.

2.4.2 Inlet Stream Sample Point

The inlet stream sample point location was located at the culvert that crosses Archibald Lake Road. This culvert is approximately 600 feet west of the west lobe of Archibald Lake. From the monitoring location, the inlet stream meanders approximately 800 feet through private property before flowing into the west lobe.

The inlet stream sample point consisted of a staff gauge for gauging the stream placed up-stream or above the two culverts. Analytical data was collected above the staff gauge in the current. Velocity measurements were collected on the downstream of the two culverts.

The culverts and surrounding shoreline were repaired with new culvert extensions and rip-rap during this study.

A further discussion on the inlet stream is located in Section 3.

2.5 Results and Analysis

The complete results of the sampling program conducted in 2003 on Archibald Lake are displayed in Appendix B. The following section provides a more detailed discussion of the sampling results of groundwater/surface water elevation measurements, temperature, dissolved oxygen levels, and trophic status indicators including total phosphorous concentrations, Chlorophyll a concentrations, and Secchi disc readings in each basin and the inlet stream.

2.5.1 Groundwater and Surface Water Elevations

Two shallow groundwater (Otto well and Yakel well) sand points were installed above the ordinary high water line in 2001. Corresponding lake gauges (Otto staff gauge and Yakel staff gauge) were also installed in the lake near the well locations in 2001. Eight lakebed sand points were installed as part of the Phase II grant in May 2003. The ten measurement points were used to assess if water is flowing from the Archibald Lake to the groundwater system or from the groundwater system to the Archibald Lake.

The lakebed sand points were measured by taking a liquid level measurement on the inside of the well pipe and outside of the well pipe. The readings were compared to one another. If the water inside the pipe was higher than water outside the pipe this indicates that groundwater was flowing to the surface water. If the inside of the pipe was lower than the water level outside the pipe then surface water is flowing to groundwater.

The data collected indicates that Archibald Lake is a seepage type lake where lake water discharges to the groundwater system at a majority of points measured. This data collected can be found in Appendix C.

The Otto well and staff gauge readings were not completed for the entire 2003 grant study period due to the sale of the Otto property. The data that was collected indicated no change from the 2001 data. At this point surface water is flowing to groundwater.

However at several of the lakebed sand points it was observed that groundwater is flowing to surface water at least seasonal or in localized areas near the north and west ends of the west basin.

Graphs for these measurements can be found in Appendix C. Table 2-2 shows a summary of the sand point data.

Table 2-2
Archibald Lake
Groundwater - Surface Water Flow Direction

Sand Point	% Surface Water to Groundwater	% Groundwater to Surface Water	No flow direction	Flow Direction Comments
SP-1	100	0	0	Surface Water to Groundwater
SP-2	89	6	5	Mostly SW to GW, Occasionally GW to SW
SP-3	16	79	5	Mostly GW to SW, Occasionally SW to GW
SP-4	10.5	79	10.5	Mostly GW to SW, Occasionally SW to GW
SP-5	47	26.5	26.3	No distinguishable flow direction

Sand Point	% Surface Water to Groundwater	% Groundwater to Surface Water	No flow direction	Flow Direction Comments
SP-6	37	32	31	No distinguishable flow direction
SP-7	55	37	8	Mostly SW to GW, Occasionally GW to SW
SP-8	47	37	16	Mostly SW to GW, Occasionally GW to SW

2.5.2 Temperature

Temperature exerts a major influence on biological activity and growth. To a point, the higher the water temperature, the greater the biological activity. Temperature also governs the kinds of organisms that can live in a lake. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have a preferred temperature range. As temperatures get too far above or below a preferred range, the survival of individual species may be limited or eliminated.

Temperature is also important because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperature, which in turn affects biological activity. An important example of the effects of temperature on water chemistry is its impact on oxygen. Warm water holds less oxygen than cool water, so it is more difficult to maintain enough oxygen in warm water for survival of aquatic life.

Stratification is a layering effect produced by the warming of the surface waters in many lakes in the summer, during which time lake water separates into layers of distinctly different temperature. Upper waters are progressively warmed by the sun and are less dense than the deeper waters, which remain cold. Because of the resulting differences in water density, the upper and lower layers of the lake don't mix. As a result, they develop different physical and chemical characteristics, often resembling two different lakes. For example, oxygen in the bottom waters may become depleted. In autumn, as the upper waters cool to about the same temperature as the lower water, the density difference in the water and associated stratification is lost and the whole lake mixes. This process is defined as fall turnover. Stratification also exists in winter. However, in the winter the warmer water is near the bottom. Water exhibits its greatest density at approximately 4o C. Therefore, during the winter months, the water temperature in most lakes will be near 4o C at the bottom and near 0o C at the surface. In spring, as ice melts, the water temperatures once again equalize and mixing occurs, a process defined as spring turnover. As summer progresses, the temperature difference (and density difference) between surface and bottom water becomes more distinct, as mentioned previously. Most lakes form three stratified layers. The upper layer, the epilimnion, is characterized by warmer (less dense) water and is the zone of light penetration, where the bulk of productivity or biological growth occurs. The next layer, the metalimnion or thermocline, is a narrow band where the transition from warmer surface waters goes to the cooler bottom layer. This transition zone helps to prevent mixing between the upper and lower layers. The bottom layer, the hypolimnion, has much colder water. Plant material either decays or sinks to the bottom and accumulates in this isolated layer.

A shallow lake, however, is more likely to be homogeneous from top to bottom. The water is well mixed by the wind and current, and physical characteristics such as temperature and oxygen vary little with depth. Because sunlight reaches all the way to the bottom, photosynthesis and growth occur throughout the water column. As in a deep lake, decomposition in a shallow lake is higher near the bottom than the top simply due to the fact that when plants and animals die they sink. It is also likely that a larger portion of the water in a shallow lake is influenced by sunlight, and that photosynthesis and plant growth is proportionately higher.

2.5.2.1 Temperature Profile of Archibald Lake

Temperature profiles of each basin on Archibald Lake were taken at a single location. The data collected shows that the lake experiences stratification in each basin during the summer and winter months. From June through early August, the temperature variation within the lake was as large as 16.6o C (61.8o F) variation. This is similar to the variations found in Phase I

The temperature variation of the inlet stream varied 9.6o C (49.3o F) variation for the five monitoring events from the April 2003 to the August 2003 monitoring event.

2.5.3 Dissolved Oxygen (D.O.) Concentration

The presence of oxygen in lake water determines where organisms such as fish and zooplankton are found. When water is well mixed, such as in spring, oxygen is usually present at all depths, thus organisms may be distributed throughout the lake. However, under stratified conditions, little or no oxygen may be produced in or introduced to the hypolimnion. Available oxygen may be consumed through decomposition of plant and animal material, and oxygen levels may become too low for fish which then must move to the top layer, or epilimnion. If these conditions are prolonged and the upper waters become too warm, cold-water fish such as trout may become stressed and eventually die. In the fall, the lake layers break down and turnover replenishes oxygen to the bottom waters. During the winter the formation of an ice cap on the water reduces the supply of oxygen to the lake from the overlying air. The extent to which oxygen is depleted is dependent on the amount of organic matter decaying in the lake and the amount of snow cover on the ice which prevents sunlight from penetrating the water column, thus inhibiting photosynthesis and oxygen generation. If oxygen levels fall too low as a result of ice and snow cover, fish and other aquatic life may die of a condition termed winter kill. Winter kill conditions occur in many eutrophic lakes.

The concentration of dissolved oxygen (D.O.) present in a lake is important as it supports aquatic life. The solubility of oxygen depends on the temperature of the water -colder water holds more oxygen than warmer water. The amount of D.O. present in lakes at different times of the day, and at different depths, is largely determined by the processes of photosynthesis and respiration. Oxygen is produced when green plants grow (photosynthesis), and is consumed through respiration. Therefore, D.O. levels tend to be higher during daylight hours (when photosynthesis occurs), and lower at night/early morning. In addition, lake depths which are below the reach of sunlight may experience oxygen depletion. Oxygen depletion is especially apparent in winter months where snow cover prevents sunlight from penetrating the water, stopping photosynthesis. In warm water, the water quality standard for D.O. is 5 mg/l, which represents the minimum amount, needed for the survival and growth of warm water fish species. D.O. concentrations between 8 mg/l and 12 mg/l indicate oxygen saturation.

2.5.3.1 Dissolved Oxygen Results

The D.O. levels in the lake vary among the varying sample dates and depths ranging from approximately 0.1 mg/l to 11.5 mg/l in each lobe. In the shallower west lobe the upper 20 feet had consistently higher D.O. levels in the open water samples. In the deeper east lobe the upper 33 feet had consistently higher D.O. levels in open water samples. During spring turnover, the D.O. concentrations were found to be uniform throughout the water column in west lobe. In the east lobe, the D.O. levels were somewhat reduced at depth during the April sampling event indicating the onset of stratification. During the spring turnover, the D.O. levels were not near saturation levels for the temperatures measured. During the summer months the oxygen levels become depleted at depths greater than about 15 to 20 feet.

A graphic illustration of the D.O. and temperature stratification along with other field measured parameters is shown in Appendix C.

The D. O. in the inlet stream ranged from 10.74 mg/l to 7.08 mg/l. These results were below D.O. saturation values for the given temperature. These D.O. readings for sampling events are below total saturation values as seen in Table 2-3.

Table 2-3
Inlet Stream
D.O. Values

Date	D.O. – mg/l	Temp.	D.O. Stat #
4/26/03	10.74	11.1	11.00
5/14/03	7.26	12.71	10.61
6/9/03	8.2	15.7	9.94
7/16/03	7.08	17.1	9.64
8/13/03	7.28	20.76	8.96

*D.O. Saturation Values as provided 1985 Standards and Methods for examination for water and wastewater. Calibration of Hydrolab instruments source is Hitchman, 1978. Values are extrapolated and averaged.

2.5.4 Trophic Status Indicators

2.5.4.1 Total Phosphorus Concentration (Total P) Lake Lobes

Phosphorus is the key nutrient which influences plant growth in over 80% of the lakes throughout Wisconsin. Excess phosphorus promotes excessive aquatic plant growth. In most lakes, phosphorus is the least available nutrient, so it's abundance, or scarcity, controls the extent of algae growth. For that reason, phosphorus is typically referred to as the limiting nutrient. If more phosphorus is added to the lake from septic tanks, urban or farmland runoff, lawn or garden fertilizers, sewage treatment plants, or even if it is released from phosphorus-rich lake bottom sediments, that limitation is taken away and more weeds and algae will grow. Under certain conditions, especially when oxygen is absent from bottom waters, phosphorus is released from bottom sediments into the overlying water, which upon lake turnover can precipitate algae blooms.

Algae and weeds are a source of food and energy for fish and other lake organisms, and are a vital part of all lakes. However, excessive amounts or nuisance types of algae or weeds can interfere with lake uses by the following:

- Reduce water clarity thus inhibiting the growth of other plants.
- Cause oxygen depletion and fish kills as algae and plants decay.
- Cause taste and odor problems in water and fish.
- Cause aesthetic problems from unsightly blooms that float on the lake surface forming algae scum

The regular occurrence of visible algae blooms often indicates that nutrient levels, especially phosphorus, are too high.

Aquatic plants may also limit many lake uses. Although aquatic plants (macrophytes) serve a vital function for the lake by providing cover, habitat, and even food for fish and other wildlife, an overabundance of rooted and floating plants can limit swimming, fishing, skiing, sailing, and boating activities, and aesthetic appreciation. Excessive plant growth can physically prevent mixing of oxygen through the water.

Two types of phosphorus analyses can be conducted which include soluble reactive phosphorus (orthophosphate) and total phosphorus. Total phosphorus is often a better indicator of the nutrient status of a lake because its levels remain more stable than orthophosphate. The concentrations of Total P detected at the sample points and the corresponding Wisconsin Trophic Status Index (WTSI) values for a three year study period from 2001-2003. This summary included the use of data collected through the self-help monitoring program. The Total Phosphorus data from the Phase 1 Lake Grant, Phase 2 Lake Grant, and the self-help monitoring database are presented in Table 2-4.

Table 2-4
Total Phosphorus
Archibald Lake

	East Lobe			West Lobe			Inlet Stream
	2001	2002	2003	2001	2002	2003	2003
Average Total P, mg/l	14.5	30.6	8.5	13.4	NA	11	14
Range Total P, mg/l	1-50	10-103	6-11	10-19	NA	10-12	10-20
Average WTSI	43	54	39	42	NA	39	42

NA sample not analyzed
WTSI <40 = oligotrophic, 40<WTSI<50 = mesotrophic, WTSI>50 = eutrophic

The total phosphorus data collected in 2003 indicates that the Archibald Lake remains a mesotrophic lake as in 2001. No data was reported in the self-help monitoring program database for the west lobe in 2002. There was also no grant study occurring in 2002 for total phosphorus trend comparison.

The WDNR guide Understanding Lake Data shows that an average total phosphorus concentration for natural lakes is 25 ug/l. This guide also states that total phosphorus should be maintained below 20 ug/l for natural lakes in order to prevent nuisance algae blooms. As indicated in Table 2-4 and Appendix B, the total P concentrations in the lake exceeded 30 ug/l in the east lobe of the lake on one occasion in 2001. The total phosphorus concentrations in the Archibald Lake indicate the potential for problematic phosphorus levels on a seasonal basis.

2.5.4.2 Total Phosphorus Inlet Stream

The total phosphorus data collected in 2003 at the inlet stream sample point was slightly higher than the west lobe lake data collected. This would indicate that the trophic status of the inlet stream would be of mesotrophic in nature. The inlet stream may have a slight impact on the total phosphorus loading into Archibald Lake. However with the last 800 feet of stream impacted by human development, this phosphorus loading may be higher as the stream flows into the west lobe.

2.5.4.3 Chlorophyll a Concentration

Chlorophyll a is a green pigment that is present in all plant life and is necessary for photosynthesis. The amount of chlorophyll a present in a lake is dependent upon the amount of algae present, and is therefore used as a common indicator of water quality. It is also one of three characteristics used to determine the trophic state of a lake. Table 2-5 identifies the concentration of chlorophyll a detected for a three year study period from 2001-2003, using self-help monitoring data and the Phase 1 and Phase 2 Grant in Archibald Lake and the corresponding WTSI status.

Table 2-5
Chlorophyll a
Archibald Lake

	East Lobe			West Lobe			Inlet Stream
	2001	2002	2003	2001	2002	2003	2003
Average Chl. *a*, ug/l	1.87	2.6	2.3	2.72	NA	2.2	1.58
Range Chl *a*, ug/l	1.0-3.0	1.6-3.5	2.3	1.0-6.0	NA	1.85-2.57	0.56-2.77
Average WTSI	37	40	39	40	NA	38	35

NA sample not analyzed
WTSI <40 = oligotrophic, 40<WTSI<50 = mesotrophic, WTSI>50 = eutrophic

Based on the results of the chlorophyll a samples, the trophic status of Archibald Lake was identified as being mesotrophic in the West Lobe and oligotrophic in the East Lobe. However, some of the chlorophyll a samples would tend to identify the East Lobe as mesotrophic also.

There is no significant chlorophyll a impact from the Inlet stream. Chlorophyll a data was consistently lower than the lake data throughout sample period. However this is not unusual to have lower chlorophyll a concentrations in a groundwater feed stream and a seepage lake

2.5.4.4 Secchi Disc Reading

A Secchi disc reading is a measure of water clarity; it is not a direct measure of water quality. However, water clarity is often indicative of a lake's overall water quality, especially the amount of algae present. Secchi disc readings are taken by lowering into the water an 8-inch disc of alternating colors of black and white, and recording the average depth where the disc disappears from sight and where it becomes visible again when raised. The Secchi disc reading is used to determine the trophic state of a lake. Table 2-6 shows the average Secchi disc readings in the main lake for a three year study period from 2001-2003, using self-help monitoring data and the Phase 1 and Phase 2 Grant and the corresponding WTSI status.

Table 2-6
Secchi Depth
Archibald Lake

	East Lobe			West Lobe		
	2001	2002	2003	2001	2002	2003
Average Secchi Depth	17	15.5	18.35	14	10.85	13.35
Range Secchi Depth	14-31	11.5-18.75	13.1-24.5	12-25	9.5-12.75	11.7-17.5
Average WTSI	36	40	35	39	43	40

WTSI <40 = oligotrophic, 40<WTSI<50 = Mesotrophic, WTSI>50 = Eutrophic

These readings also indicate the Archibald Lake water quality is a mesothrophic trophic status in the west lobe and oligotrophic in the east lobe. However, some of the Secchi depth readings would tend to identify the east lobe as mesotrophic on a seasonal basis.

No secchi disc readings were collected on the inlet stream due to the shallow depth.

2.5.5 Non-Trophic Status Indicators

2.5.5.1 Nitrogen

Nitrogen is an important plant nutrient. While phosphorus is typically the limiting nutrient for algae growth, nitrogen can be limiting under some circumstances. Inorganic and organic nitrogen compounds are present in lake. The inorganic forms are ammonia and nitrite/nitrate (NO2 + NO3) which are forms that are available to plants for growth. The organic form is included in Total Kjeldahl Nitrogen (TKN). Organic nitrogen is associated with plant and animal tissues.

The data collected in the April 2001 sample shows relatively low values for inorganic nitrogen. The value for ammonia was 0.063 mg/l. The value for nitrite/nitrate (NO2 + NO3) was 0.057mg/l. Ammonia can be toxic to aquatic organisms in concentrations exceeding 5 mg/l. Also toxicity of total ammonia solutions was greater at higher pH values and decreasing oxygen levels. Due to problems with the State Laboratory of Hygiene, a comparison sample that was collected in August 2001 sampling event was not analyzed.

The inorganic forms of nitrogen data collected in the inlet stream samples, in 2003, shows a relatively low values for inorganic nitrogen. The NO2 + NO3 concentrations were all below detection limits. The ammonia values ranged from 0.018 mg/l – 0.022mg/l and increased during growing season.

The organic forms of nitrogen, TKN ranged from <0.14 mg/l in April 2003 to 0.30 mg/l in August 2003. The TKN data also increased during the growing season.

The total nitrogen in 2003 averaged approximately 0.3 mg/l. When compared to the total phosphorus of 0.011 mg/l, the nitrogen to phosphorus ratio is 27:1. This ratio shows Archibald Lake to be phosphorus limited in regard to plant and algae growth in the lake.

2.6 Water Quality Conclusions

2.6.1 Temperature

The lake does have a strong stratification characteristic and has demonstrated varying temperatures for most of the year, meaning that the temperatures vary greatly from the top to the bottom of the lake. Because the lake remains stratified, oxygen is not distributed evenly during the winter and summer months throughout the lake, as seen from the D.O. readings.

2.6.2 Dissolved Oxygen

Typical of mesotrophic lakes, D.O. concentrations were lower at the bottom of the lake in summer and winter. The D.O. was depleted at depths greater than 20 feet in the west lobe and greater than 33 feet in the east lobe during the summer stratification months. During the winter stratification months the depleted of oxygen depths rose higher in the water column, 15 feet for the west lobe and 25 feet for the east lobe. These reduced D.O. concentrations are not adequate for survival of fish and other aerobic aquatic organisms.

2.6.3 Total Phosphorus

Concentrations of total phosphorus were consistently in the upper oligotrophic to mesotrophic range. This was in complete agreement to the chlorophyll a and Secchi disk readings which were also in the same range. More data is needed over a longer period time to determine further any trends and the rate of change.

2.6.4 Chlorophyll a

Measurements of chlorophyll a were in the oligotrophic to mesotrophic range. Chlorophyll a measurements do not show a significant trend over the three year study period.

2.6.5 Secchi Disc

The Secchi disc measurements were generally in the oligotrophic range in the east lobe and in the mesotrophic range in the west lobe. Water clarity decreases with an increase in algae growth. As the water clarity decreases, so does the size of the littoral zone, that area of a lake where the light penetration reaches the bottom. The littoral zone is the area that can support rooted macrophytes, an important component of the aquatic ecosystem.

Through the entire study period there was a consistent seasonal decrease in water clarity. The clarity improved in cool and cold water conditions. Water clarity decreased during warm water conditions with significant algae blooms noted by all monitoring personnel who participated in collecting data.

2.6.6 Nitrogen

Ammonia concentrations from most recent sampling event indicate low levels of ammonia in both lobes of the lake during non-stratification period or spring turnover. The low levels of ammonia do not appear to be causing toxicity to aquatic organisms.

2.6.7 Water Quality Summary

The water quality parameters showed that Archibald Lake is to be classified as a mesotrophic water body for phosphorus and other parameters measuring algae growth. The phosphorus concentrations in both lobes are high enough to encourage algae growth in the lake. The D.O. is adequate for fish survival and other aquatic life requiring an aerobic environment.

3. Inlet Stream Gauging

Stream gauges measure the quantity and variability of our surface water resources. In addition, the analysis of stream flow data in combination with groundwater data helps us understand the relationships of the hydrologic cycle.

The two types of data collected from stream gauging is the stage and discharge.

The data most often collected at a gauging station, are stage. Stage is the height of the water surface above a reference elevation. Stage data is most widely used in predicting floods. This is usually read by a pressure transducer or a graduated staff gauge.

Although stage information is useful for some purposes, most users of stream flow data find it necessary to have discharge information about a stream. Discharge is the volume of flow passing a specified point in a given interval of time and it is usually measured in cubic feet per second (cfs). Discharge includes not only the volume of water, but also any sediment, chemicals, or solids that may be mixed with or dissolved in the water. Unfortunately, providing discharge data is more difficult than providing stage data.

Discharge is usually estimated from stage/discharge relations known as rating curves. In order to develop a rating curve, Foth & Van Dyke field personnel must visit a gauging station to measure river discharge and compare it to the stage. A Current or Velocity Meter is the instrument that is frequently used to perform discharge measurements. Year after year, discharge and stage data are gathered in the field, sometimes as often as once a month. Over time, a stage/discharge rating curve is gradually developed. Unfortunately, rating curves are never fully complete due to the constant changes occurring in rivers and streams. Sedimentation, scour, changes in riverbed roughness, ice, debris or aquatic vegetation, and human impacts may significantly alter stage/discharge curves and must be adjusted for. In order to keep discharge estimates accurate, it is necessary for personnel to continue taking discharge and stage measurements in the field to keep the curves updated.

3.1 Inlet Stream Drainage Area

The Archibald Lake watershed is relatively small, and the inlet stream drains a relatively small portion of that drainage basin which is situated within the North Branch Oconto River Watershed, in Oconto County, Wisconsin. The watershed of Archibald Lake comprises a land area of approximately 2,491 acres while the lake itself comprises approximately 430 acres of surface water. The inlet stream drains from a wetland to the west of the lake approximately ½ mile west of the sampling location.

This wetland is believed to be groundwater fed for two reasons. One, an area in the wetland contained a previously unknown well point that occasionally is under flowing conditions as indicated by a residence on Archibald Lake near the wetland. However when Foth & Van Dyke personnel went to the sample point they found a 10 foot deep 3 inch steel pipe not under flowing conditions. But Foth & Van Dyke personnel did find water welling up from around the base of the steel pipe and surrounding area flowing to the inlet stream.

The second reason the inlet stream is believed to be groundwater feed is because of analytical data supports groundwater intrusion. Higher concentration levels in field specific conductivity and mineral content concentrations such as total hardness, total alkalinity, total magnesium, and total calcium concentrations all are indicative of groundwater rather than surface water.

Not all areas of the watershed are equal nutrient or pollutant contributors. The inlet stream was identified as possible significant source of impact due to groundwater interaction and direct drainage into Archibald Lake. In small watersheds, such as Archibald Lake, lakeside and stream activities may be more critical pollutant contributors where groundwater flows to surface water.

3.2 Flow Calculations

The total input of volume or flow from the inlet stream is significant. Stream flow rates range from 1.5 cubic feet/seconds (cfs) in winter to 3.3 cfs after a major spring rain event.

Documentation for flow calculations, regression curve calculations for aiding in determining flows at a specific level and the corresponding chart for stage/discharge rating curve can be found in Appendix D.

Weekly staff gauge readings were collected between April 26 and October 2 of 2003 at the Archibald Lake Inlet Creek. In addition, five stream flow rate samples and four phosphorus samples were collected on regular intervals between April 26 and August 13 of 2003. These data were used to estimate total phosphorus loadings (in pounds) to the lake due to the inlet creek upstream of the residential area.

Since many more staff gauge readings were available than stream flow measurements, total water volume entering the lake from the inlet creek was estimated based on the staff gauge data. This was accomplished by developing a regression model correlating staff gauge results to flow rates. The resulting model is expressed as: Flow Rate = 5.31 x Staff Gauge Reading – 10.72. It was concluded that although utilizing this model introduced some error into flow rate values, the additional amount of data available with the staff gauge readings improved the accuracy of the yearly estimate of water volume from the inlet creek.

The staff gauge readings, measured flow rates, predicted flow rates, and phosphorus results are summarized in the table below:

Table 3-1

Date	Staff Gauge Reading	Flow (cfs)	Predicted Flow (cfs)	Phosphorus (ug/L)
04/26/03	2.28	1.51	1.39	20
05/03/03	2.31		1.55	
05/11/03	3.68		8.82	
05/14/03	2.58	3.30	2.98	11
05/18/03	2.60		3.09	
05/25/03	2.41		2.08	
05/30/03	2.50		2.56	
06/06/03	2.42		2.13	
06/09/03	2.52	2.98	2.66	
06/12/03	2.48		2.45	
06/19/03	2.44		2.24	
06/26/03	2.47		2.40	

Date	Staff Gauge Reading	Flow (cfs)	Predicted Flow (cfs)	Phosphorus (ug/L)
07/03/03	2.48		2.45	
07/09/03	2.48		2.45	
07/16/03	2.50	2.07	2.56	15
07/17/03	2.48		2.45	
07/25/03	2.48		2.45	
07/31/03	2.55		2.82	
08/08/03	2.52		2.66	
08/13/03	2.51	2.27	2.61	10
08/14/03	2.50		2.56	
08/22/03	2.42		2.13	
08/29/03	2.58		2.98	
09/04/03	2.45		2.29	
09/13/03	2.82		4.25	
09/18/03	2.56		2.87	
09/25/03	2.56		2.87	
10/02/03	2.60		3.09	
Average	2.54	2.43	2.78	14
Lower C.I.			2.48	10.5
Upper C.I.			3.07	17.5

In addition to the average for each variable, lower and upper confidence intervals were estimated for the average predicted flow rate and average phosphorus. The lower and upper confidence intervals give a range for which the true average could fall with some reasonable statistical certainty. The individual confidence intervals were calculated at a two-tailed Type I error level of 0.225. This gives an overall confidence level of approximately 95% when the results of both the predicted flow rate and phosphorus samples are combined to estimate total phosphorus loadings.

The average predicted flow rate between April 26 and October 2 was 2.78 cfs. For estimating yearly 2003 water volume from the inlet creek, it will be assumed that 2.78 cfs is representative from April 1 to October 31. The lower confidence interval estimate is 2.48 cfs, and the upper confidence interval estimate is 3.07.

Due to decreased flow rates during the winter months, it will be assumed that the value of 1.51 cfs measured on April 26 is representative from January 1 to May 31, and from November 1 to December 31. Since no data was collected during these time periods, it is not possible to give an estimate of the variance in the data, and therefore not possible to calculate lower and upper confidence intervals.

The average phosphorus measurement was 14 ug/L. The average 2003 phosphorus loading from the inlet creek is then calculated as:

$$\left[(2.78 cfs \times 86400 \tfrac{seconds}{day} \times 214 days) + (1.51 cfs \times 86400 \tfrac{seconds}{day} \times 151 days)\right] \times 14 \tfrac{ug}{l} \times 28.317 \tfrac{l}{cf} \times 2.205 \times 10^{-9} \tfrac{lbs}{l} = 62.1 lbs.$$

Similarly, the lower 95% confidence estimate for the phosphorus loading is 43.2 lbs., and the upper 95% confidence estimate for the loading is 83.4 lbs.

The analytical results from the Inlet Stream monitoring program have been discussed in other sections of this report.

3.3 Inlet Stream Conclusions

The inlet stream may have a significant impact on the overall nutrient water quality of the Archibald Lake's west lobe with an annual phosphorus load of 62 pound per year. However their may be an additional impact related to the inlet stream between the sample point and the west lobe. The Phase III report will discuss further impacts from the inlet stream relating to erosion.

4. Shoreline Monitoring

The purpose of the shoreline monitoring was to try to identify individual areas where groundwater discharges to surface water. This was accomplished by paddling in a canoe along the shoreline and delineating any areas where specific conductivity changes greatly. In general in seepage lakes such as Archibald Lake specific conductivity measured in surface water usually is much lower than specific conductivity in surrounding groundwater.

If subsurface areas can be identified by a significant increase in specific conductivity, this would be an area of concern where groundwater is flowing into the lake basin and a possible source of greater impact to the water body due to septic systems. This method can only be used in shallow water due to dilution and difficulty delineating deep water. For this activity generally water depth of less than six feet were monitored.

In addition other parameters such as dissolved oxygen, temperature, pH, and oxidation reduction potential (REDOX) were also monitored. These parameters would have a secondary role in identify groundwater intrusion in shallow water.

Usually, groundwater has a lower temperature and lower dissolved oxygen content in the summer months than shallow surface waters. While a variation in pH and Redox readings could indicate a possible source of increase activity of biological degradation alga activity.

Figure 4-1 illustrates the shoreline monitoring data. A summary of the data is presented below.

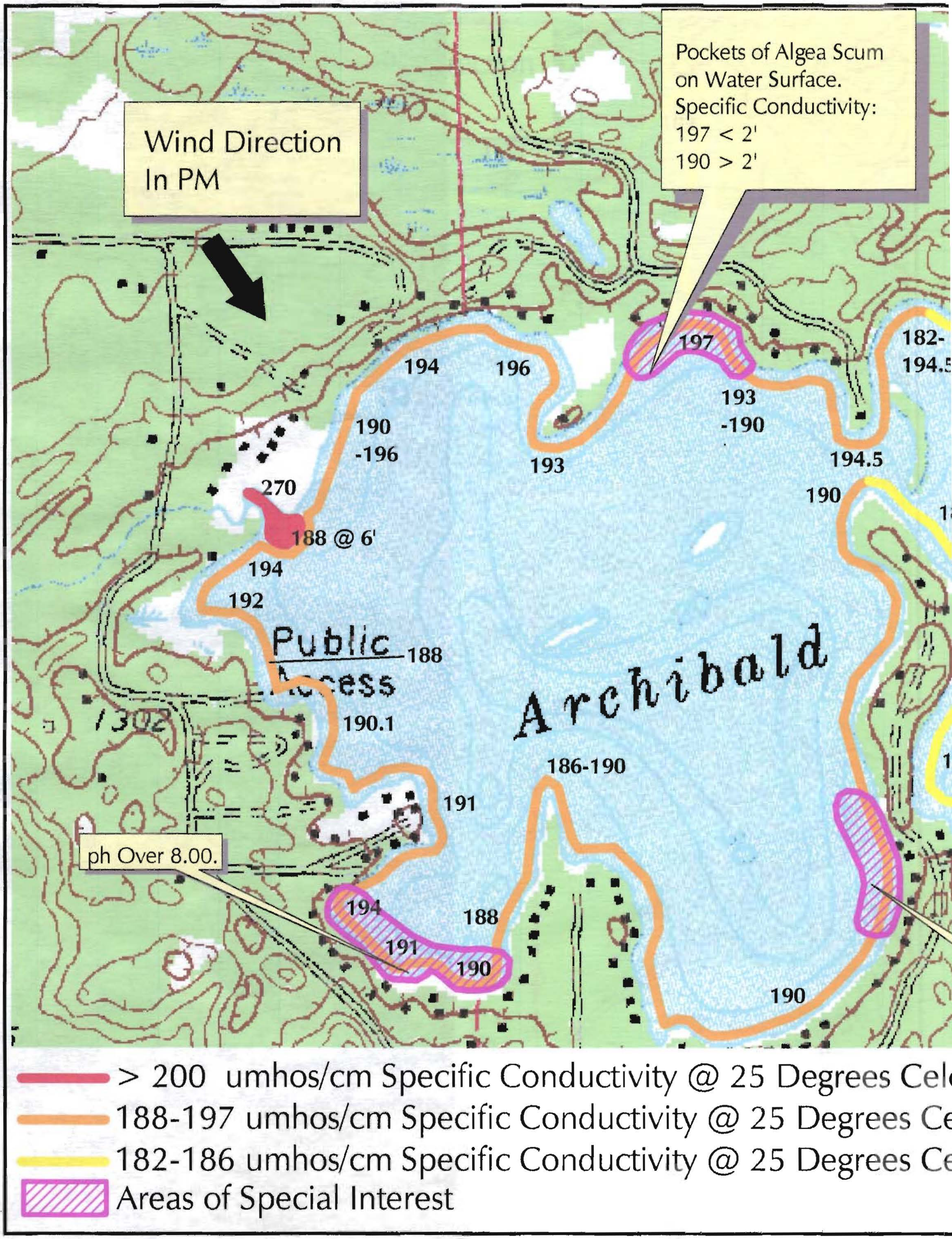
4.1 Shoreline Monitoring Evaluation Procedure

Monitoring occurred on August 12, 2003, a bright sunny day with light winds from the north – northeast, with a very slight chop on the lake that made canoe control easy. Readings started at the boat landing on the west end of the West Basin and circled Archibald Lake in a clock-wise direction along the north shore eastward, than along the south shore westward back to the boat landing. Most of the readings were taken in less than 4 feet of water unless a specific area needed to be delineated.

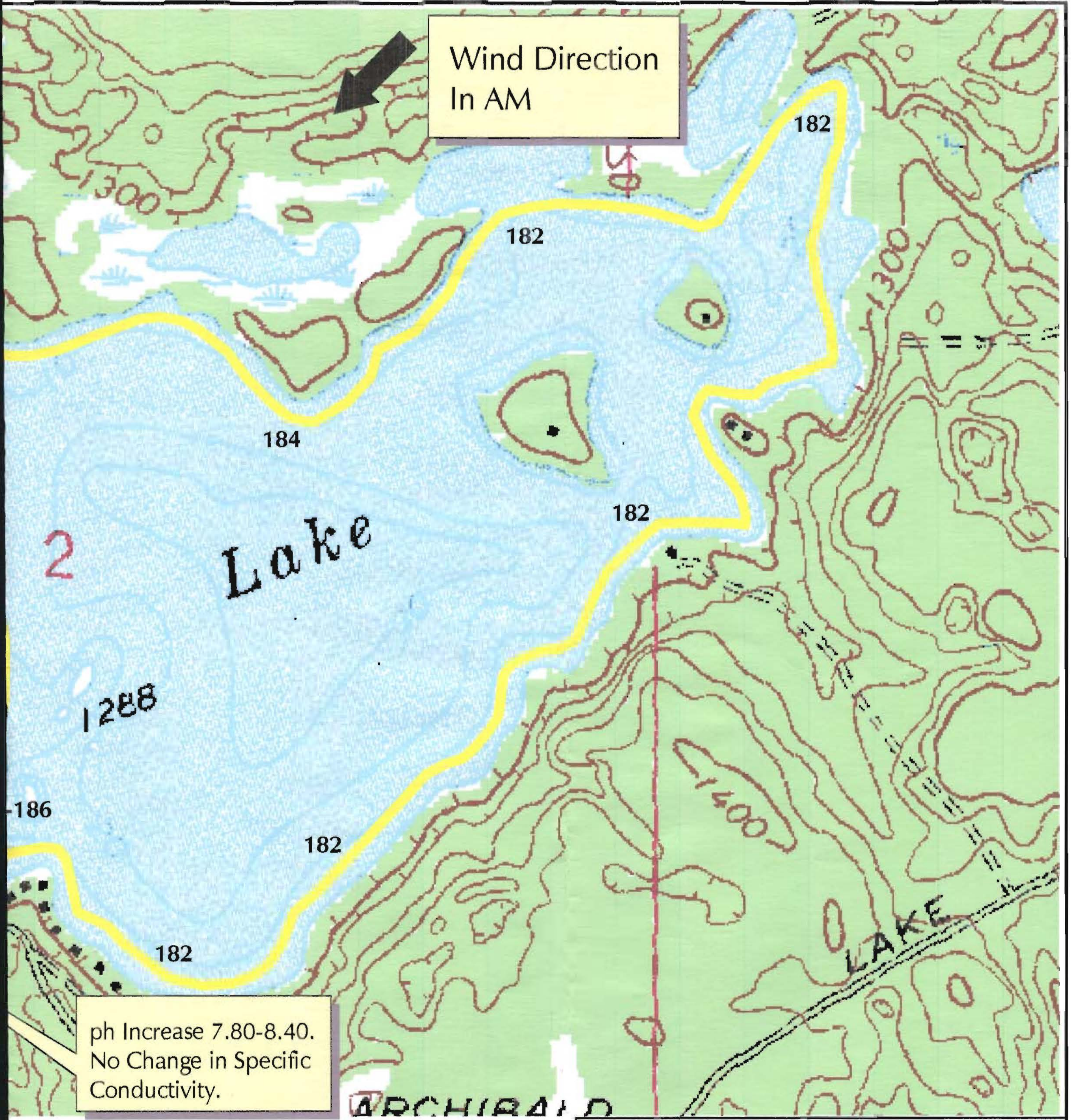
4.1.1 East Basin

There was little significant changes in the specific conductivity in the east basin. The east basin had consistent readings throughout ranging from 188 umhos on the far west end to 182 umhos for most of the east basin. Areas near the west end of the east basin and the pocket in the southwest corner had the highest specific conductivity readings of 188 umhos. These areas had the greatest area of human impact and may have been influenced by water from the west basin. Also noted was an increase in aquatic vegetation in these areas compared with the rest of the east basin. Temperature was 23.8 degrees C throughout east basin. The east basin consistently had a lower specific conductivity than the west basin.

There was a blue green algae bloom occurring on the day of monitoring noted along the south and southwest shoreline of the east basin. Foam was also noted on the shoreline in the same area. Shampoo and bar soap was observed on several docks in this area.



Pockets of Algea Scum on Water Surface. Specific Conductivity: 197 < 2' 190 > 2'
Wind Direction In PM
194
196
197
182-
194.5
193 -190
190 -196
193
194.5
190
270
188 @ 6'
194
192
Public Access
188
Archibald
190.1
186-190
191
ph Over 8.00.
194
188
191
190
190
> 200 umhos/cm Specific Conductivity @ 25 Degrees Cel
188-197 umhos/cm Specific Conductivity @ 25 Degrees Ce
182-186 umhos/cm Specific Conductivity @ 25 Degrees Ce
Areas of Special Interest



us
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This drawing is neither a legally recorded map nor a survey and is not intended to be used as one. This drawing is a compilation of records, information and data used for reference purposes only.

Source: U.S.G.S. 7.5-minute topographic quadrangle. Townsend (1972) - Oconto County, Wisconsin.

N

Foth & Van Dyke
consultants · engineers · scientists

0 200 400 600 800 1000 Feet

m:\00a017\apr\townsend3.apr

ARCHIBALD LAKE		
FIGURE 4-1 SHORELAND MONITORING - PHASE II AUGUST 12, 2003		
Scale: AS SHOWN		Date: JANUARY 8, 2004
Drawn By: kpk1	Checked By: sdj	Scope: 00a017

4.1.2 West Basin

The majority of the West Basin had a greater variability in specific conductivity with a range from 188 umhos to 197 umhos. The water temperature was at 23.8 o C. There was a blue green algae bloom occurring on the day monitoring occurred.

The only area noted where significant specific conductivity change occurred was at the mouth of the inlet stream on the northwest end of the west basin. This area had specific conductivity readings as high as 270 umhos. This area noted an increase aquatic plant growth outside from the current area. This area also had significantly cooler in water temperatures, a change of approx. 8o C less than the surrounding water body. Monitoring of the water approximately 4 to 6 feet deep, the temperatures increased and specific conductivity decreased to what was recorded in the surrounding water body. There was little or no change in pH or Redox.

This area where the inlet stream enters the west basin is an area of highly developed shoreline.

In the southwest corner of the West Basin area was delineated approximately 150' long X 50' wide of a marked jump in pH from 7.8 to 8.9. Specific conductivity remained consistent between 190-191 umhos. This area is along a highly developed shoreline.

Soap and shampoo was also noted on various docks in the West Basin. Some algae scum mats were noted in the north and northwest end of west basin. This is also an area of shoreline impact. This area is along a highly developed shoreline.

4.2 Shoreline Monitoring Conclusion

The only area of Archibald Lake where specific conductivity indicates groundwater intrusion is from the inlet stream inlet area in the west basin's northwest corner. However, there are areas of human impacts to water quality identified by the use of soap and shampoo along the Archibald Lakes shoreline and lack of any shoreline buffer areas. There is a distinct difference between the east and west basins. The west basin has a higher conductivity due to the greater influence from the inlet stream and groundwater intrusion.

5. Conclusions and Recommendations – Phase II Lake Study

5.1 Conclusions

5.1.1 Groundwater Evaluation

- Groundwater flows into the Archibald Lake mainly in the north and west sides of the west lobe of the lake.

- Lake water flows into the groundwater mainly on the south and east side of the lake.

- The flow direction of groundwater varies seasonally and most areas of the lake can have groundwater flow in either direction.

- Because Archibald Lake is a seepage lake with an inlet stream and no outlet stream, the overall direction of groundwater flow is out of the lake.

5.1.2 Water Quality Evaluation

- The water quality in Archibald Lake was measured for trophic status indicators (phosphorus, chlorophyll a, and secchi depth). The water quality indicates the lake is mesotrophic.

- The west basin is consistently higher in trophic status (more eutrophic) than the east basin.

- The water quality as measured in 2003 showed no significant variation when compared to 2001.

- The inlet stream had a phosphorus concentration that averaged 14 ug/l. This value is higher than the west basin (11 ug/l) and the east basin (8.5 ug/l).

- The nitrogen to phosphorus ratio is 27:1 showing the lake to be phosphorus limited.

- Beaver activity in wetland north of east lake lobe has been kept to a minimum to reduce phosphorus.

5.1.3 Inlet Stream Evaluation

- The inlet stream had an average flow of 2.78 cfs (1.8 million gallons per day).

- The stream is groundwater fed.

- The phosphorus loading from the stream is 62 pounds per year.

- The inlet stream flow gives an lake volume exchange value of about 3 to 4 years (assumes average lake depth is 15 feet with some areas of lake greater than 50 feet deep).

5.1.4 Shoreline Monitoring

- Conductivity was measured along the shoreline to observe obvious groundwater intrusion. No large groundwater sources were identified during the study.

- The inlet stream caused a plume with conductivity 50% greater than the surrounding area.

- The east basin had lower conductivity (about 5% lower) than the west basin.

5.2 Recommendations

- The inlet stream is a significant source of water to the lake and impacts water quality. Protecting the watershed adjacent to the inlet stream is important in keeping water quality good in the stream. Specific recommendations for protecting the stream would include preventing erosion, prohibiting development within the vicinity of the stream and wetland, and protecting the forest habitat around the stream. Residential development in the watershed should include storm water detention basins.

- The groundwater flow around the lake is variable. Maintaining good groundwater quality in residential areas is important in protecting lake water quality. Specific recommendations should be based on findings in the Phase 3 report.

6. References

UW-Extension. Understanding Lake Data. Publication 63582.

Hydrolab Operating Manual 1997 Appendix 1: Dissolved Oxygen Pg. A1-1