LAKE MANAGEMENT STUDY

PIGEON LAKE
MANITOWOC COUNTY, WISCONSIN

September 18, 1995

LPL-166

Northern Environmental[SM]
Hydrologists • Engineers • Geologists

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1.0 EXECUTIVE SUMMARY

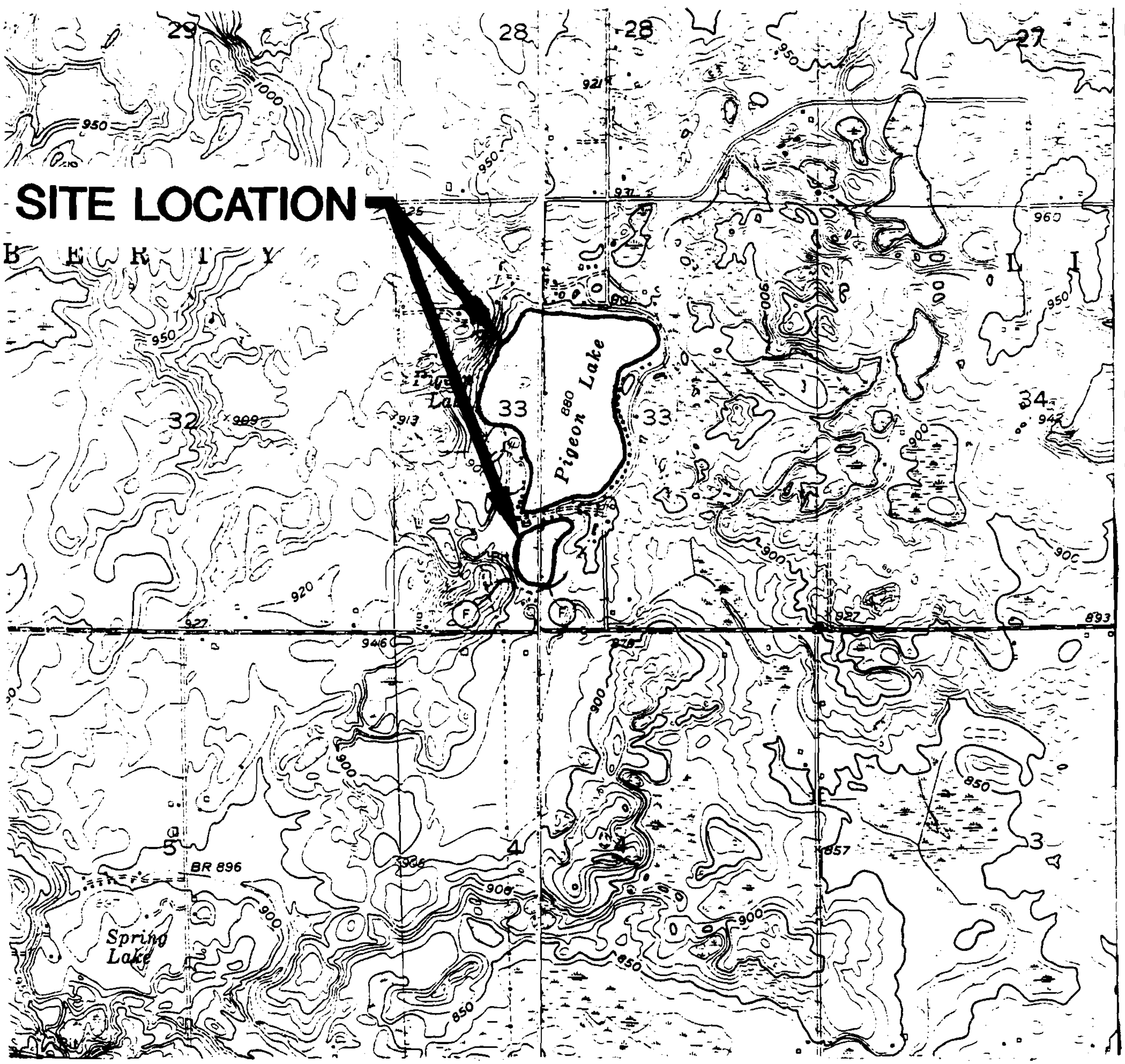
On behalf of the Pigeon Lake Association (PLA), Northern Environmental Technologies, Incorporated (Northern Environmental) completed a lake management study of Pigeon Lake/Little Pigeon Lake under a Lake Management Planning Grant received by the Pigeon Lake Sanitary District (PLSD) during April 1993. Pigeon Lake is an 80-acre seepage lake with a single perennial outlet located in southwest Manitowoc County (Figure 1). The lake has a maximum depth of 68 feet, an average depth of 19 feet, 1.6 miles of shoreline, about 80 dwellings, and a 1569-acre watershed (Figure 2). Little Pigeon Lake is an adjacent drainage lake with a surface area of 8 acres and a maximum depth of 15 feet. The Little Pigeon Lake shoreline is populated with purple loosestrife, an aggressive non-native plant.

During 1993, Northern Environmental began a two-year lake management study. Specific areas of investigation were chemical and physical characteristics of Pigeon Lake and Little Pigeon Lake, the watershed, hydrophytic vegetation, bathymetric mapping, and public opinions. Final work products include detailed baseline-water quality data, an aquatic macrophyte survey, a revised bathymetric map, and a lake management plan.

Water quality analysis revealed that Pigeon Lake's water quality classifies it as a mesotrophic lake. Mesotrophic lakes have lower nutrient levels, less biologic productivity, and better water clarity than eutrophic lakes. The aquatic macrophyte survey revealed that milfoil is growing in 100 percent of the vegetation sample transects in Pigeon Lake and Little Pigeon Lake. Thirty-three percent of the sample transects have Eurasian milfoil growth. Eurasian milfoil is an aggressive non-native submergent plant that is a common nuisance plant in shallow Wisconsin lakes. Northern water milfoil, a native Wisconsin species, accounts for 67 percent of all milfoil and is not as aggressive. Mechanical harvesting of Eurasian milfoil can decrease internal nutrient cycling and increase the recreational boating opportunities on Pigeon Lake. More importantly, purple loosestrife is growing in all of the sample transects on Little Pigeon Lake. Purple loosestrife is a state-regulated noxious plant which is illegal to possess or cultivate.

The lake management plan provides a guideline for maximizing public use without compromising the lake's natural integrity, and addresses the physical and cultural concerns of the lake. Highlights of the plan include continuing best management practices, preserving the "Camp Bay" wetland area, protecting sensitive areas, distributing lake educational materials, experimenting with sediment covers, creating a fish management plan, completing a wetland restoration project (purple loosestrife control), appointing a volunteer lake monitor, recreational boat regulations (buoys and boating lanes), and forming lake committees. Implementing management plans will reduce negative cultural impacts on the lake by stabilizing and protecting water quality.

Milwaukee • St. Paul • Green Bay



SCALE 1" = 2000'

1000 0 1000 2000 3000 4000 5000 6000 7000

CONTOUR INTERVAL 10 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929

QUADRANGLE LOCATION

N

BASE MAP SOURCE: 7.5 MINUTE TOPOGRAPHIC MAP, SCHOOL HILL AND CLEVELAND WEST, 1973.

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FIGURE 1

2.0 INTRODUCTION

2.1 Background Information

Pigeon Lake is an 80-acre seepage lake located in southwestern Manitowoc County, Wisconsin. The lake has a single perennial outlet, a maximum depth of 68 feet, an average depth of 19 feet, and 1.6 miles of shoreline with about 80 dwellings and one recreational camp. Pigeon Lake has a 1589 acre, primarily agricultural, watershed (Figure 2). The watershed to lake ratio is 19.6 to 1. About 70 percent of the shoreline is developed, while the other 30 percent is undeveloped. Most of the undeveloped shoreline is occupied by the Camp, the boat landing, and two small wetlands.

2.2 History

Pigeon Lake was formed at the end of the last Ice Age (about 10,000 years ago) in an area underlain by glacial outwash deposits adjacent to a northeast-southwest trending terminal moraine. A large piece of glacial ice probably was left behind, and when it melted formed Pigeon Lake. This type of lake is typically called a "Kettle Lake". The other small lakes and ponds in the watershed (including Little Pigeon Lake) were formed in the same manner but on a smaller scale.

Today, Pigeon Lake suffers from post-settlement human activities. Land use changes from pre-settlement conifer-hardwood forest to agriculture has increased nutrient and sediment loads to Pigeon Lake. Pigeon Lake is one of the more heavily used lakes in Manitowoc County.

2.3 Workplan

During April 1992, the Pigeon Lake Sanitary District (PLSD) received a Lake Management Planning Grant from the Wisconsin Department of Natural Resources (WDNR). The grant was to be used to evaluate Pigeon Lake's trophic state and Pigeon Lake's watershed. An aquatic macrophyte survey was also to be completed and a revised bathymetric map produced.

Northern Environmental Technologies, Incorporated (Northern Environmental) coordinated with the Pigeon Lake Association (PLA) to prepare the desired plan and was later contracted to complete the study. The objectives of the project are listed below.

- Evaluate physical and chemical characteristics of Pigeon Lake and Little Pigeon Lake
- Identify non-point source pollution in the Pigeon Lake watershed
- Inventory vegetation of Pigeon Lake and Little Pigeon Lake
- Revise the Pigeon Lake bathymetric map
- Produce a Lake Management Plan

This report summarizes the methods used to conduct the study, presents the results, discusses significance of the results, and provides a Lake Management Plan.

3.0 METHODS OF INVESTIGATION

A variety of methods were used to evaluate aquatic vegetation, water quality, and watershed characteristics. These methods are briefly discussed below, and are described in more detail in Appendix A.

3.1 Chemical and Physical Analyses

Northern Environmental personnel collected ten water quality samples over a two-year period. Two water samples were taken from Pigeon Lake's deepest point (one meter below surface and one meter above and the bottom). One water sample was collected at mid depth at the deepest point of Little Pigeon Lake. This site was selected so water samples could be taken while collecting physical data which requires evaluation of the entire water column at the deepest point of the lake. Chemical tests were performed to determine levels of nutrients, alkalinity, and algae. Dissolved oxygen content, temperature, conductivity, and transparency were measured to classify Pigeon and Little Pigeon Lakes' trophic state. All laboratory tests were performed by the State Laboratory of Hygiene in Madison.

3.2 Watershed Analyses

Pigeon Lake's watershed was examined using topographic maps, Soil Conservation Service soil surveys, meteorologic and hydrologic data, and watershed modeling. Data was first examined and then field verified. A watershed survey was conducted to determine point source pollution, identifiable discharges and non-point source pollution, and agricultural runoff into Pigeon Lake.

3.3 Vegetation Survey

Vegetation surveys were conducted to identify and evaluate the plant species present in Pigeon Lake. The Pigeon Lake vegetation survey was completed on August 3 and 4, 1994. Vegetation surveys are used to assess the quality and function of the lake system. All species were identified to both genus and species level whenever possible. A base map was drawn with twenty points or transects distributed around the perimeter of Pigeon Lake (Figure 3).

The transects extended perpendicular to the shoreline for a distance calculated by dividing the total shoreline length by the number of established transects. The length of each transect was either the calculated distance or the distance from the shoreline to the maximum rooting depth determined by the following equation (Reference 8).

$$\text{maximum rooting depth (feet)} = 2.73 + 1.22\,\text{(mean secchi disk depth in feet)}$$

The latitude and longitude at the intersection of the shoreline and transect were measured with a Magellan Global Positioning System. A Silva compass was used to determine transect bearings. The transects proceeded in the direction of the established bearing. The following measurements were recorded at the end of each transect:

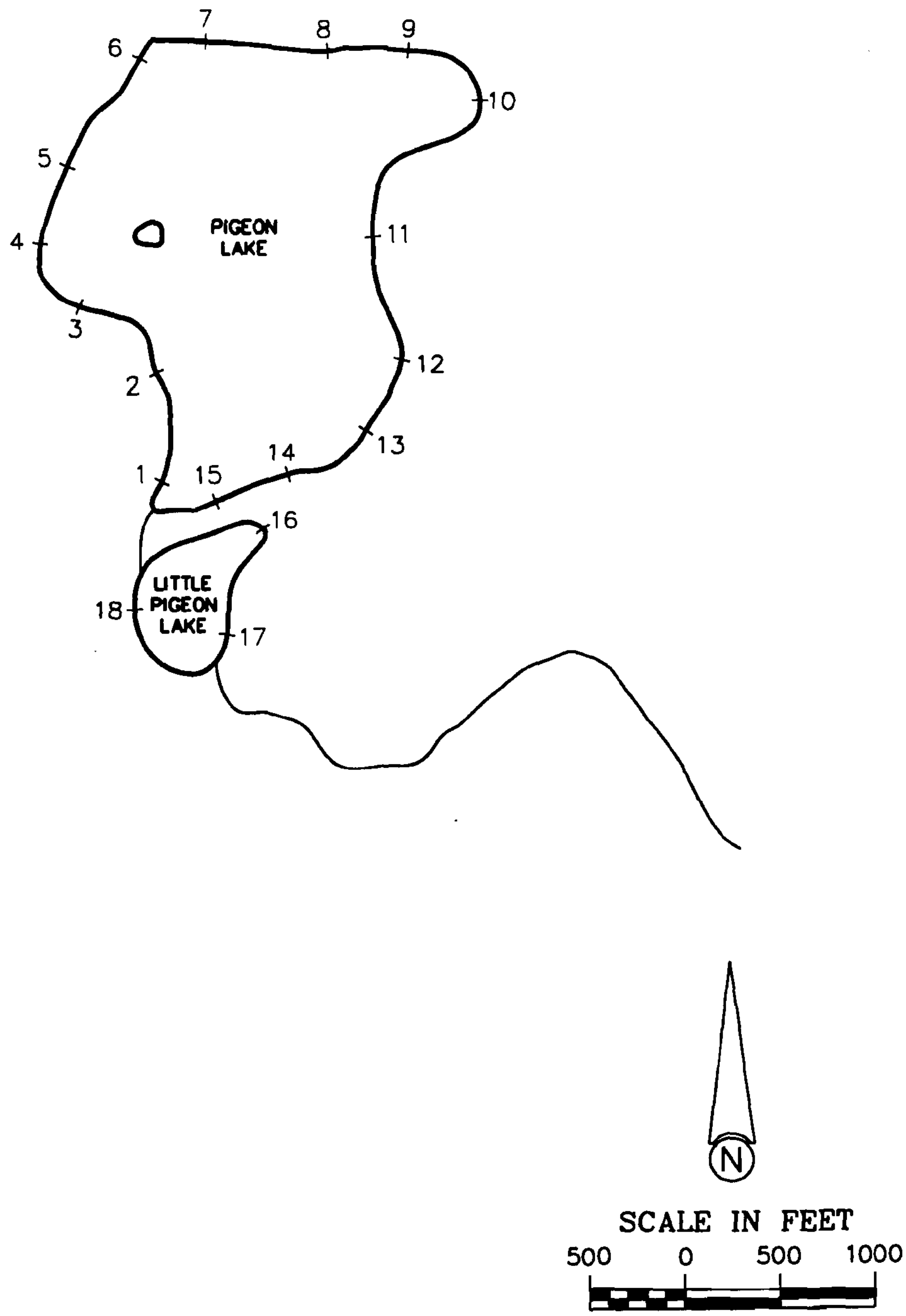

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FIGURE 3

- ▲ Distance to the starting point (the shoreline)
- ▲ Latitude and longitude
- ▲ A compass bearing back to the starting point

Along each transect, a ten-foot diameter circle was randomly selected in each of the corresponding depth ranges:

FREQUENCY OF OCCURRENCE

Depth Code	Depth Range (feet)
1	0.00 - 1.75
2	1.76 - 5.00
3	5.10 - 10.00
4	10.00 - 20.00
5	>20.10

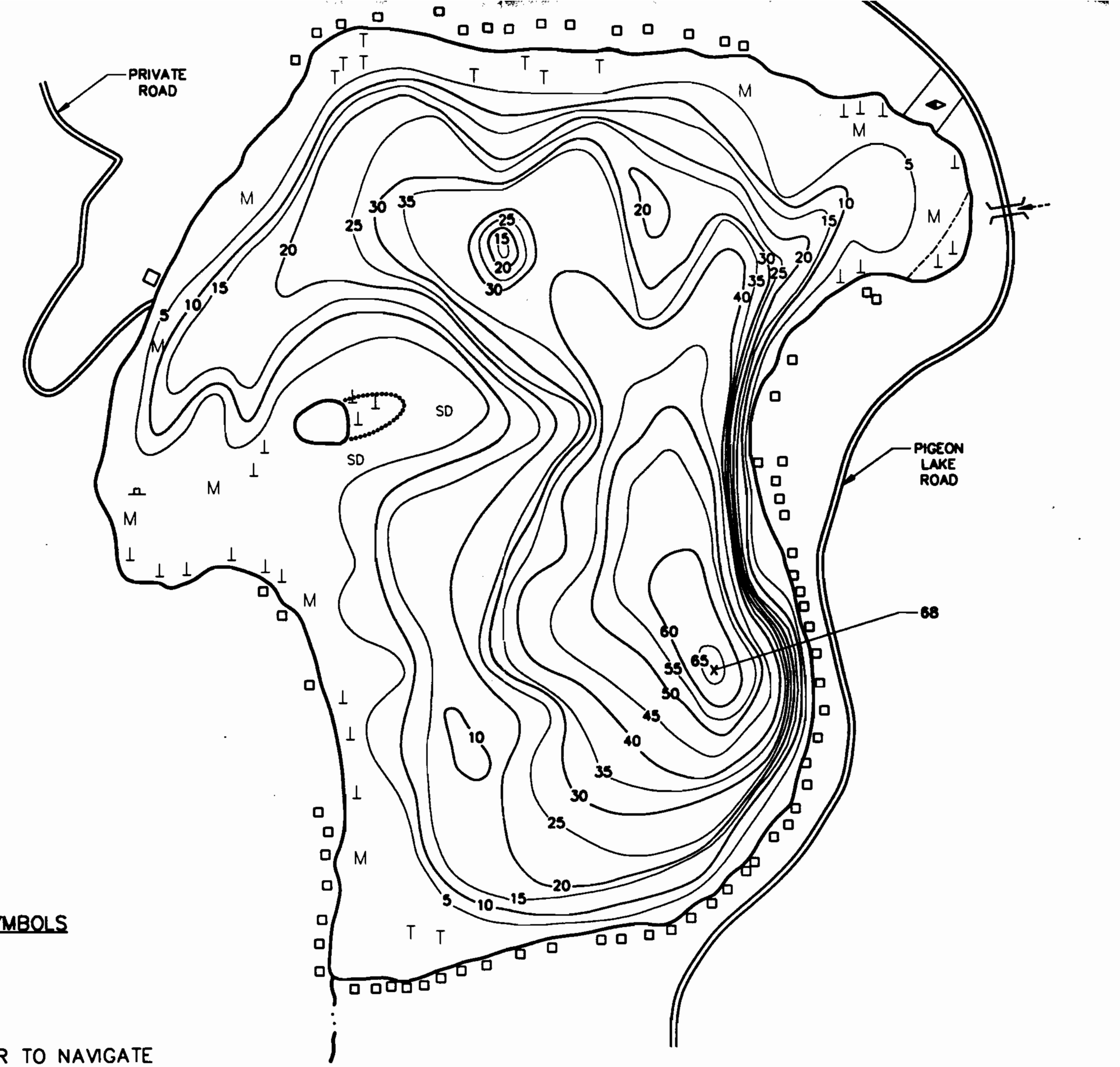
The circle was subdivided into four quadrants. A density rating was determined for each quadrant by eye or with a modified rake. In areas where the bottom could be clearly observed (i.e., in water less than 1.75 feet), visual means were used. A dragging test was necessary to correlate visual and rate density ratings. The test was performed in shallow water to determine how much plant matter would be collected by the teeth of the rake. A rake with an extended handle was used in depths too great for visual observations. The rake was thrown into each quadrant, allowed to settle, and was slowly retrieved with a rope. A density rating, based on the following criteria, and observations regarding substrate type, were recorded along with the depth in feet.

SPECIES MEAN DENSITY RATING

Recovery	Species Density Rating
Rake teeth full in all four quadrants	5
Rake teeth partially full	
▲ In four quadrants	4
▲ In three quadrants	3
▲ In two quadrants	2
▲ In one quadrant	1

3.4 Bathymetric Map Revision

During June 1995, depths to bottom in Pigeon Lake were measured. Depths were measured using a grid method and two sonar depth finders. Depths measured were compared to the WDNR Lake Survey Map for Pigeon Lake. Significant differences were noted and changes made to the bathymetric map (Figure 4). The sonar's precision was checked with a standard



TOPOGRAPHIC SYMBOLS	LAKE BOTTOM SYMBOLS	
DWELLING	M	MUCK
ACCESS WITH PARKING	SD	SAND
INDEFINITE SHORELINE		ROCK DANGER TO NAVIGATE
INTERMITTEN STREAM	T	SUBMERGED VEGETATION
INTERMITTEN CULVERT	⊥	EMERGENT VEGETATION
		FLOATING VEGETATION

NOTE: REVISED USING DUAL SONAR BY BSL, 6-12-95

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100-foot tape measurer at the deepest point of Pigeon Lake, the sonar read 68 feet and the tape measurer read 68 feet.

3.5 Public Opinion Survey

A public opinion survey was distributed to all Pigeon Lake residents pertaining to pertinent lake issues. Important issues expressed by residents will be incorporated into the Lake Management Plan. Surveys were distributed and returned, and the results compiled. Areas of specific concern were also examined in the field.

3.6 Lake Management Plan

A Lake Management Plan was created by comparing data and test results with public opinion. The result is a document which provides a guideline for managing Pigeon Lake that will maximize public use without compromising the lake's natural integrity. Recommendations in the plan can be implemented to stabilize and protect water quality in Pigeon and Little Pigeon Lakes.

4.0 RESULTS

4.1 Chemical Characteristics

Chemical characteristics can be grouped into three categories: nutrients (phosphorus and nitrogen), carbonates (alkalinity and pH), and pollution indicators (chloride). Results are found in Tables 1 and 2. Phosphorus and nitrogen are vital to microphyte (algae) and macrophyte (milfoil and pondweeds) plant growth. Chlorophyll a is also included with nutrients because it is a measure of algae content which is directly related to nutrient levels. Chlorophyll is a chemical present in green plants which allows them to produce energy from the sun through photosynthesis.

Concentrations of both soluble phosphorus and total phosphorus were determined. Average Spring soluble phosphorus concentrations in Pigeon Lake and Little Pigeon Lake measured 0.002 milligrams per liter (mg/l) and 0.007 mg/l, respectively. This is well below the recommended Spring soluble phosphorus level of 0.01 mg/l to prevent algae blooms. Total phosphorus results averaged 0.022 mg/l and 0.023 mg/l, respectively. Total phosphorus levels of 0.02 mg/l are considered average for natural lakes. The median of 61 southeast Wisconsin lakes is 0.03 mg/l (Reference 4). Lakes with total phosphorus levels below 0.02 mg/l will generally not have nuisance algae blooms (Reference 3). Lakes with total phosphorus levels between 0.01 and 0.03 mg/l are considered to have good water quality.

Nitrogen levels were measured for ammonia-nitrogen, nitrate and nitrite, kjeldahl nitrogen, and total nitrogen. Ammonia-nitrogen concentrations averaged 0.299 mg/l and 0.07 mg/l, respectively. Nitrate and nitrite concentrations averaged 0.143 mg/l and 0.103 mg/l, respectively. Both ammonia and nitrate and nitrite nitrogen series are inorganic forms of nitrogen. If inorganic nitrogen levels are below 0.3 mg/l summer algae blooms are not likely. Kjeldahl nitrogen is an organic form of nitrogen and is used to quantify total nitrogen. Total nitrogen is calculated by adding nitrate and nitrite to kjeldahl nitrogen. The average concentration of total nitrogen in Pigeon Lake is 1.02 mg/l, while Little Pigeon Lake's average is 0.83 mg/l. The median for 61 southeastern Wisconsin lakes is 1.18 mg/l (Reference 4).

Pigeon Lake's total nitrogen to total phosphorus ratio is about 50:1. Little Pigeon Lake has a nitrogen to phosphorus ratio of 35:1. When the ratio is greater than 15 to 1, algae growth in the lake is considered phosphorus limited. When the ratio is below 10 to 1, nitrogen is the limiting nutrient for algae growth, values between 10 to 1 and 15 to 1 are considered transitional. Most of Wisconsin Lakes are phosphorus limited.

Chlorophyll a is a green chemical pigment used by plants during photosynthesis. Concentrations of chlorophyll a are generally an indicator of the amount of algae in lake water. High levels correspond to summer and fall algae blooms. Winter algae blooms also occur when solar input is sufficient through clear ice without snow cover. However, normal chlorophyll a levels for winter are low. Average chlorophyll a concentrations in Pigeon Lake and Little Pigeon Lake are 4.7 micrograms per liter (μg/l) and 11.4 μg/l, respectively. Values of 10 μg/l or higher are associated with algae blooms. Chlorophyll a readings less than 10 μg/l indicate good water quality (Reference 3).

Table 1 Pigeon Lake Water Quality Data, August 1993 through June 1995

Sample Date	08/26/93		01/06/94		04/19/94		06/09/94
Sample Depth	1 M	17 M	1 M	16 M	1 M	19 M	1 M
Calcium (mg/l)	28	NT	37	39	40	38	32
Chloride (mg/l)	6.5	6.4	6.8	6.9	6.6	6.5	6.7
Chlorophyll *a* (µg/l)	2.79	NT	13.5	NT	7.41	NT	3.34
Conductivity (µohms/cm)	360	416	NT	NT	NT	NT	340
pH	9.16	7.39	8.2	8.2	8.5	8.5	8.6
Alkalinity (mg/l)	178	207	NT	NT	NT	NT	191
Hardness (mg/l)	200	NT	230	240	230	220	210
Magnesium (mg/l)	32	NT	34	34	32	31	32
Ammonia-N (mg/l)	0.009	0.771	0.18	0.226	0.052	0.06	0.02
Nitrate+Nitrite (mg/l)	0.015	ND	0.149	0.182	0.272	0.496	ND
Kjeldahl-N (mg/l)	0.6	1.4	0.6	0.7	0.6	0.5	0.7
Total Phosphorus (mg/l)	<0.02	0.03	0.012	0.011	<0.02	<0.02	0.014
Dissolved Phosphorus (mg/l)	ND	ND	NT	NT	0.002	0.003	ND
Potassium (mg/l)	1	NT	1.1	1.06	1.42	1	1.17
Total Dissolved Solids (mg/l)	236	NT	258	264	258	258	246

NOTE:

M = meters
mg/l = milligrams per liter
µg/l = micrograms per liter
µohms/cm = micro ohms per centimeters
NT = no test performed
ND = no detection, below LOD (Level of Detection)

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07/19/94		08/15/94		01/23/95		04/18/95		06/12/95		07/18/95	
1 M	59.4 ft 18 M	1 M	16 M	1M		1M	39.6 12M	1M	16M	1M	16M
31	43	30	41	37	NT	34	35	34	38	28	39
7.1	6.4	6.7	7.4	6.8	NT	7.2	7.2	6.8	6.4	7.3	7.5
3	NT	4.13	NT	4.55	NT	3.03	NT	3.92	NT	0.92	NT
360	330	320	300	360	NT	410	370	380	330	440	300
8	7.1	9.3	8.4	8.4	NT	8.4	8.4	8.7	7.8	8.6	7.8
189	219	184	219	198	NT	201	202	198	212	187	215
210	230	210	230	230	NT	210	220	220	230	210	230
31	31	32	32	33	NT	31	32	34	33	34	33
0.02	0.793	0.034	0.787	0.217	NT	0.111	0.111	ND	0.41	ND	0.589
0.023	ND	0.022	ND	0.089	NT	0.217	0.188	0.051	0.139	ND	ND
0.8	1.4	0.68	1.47	0.9	NT	0.8	0.8	0.9	1.2	0.7	1.4
0.016	0.035	0.015	0.029	0.02	NT	0.015	0.015	0.016	0.032	0.012	0.043
ND	0.003	ND	ND	ND	NT	ND	ND	0.005	0.007	0.003	0.004
1.3	1.28	1.23	1.12	1.1	NT	1.2	1.1	1.3	0.9	0.9	10.9
208	NT	240	NT	240	NT	258	NT	222	NT	216	NT

Table 2 Little Pigeon Lake Water Quality Analysis, August 1993 through June 1995

Sample Date	08/26/93	01/06/94	04/19/94	06/09/94	07/25/94	08/15/94	01/23/95	04/18/95	06/12/95
Sample Depth	2.5M	1M	1M	1M	1M	1M	1M	2M	2M
Calcium (mg/l)	36	42	40	34	33	34	37	35	34
Chloride (mg/l)	6.7	9.3	6.3	6.6	6.4	6.7	6.8	7.2	7.0
Chlorophyll *a* (µg/l)	39.7	21.4	19	4.65	13.9	4.86	4.55	NT	1.77
Conductivity (µohms/cm)	406	NT	NT	310	400	330	350	400	430
pH	NT	8.2	8.6	8.5	8.5	8.8	8.5	8.5	8.5
Alkalinity (mg/l)	202	NT	NT	198	196	198	198	197	200
Hardness (mg/l)	220	250	220	220	220	210	230	210	220
Magnesium (mg/l)	22	36	30	32	33	32	33	30	33
Ammonia-N (mg/l)	0.008	0.223	0.008	0.022	0.007	0.007	0.217	ND	ND
Nitrate+Nitrite (mg/l)	ND	0.253	ND	0.01	ND	ND	0.089	0.059	ND
Kjeldahl-N (mg/l)	0.9	0.9	0.9	0.7	0.74	0.67	0.9	0.7	0.8
Total Phosphorus (mg/l)	0.04	0.021	0.03	>.02	0.021	0.016	0.02	0.025	0.02
Dissolved Phosphorus (mg/l)	ND	NT	0.012	ND	ND	ND	ND	0.002	ND
Potassium (mg/l)	1.22	1.23	1.29	1.04	0.88	1.12	1.1	1.4	1.3
Total Solids (mg/l)	266	280	256	256	252	252	240	248	226

NOTE:

M = meters
mg/l = milligrams per liter
µg/l = micrograms per liter
µohms/cm = micro ohms per centimeter
NT = no test performed
ND = no detection, below LOD (Level of Detection)

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Alkalinity is one measure of the carbonate system in a lake. Alkalinity is represented by carbonate ($CO_3^{=}$) and bicarbonate (HCO_3^-). These compounds bond with calcium and/or magnesium. Alkalinity is measured by the amount of $CaCO_3$ (calcite) in the water. A high alkalinity reading translates into high hardness levels. Hardness relates to presence of soluble minerals in the lake. Northern Environmental water sample data indicates Pigeon Lake has an average alkalinity level of 201 mg/l and Little Pigeon Lake of 210 mg/l. This means Pigeon and Little Pigeon Lakes are hardwater lakes. Hardwater lakes are less susceptible to acid rain and more biologically productive than soft water lakes.

pH is an exponential index of hydrogen ion concentration used to measure acidity. pH is represented on a logarithmic scale from 1 to 14, 7 being neutral. Readings above seven have less hydrogen ions and are basic (alkaline), readings below seven have less hydrogen ions and are considered acidic. Pigeon Lake's average pH reading is 8.3, classifying it as an alkaline, or hardwater lake. Similarly, Little Pigeon Lake's pH average is 8.5. Most lakes have a pH between 6.0 - 9.0 (Reference 5).

The presence of high chloride levels usually indicated human pollutants like road salt, fertilizers, septic system effluent, and animal wastes. Chloride concentrations of 50 to 100 mg/l are usually associated with septic effluent (Reference 3). The world chloride average for lakes and streams is 7.8 mg/l (Reference 5). The geographic distribution of natural chloride from limestone deposits for Wisconsin indicates Manitowoc County averages about 10 mg/l of chloride in surface waters (Reference 3). Pigeon Lake and Little Pigeon Lake have average chloride concentrations of 6.8 and 7.0 mg/l respectively. The chloride concentrations in Pigeon Lake do not reveal human influences and can be considered normal.

4.2 Physical Characteristics

Physical characteristics include dissolved oxygen content, temperature, specific conductance, and transparency. Physical characteristics were measured and analyzed to help determine the trophic state of Pigeon Lake.

Dissolved oxygen is the amount of gaseous oxygen in water. The degree of gaseous solubility is dependent on water temperature, atmospheric pressure, and water salinity. Cold water holds more dissolved oxygen than warm water. Dissolved oxygen is also affected by a lake's biological productivity. Green plants produce oxygen but decomposition and respiration use oxygen. Low levels of dissolved oxygen can cause winter fish kills because winter ice does not allow air to water oxygen transfer or photosynthetic oxygen production to balance the loss of oxygen from winter decomposition of organic matter and winter biologic activity. The WDNR water quality standard for warm water lakes is 5 mg/l of dissolved oxygen and 7 mg/l of dissolved oxygen for trout waters. These standards are the minimum amount of oxygen required to maintain a healthy fish population. Sufficient dissolved oxygen levels in Pigeon and Little Pigeon Lakes were recorded to an average depth of 31.7 and 8.6 feet, respectively, in summer months to support warm water fish. During January 1994, sufficient dissolved oxygen for warm water fish (>5 mg/l) was observed in the entire Pigeon Lake water column, while in Little Pigeon Lake the dissolved oxygen dropped below 5 mg/l at 9 feet. During January 1995, sample equipment failure resulted in dissolved oxygen measurements not being recorded for both lakes. Dissolved oxygen profiles are presented in Figures 5 and 6.

Figure 5
Pigeon Lake Dissolved Oxygen Profile

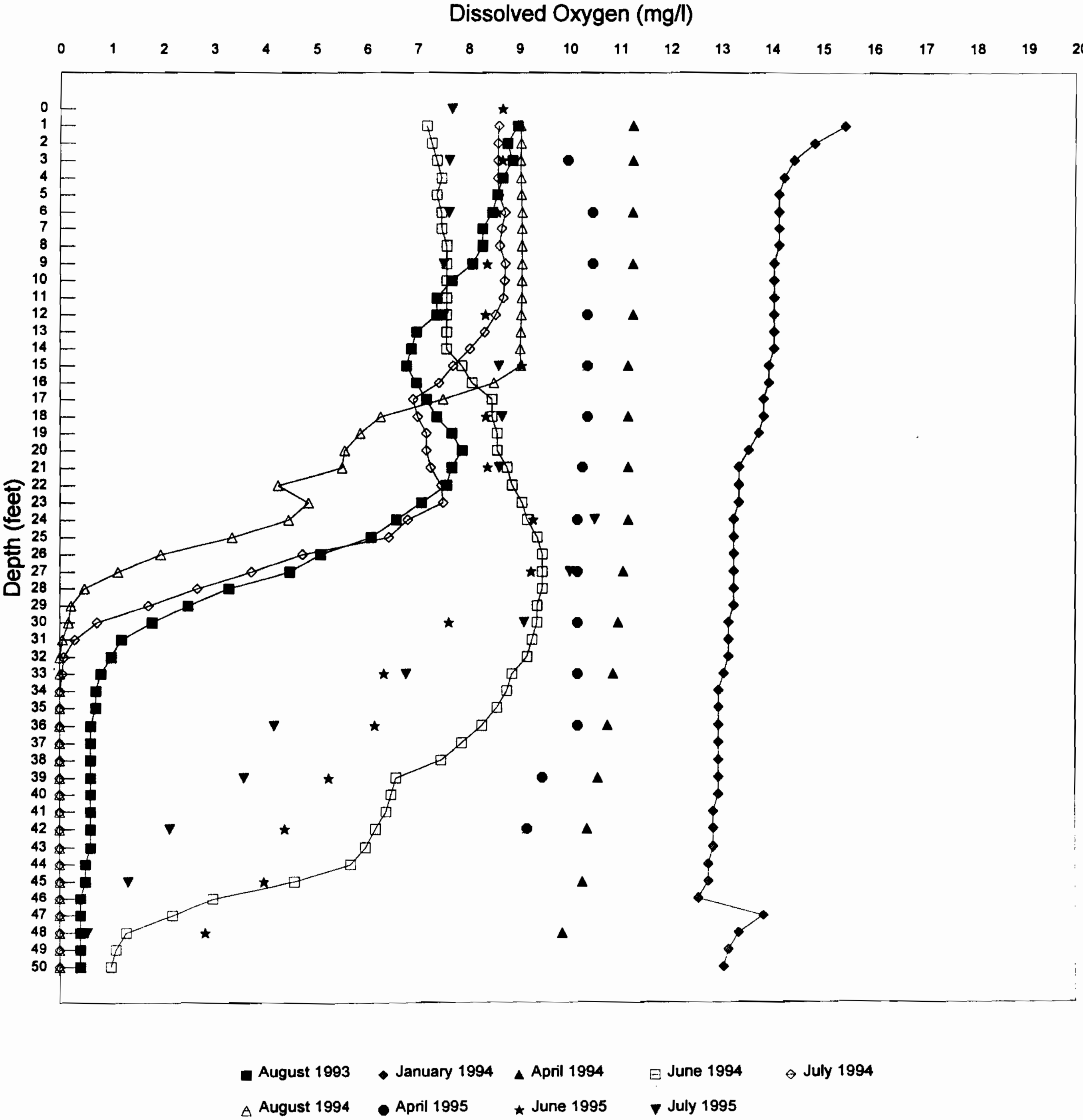

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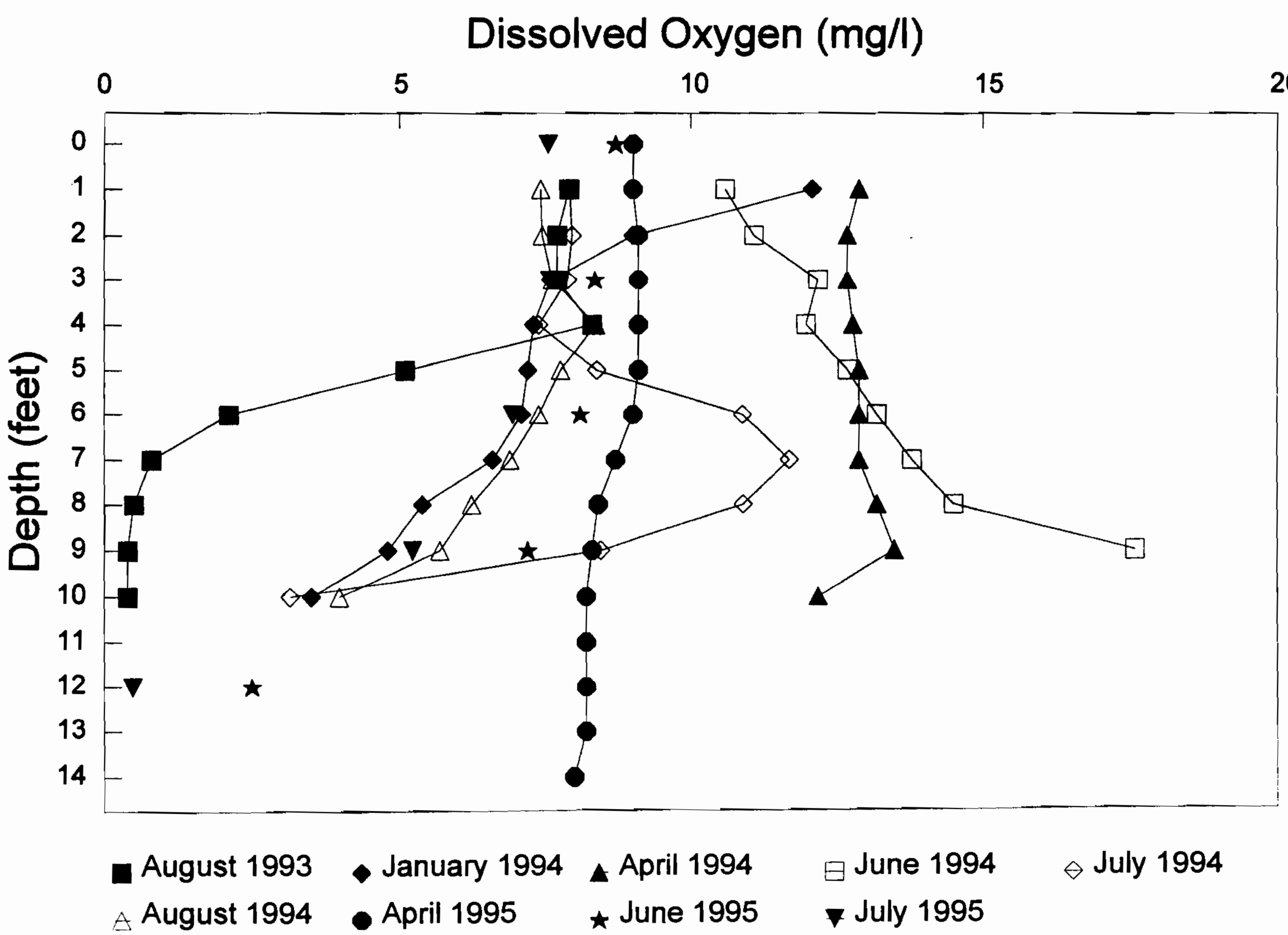
Figure 6
Little Pigeon Lake Dissolved Oxygen Profile



Temperature profiles for Pigeon and Little Pigeon Lakes are presented in Figures 7 and 8. Water temperature is related to climate, wind patterns, dissolved oxygen content, solubility rates, and chemical reactions. Water temperatures vary with depth. When there is little variation of temperature in the water column, a lake is termed mixed. When temperatures vary from the surface to the bottom, the lake is thermally stratified. Pigeon Lake is a dimitic lake that thermally stratifies. Thermal stratification in shallow lakes often breaks down in summer, resulting in mixing. A dimitic lake is one that has winter ice and mixes in spring and fall. During summer, thermally stratified lakes have three temperature zone associated with different depths: epilimnion (warm surface layer), metalimnion (transition layer), and hypolimnion (cold bottom layer). Thermal stratification occurs due to differences in water density associated with temperature. During winter, thermal stratification occurs and warmer (39°F) more dense water sinks to the bottom and colder (32 to 38°F) less dense water stays at the surface under a layer of ice (Figure 7, profile January 1994). Mixing occurs in spring and fall when the ice breaks up and before the ice forms. Both mixing events are closely related to local weather and solar input warming and cooling the lake water. Little Pigeon Lake is a shallow dimitic that often experiences thermal breakdown due to its shallow depths. Summer mixing can contribute to algae blooms. The lower portion of the hypolimnion is often anoxic (void of oxygen). Nutrient rich bottom sediments in an anoxic environment will release phosphorous into the water column. Summer mixing results in increased nutrient availability for algae. A similar occurrence is associated with normal spring and fall mixing.

Specific conductance or conductivity quantifies the amount of dissolved inorganic chemicals in a lake. Generally, lakes with high conductivity readings are eutrophic (fertile and productive). Conductivity readings are commonly twice the alkalinity levels (Reference 3). Pigeon Lake's average conductivity reading for the two year sample period is 355 μohms per centimeters (μohms/cm). Little Pigeon Lake's conductivity average is 376 μohms. Since these values are almost twice the alkalinity values, they can be considered normal and not suspect of receiving large quantities of human contaminants. Septic affluent and fertilizers are common human pollutants which can cause high conductivity readings.

Transparency is a function water color and turbidity and is measured by recording secchi disk depths. A secchi disk is a circular plate painted with alternating quadrants of black and white. Depths are recorded when an observer can no longer see the secchi disk as it is lowered from the surface and when it reappears as it is raised to the surface. The two measurements are averaged to give a reading. The deeper the secchi disk reading, the better the water clarity. High algae content in the water usually accounts for shallow secchi disk readings. The average secchi disk reading for Pigeon Lake during the sample period is 9.1 feet (2.8 meters), and indicates good water clarity. The average secchi disk reading for Little Pigeon Lake during the sample period is 7.6 feet (2.3 meters), also indicating good water clarity.

Total phosphorous, chlorophyll a, and secchi disk depths are used to classify a lake's trophic state. A trophic state is an indicator of water quality. Pigeon Lake's average total phosphorous level is 0.022 mg/l, average chlorophyll a reading is 4.7 μg/l, and average secchi disk depth is 9.1 feet. Little Pigeon Lake's average total phosphorus level is 0.023 mg/l, average chlorophyll a reading is 11.4, and average secchi disk is 7.6 feet. These three parameters, along with professional judgement, place Pigeon Lake and Little Pigeon Lake in the mesotrophic class of trophic states (Reference 3). Pigeon Lake's averaged Carlson Trophic

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Figure 7
Pigeon Lake Temperature Profile

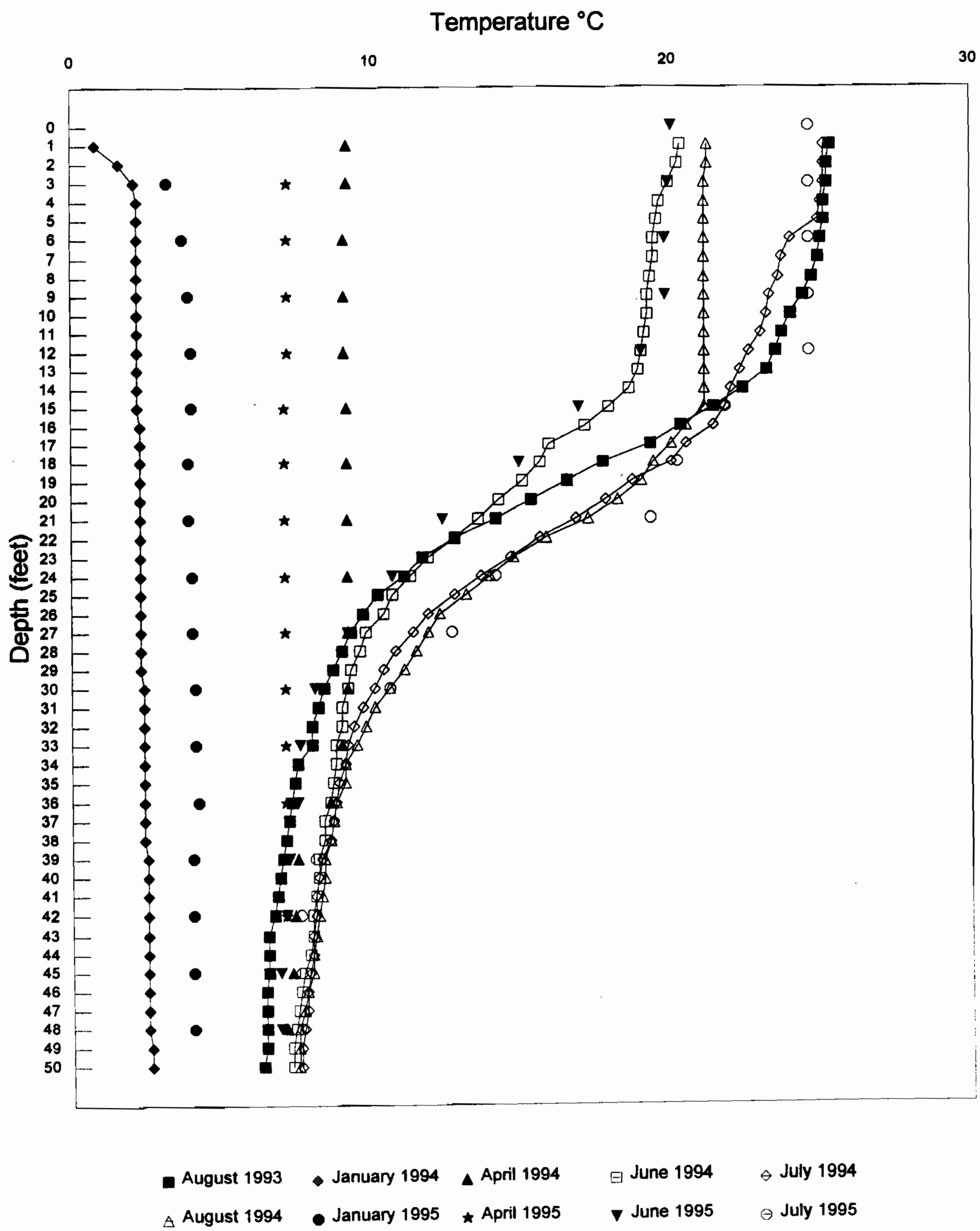
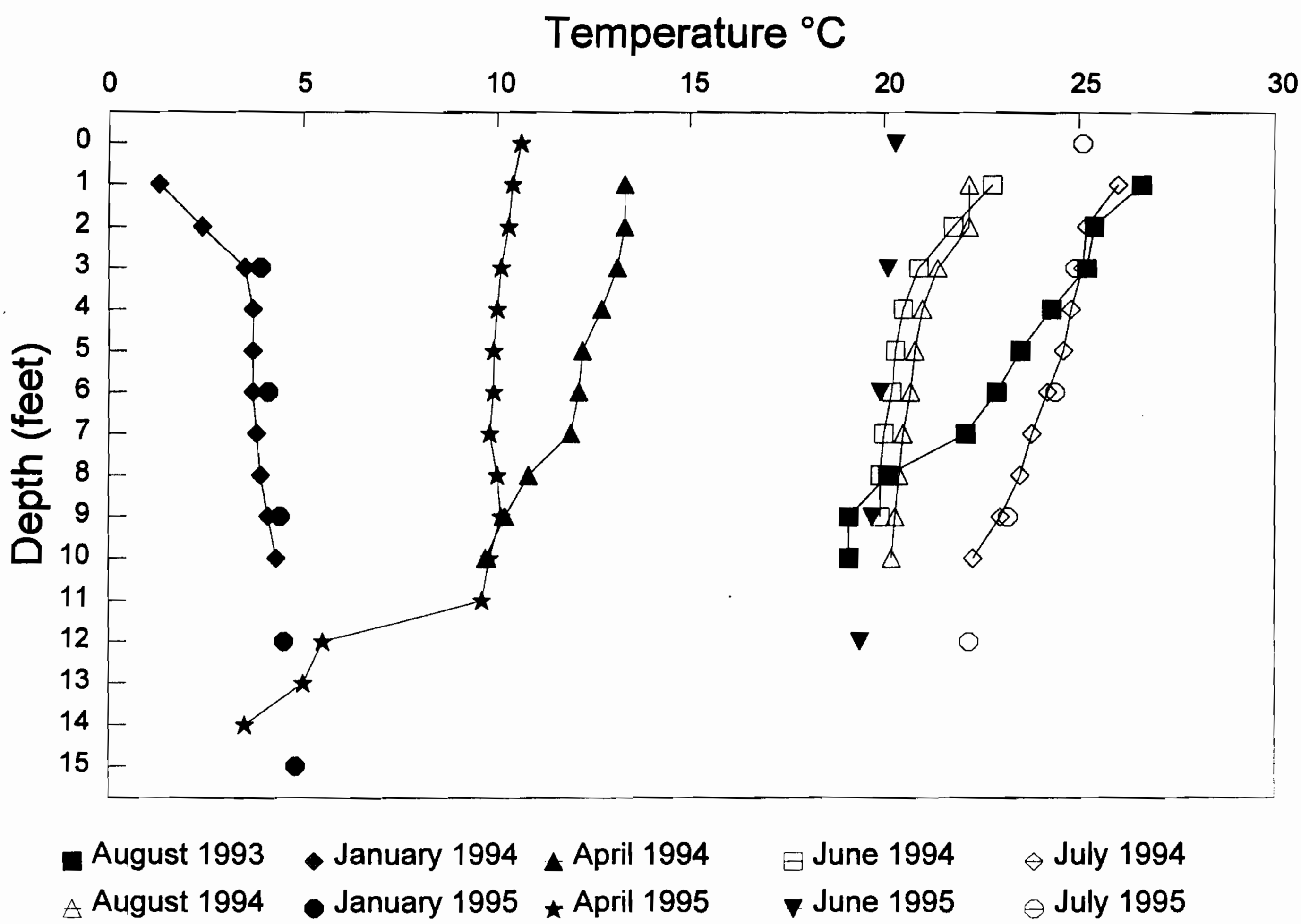


Figure 8
Little Pigeon Lake Temperature Profile



State Index (Table 3) value is 45.5 and Little Pigeon Lake's averaged value is 48.9. Mesotrophic lakes have occasional algae blooms, medium productivity, sediment/phosphorous cycling, accumulated organic matter, fair to good water quality, and good fisheries.

4.3 Watershed Analysis

The watershed inventory of the Pigeon and Little Pigeon Lake watershed includes identifying the watershed boundary and sensitive areas, determining land use type and location, and evaluating phosphorus loading in the watershed. The following section describes the results of the inventory.

Figure 1 depicts the topography of the watershed as represented by the United States Geological Survey (USGS) topographic map. The boundary of the watershed is shown in Figure 2. The total watershed area is 1569 acres. Pigeon Lake is approximately 80 acres and Little Pigeon Lake is 8 acres, or combined 5.6 percent of the watershed. The watershed to lake ratio is 19.6 to 1. The larger the watershed to lake ratio, the more impact the watershed has on the lake. Usually, lakes or impoundments with large ratios are more likely to be eutrophic. Lakes with large watersheds have more surface area which translates into greater surface water inputs into the lake. These surface water inputs typically contain higher levels of nutrient and sediments than water from a smaller watershed, because the water has more land to flow over.

4.3.1 Sensitive Areas

Three sensitive areas in the watershed were identified based on natural resource components. These components include woodlands, wetlands, steep slopes, and aesthetic value. The three areas combined occupy about 545 acres, or 34.5 percent, of the watershed. These sensitive areas represent tracts of land that, if protected or if developed and properly managed, will preserve not only the water quality of Pigeon Lake, but also the natural character of the watershed. Upland portions of the sensitive areas represent undeveloped land uses that if developed would increase runoff into the lake.

Sensitive area number 1 is 312-acre parcel of which 207 acres (66 percent) is wooded. The remaining 105 acres are a composite of grassland, agricultural land, wetland, and developed land in order of decreasing acreage. A large wooded area covers steep slopes (6 to 25 percent) which, if developed, may cause erosion and runoff problems. The sensitive area also contains a small segment of undeveloped shoreline to the south of the Camp. Adjacent to this undeveloped area is a small shoreland wetland. A series of small depressional wetlands are located in the wooded area which provide habitat diversity to the woods and increases the overall quality of the wildlife habitat. Land use changes can be seen as more homes are built in the "L-shaped" development inside the sensitive area on the south edge. X

Sensitive area number 2 is a 225-acre upland-wetland complex typical of end moraines in glaciated areas. Land use in this area is divided into agricultural land, wetland, grassland, woodland, and developed land in decreasing order of abundance. Four small ponds and three intermittent ponds also dot the sensitive area making the area good wildlife habitat despite the intermingled agricultural areas. A new 18-hole golf course,

Table 3
Carlson Trophic State Index*

Trophic Category Descriptions

Category *	TSI	Lake Characteristics
Oligotrophic	1-40	Clear water; oxygen rich at all depths, except if close to mesotrophic border; then may have low or no oxygen; cold-water fish likely in deeper lakes.
Mesotrophic	41-50	Moderately clear; increasing probability of low to no oxygen in bottom waters.
Eutrophic	51-70	Decreased water clarity; probably no oxygen in bottom waters during summer, warm-water fisheries only; blue-green algae likely in summer in upper range; plants also excessive.
Hyper-Eutrophic	70-100	Heavy algal blooms throughout the summer; if >80, fish kills likely in summer and rough fish dominate.

* Adapted for Wisconsin

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9 holes currently under construction, is on the north side of the sensitive area occupying old farm fields. The wetland directly east of the Pigeon Lake boat launch was probably connected to the lake prior to the construction of North Shore Drive, and provided more wetland functions than it presently does. Wetland functions lost on account of road construction include decreased wildlife habitat (fish spawning, nesting, and food supply accessibility). Wildlife must now cross the road, or be able to fit through the culvert, to move between the wetland and the lake. The 30 acre woods in the sensitive area is on steep slopes (12 to 20 percent), and is adjacent to wetland areas.

Sensitive area number 3 is an eight-acre section of the lake with shallow water depths, diverse aquatic vegetation, and a small island. Motorboating and jetskiing in this area disturbs sediment due to the shallow depths. The presence of diverse aquatic vegetation in this section of the lake shows that this is an important habitat area. The only island in the lake is also in this sensitive area and provides valuable aesthetic benefits.

4.3.2 Land Use

Land use in the watershed is divided into six main groups: Surface Water (Pigeon and Little Pigeon Lakes), Wetlands, Woodlands, Grasslands, Developed Land, and Agricultural. Land use groups by acreage are summarized below.

PIGEON LAKE WATERSHED ANALYSIS

Land Use	Area	%Watershed
Pigeon Lake	80 Acres	5.1%
Little Pigeon Lake	8 Acres	0.5%
Wetlands	179 Acres	11.4%
Woodlands	333 Acres	21.2%
Grasslands	188 Acres	12.0%
Developed Land*	157 Acres	10.0%
Agricultural	624 Acres	39.8%
TOTAL WATERSHED AREA	**1569 ACRES**	**100.0%**
SENSITIVE AREA #1	**312 ACRES**	**20.0%**
Woodland	207 Acres	
Grassland	44 Acres	
Agricultural	43 Acres	
Wetland	10 Acres	
Developed	8 Acres	

SENSITIVE AREA #2	**225 ACRES**	**14.0%**
Agricultural	44 Acres	
Wetland	66 Acres	
Grassland	45 Acres	
Woodland	36 Acres	
Developed (Golf Course)	34 Acres	
SENSITIVE AREA #3	**8 ACRES**	**0.5%**
Eight-acre area with shallow depths to bottom, emergent vegetation, and a small island		

* = Residential, farmstead, gravel pit, roads
Note: +/- seven percent error

The largest watershed component is agricultural lands, representing almost 40 percent of the total area. There are three large agricultural areas which account for about 424 acres of the 624 acres of agricultural land. Their general sizes and locations are as follows: 1) 160 acres northwest of Pigeon Lake, 2) 120 acres west of Little Pigeon Lake, and 3) 144 acres along the east edge of the watershed. These agricultural areas contribute more the 50 percent of the phosphorus loading in the watershed.

The second largest watershed component is woodlands, about 20 percent of the total area. More than 200 of the 333 acres of woods in the watershed are in sensitive area number 1. Agricultural areas between the woods and Pigeon Lake would receive more runoff if the woods were developed or significantly impacted. A secondary effect of the agricultural areas receiving increased runoff would be water quality impacts to both Pigeon and Little Pigeon Lakes. Other wooded areas include the partially wooded shoreline of Little Pigeon Lake, an approximately 40 acre wood lot in and adjacent to sensitive area number 2, and other scattered small wood lots.

The 188 acres of grassland is the third largest land use in the watershed. This land use category includes lawns, pasture, abandoned agricultural fields, cleared woodlands, and small areas of unused land. Grasslands areas are important for bird nesting and provides habitat for small mammals and rodents. Grasslands also act as filters of runoff and help stabilize the soil.

Comprising 11.4 percent of the watershed is 179 acres of wetlands. Until recent times the phrase "wetlands are wastelands" was commonly heard. Wetlands are now labeled "vital resources" which have been lost over years of filling and draining. Wetlands are very biologically productive and provide good wildlife habitat. Wetlands also act as natural filters and sponges in the water cycle, purifying water and holding water in times of flooding. The U.S. Environmental Protection Agency (EPA) has stated that about 35 percent of all plants and animals that are listed as threatened or endangered in the U.S. live in wetlands or rely on them in some way. The WDNR reports 32% of Wisconsin's threatened and endangered plants and animals are wetland dependent. The highest concentration of wetlands in the watershed is northeast of Pigeon Lake.

Developed land covers about 10 percent of the watershed. Residential homes, farmsteads, roads, the gravel pit, and the new golf course are included under the category developed land. Residential development along the shoreline and other farm and single family homes account for most of the developed area.

Pigeon Lake is 80 acres in size, or 5.1 percent of the watershed, with a volume of 1715 acre feet and 1.6 miles of shoreline. Little Pigeon Lake is about 8 acres in size and represents the smallest land use area in the watershed (0.5 percent). The shoreline of Little Pigeon Lake measures approximately 0.5 miles.

4.3.3 Phosphorus Loading

As discussed earlier, the larger the watershed, the larger the impact on the lake. This effect can be illustrated by examining the phosphorus loading in a watershed. Different land uses are assigned loading values based on criteria developed by Mr. John Penusca at the WDNR Non-Point Source Section in Madison. The "most likely" general phosphorus loading values for associated land use types are as follows:

Agriculture:	0.5 kg/ha-yr
Forest:	0.1 kg/ha-yr
Urban:	1.0 kg/ha-yr
Open grassland:	0.3 kg/ha-yr
Wetland:	0.1 kg/ha-yr
Precipitation:	0.3 kg/ha-yr

The table below presents the estimated values for phosphorus loading in the Pigeon Lake watershed by land use type. Loading values are presented in kilogram of phosphorus per hectare per year (kg/ha-yr) for each land use type. Total phosphorus is measured in kilograms per year (kg/yr). Phosphorus loading from precipitation is obtained by multiplying the loading value for precipitation by the surface areas of the lakes.

PHOSPHORUS LOADING IN THE PIGEON LAKE WATERSHED

LAND USE (type)	LOADING VALUE (kg/ha-year)	AREA (hectare)	TOTAL P-LOADING (kg/year)
Lake	0.3	32.1	10.7
Wetlands	0.1	72.4	7.2
Woodlands	0.1	134.7	13.5
Grasslands	0.3	76.08	22.8
Agricultural	0.5	252.53	126.3
Developed	1.0	63.53	63.5
TOTAL		**631.25**	**244.0**

The land use that contributes the largest portion of the phosphorus loading in the watershed is agricultural land. Increasing Best Management Practices (BMP) on agricultural lands will help reduce phosphorus (and other nutrient and pollutant) loading in the watershed. The second largest contributor is developed land. Even though developed land only accounts for about 10 percent of the land area, it contributes 26 percent of the phosphorus loading. The loading value for developed land is the highest at 1.0 kg/ha-yr. Developed land is mostly impervious, resulting in high runoff coefficients, and also has special land use practices. Some of these practices include application of pesticides and fertilizers, pet wastes, yard wastes, road salt, and automotive pollutants. BMPs have also been created for urban (developed) lands which can be implemented by home and business owners to reduce water quality impacts in the watershed.

4.4 Vegetation Survey

The vegetation of Pigeon Lake and Little Pigeon Lake were surveyed. The results of this survey are listed in Appendix B. Pigeon Lake exhibits medium species diversity and moderate productivity. Little Pigeon Lake exhibits medium diversity with high productivity. A total of 23 plants were identified, 22 to the species level (References 9, 10, 11). The most abundant genus is Potamogeton (pondweed), with six species represented. Milfoil was present at 100 percent of the sample points. Milfoil was found growing at a maximum depth of 28 feet, other plants were observed growing at 20 feet include Najas and Nitella. The growth patterns and population levels of milfoil suggest that the non-native Eurasian milfoil was present. Thirty-three percent of the transects with milfoil were Eurasian milfoil, while the other 67 percent were Northern water milfoil. Milfoils provide fish cover and supports insects for food, but do not provide much value for wildlife. Chara vulgaris was the second most abundant species occurring at 83 percent of the sample points. This species is beneficial to wildlife as food, and supports insects which are valuable food for fish. In general, the aquatic plant communities of Pigeon and Little Pigeon Lakes are fair food sources for wildlife and benefit fish by providing food, cover, and spawning habitat. However, a large population of purple loosestrife in Little Pigeon Lake may de-stabilize the food chain.

No federal or state-designated threatened or endangered species were observed during the vegetation surveys. Most state designated threatened and endangered species listed for Manitowoc County are found in the coastal zone along Lake Michigan.

4.5 Bathymetric Map Revision

During June 1995, Northern Environmental examined the bathymetric, or bottom topography, and water depths of Pigeon Lake. Significant findings include a change in the maximum depth of 68 feet and remapping the location of the "Deepest Hole," the "Camp Bay," and the "Island Peninsula;" location of drainage culvert; and mapping of additional submergent and emergent vegetation. All of these changes are depicted on the revised bathymetric map (Figure 5). Based on this information, it appears that the first bathymetric mapping was not as accurate as the revision, meaning the lake did not get deeper but that the first mapping did not measure the depth accurately.

4.6 Public Opinion Survey

In July 1993, an opinion survey was distributed to the residents of Pigeon Lake. A total of 52 surveys were returned, representing about 65 percent of the waterfront owners. The most

important findings of the survey are presented below. A complete analysis of the survey is available. A sample survey can be found in Appendix C.

- Nuisance aquatic vegetation and water quality degradation are of greatest concern to respondents
- Appreciation of peace and tranquility is the most important reason for purchasing property on a lake
- Clear water and good water quality were how the most respondents view the lake

Generally, the residents feel their lake has fair to good water quality and needs a long-term Lake Management Plan to address the issues effecting Pigeon Lake.

5.0 CONCLUSIONS

Pigeon and Little Pigeon Lakes' physical and chemical characteristics indicate that water quality was good during the 1993 to 1995 study. Average values for nutrient concentrations in Pigeon Lake are below levels which would indicate algal blooms. However, Little Pigeon Lake does have an average total phosphorous concentration which would support occasional algal blooms. The probable source of the excess nutrients in Little Pigeon Lake is the bottom sediments, which are mostly organic muck. The shallow depths in Little Pigeon allows mixing which causes nutrients from the bottom to be released. Other typical nutrient sources for lakes include agricultural runoff and roadway runoff which contains nitrogen, phosphorous, and chlorides. Residential stormwater, agricultural runoff, roadway runoff, increases in impervious land area, septic leachate, sedimentation, and even boating can contribute to cultural eutrophication.

The amount of nutrients and sediments entering Pigeon and Little Pigeon Lake has increased from cultural influences. A watershed once consisting of mature conifer-hardwood forests is now almost 42 percent cropland. An undeveloped natural pre-settlement shoreline is now 70 percent developed. Pigeon Lake and Little Pigeon Lake have total phosphorous levels, secchi disk depths, and chlorophyll a levels which place them in the mesotrophic category of the trophic classification scheme (Appendix D).

Mechanical harvesting provides short-term relief from an aquatic macrophyte problem. Long-term management strategies include dredging, water level drawdown, shading/sediment covers, and biologic controls. Dredging and shading/sediment covers are both expensive management methods, costing between $1,000.00 and $10,000.00 per acre not including dredge disposal costs or cover application costs (Reference 13). Negative impacts of dredging include site disposal problems related to discharging nutrient rich sediment which may contain heavy metals and other toxic compounds. Prior to dredging, the sediment should be chemically analyzed, which can be costly. Chemical composition of sediments can cause increased disposal costs. Even though sediment covers are costly, they have few negative impacts. Sediment covers are natural or synthetic barriers which limit light from reaching sediments and prevent plants from rooting. Temporary damage to benthic invertebrates is unavoidable. Other aquatic management techniques include drawdowns and biologic controls. Water level drawdowns are effective for aquatic plant control, but they are based on exposing large areas of lake bed along the shore. Many residents would be opposed to this based on aesthetics and limits placed on recreation. Drawdowns need to occur during successive freezing and drying periods which damage plants, their roots, and seeds. Biologic aquatic plant controls using the aggressive grass carp are prohibited in Wisconsin and aquatic insects are restricted to warm weather southern lakes. Drawdowns and biologic controls probably would not be effective management techniques for Pigeon Lake.

An experimental sediment cover plan could be implemented for Little Pigeon Lake. Covers could be applied to areas in the lake void of emergent vegetation. There are no disposal requirements or aesthetic impacts associated with sediment covers. A small area should be selected for application and monitored for success. Following monitoring, an assessment should be completed to determine the long-term feasibility of this management technique for Little Pigeon Lake. Typar costs about $3,500.00 an acre, has a low application difficulty rating, and is considered effective (Reference 13).

Wetlands serve as open spaces increasing the aesthetics and natural beauty of a lake. Many public survey respondents indicated that peace and tranquility are very important to lake front owners. To assure that present levels of wildlife, water quality, and aesthetics are maintained, steps should be taken to conserve the wetlands in the watershed. These wetland sensitive areas act as natural buffers to human activities and impacts. The wetlands around Pigeon Lake filter sediments and nutrients from runoff that enters the lake.

Achieving stability and improving water quality can be accomplished by implementing the recommended Lake Management Plan. Not all of the recommendations need to be implemented, but all of them will provide benefits for the lake and for the community.

6.0 RECOMMENDATIONS: LAKE MANAGEMENT PLAN

Lake planning projects should present recommendations in a Lake Management Plan (Table 4). Creating a long-term management plan is also important to Pigeon Lake residents, as expressed in the public opinion survey. Management recommendations take into account effectiveness, negative effects, and costs. Effectiveness relates to longevity of the management technique, probability of success, and whether or not the technique addresses the cause of the problem or the effect of the problem. Management techniques are divided into watershed management and in-lake management techniques (Reference 13). Watershed management techniques focus on watershed-wide issues such as agricultural and rural point and non-point source pollutants. In-lake management techniques focus on lake physical issues like nuisance aquatic plants, algal blooms, and fisheries; and policy issues like recreational uses and zoning ordinances.

6.1 Watershed Management Techniques

Continuing and increasing use of BMPs in the Pigeon Lake watershed are the most effective methods for controlling non-point source pollutants. Implementation costs vary greatly between management techniques, however, most are eligible for cost-sharing under WDNR NR 120. A list of BMPs can be found in Table 5 (Reference 6).

Preserving the unprotected western wetland area in the "Camp Bay" area will allow this wetland to continue acting as a buffer for Pigeon Lake. Purple loosestrife growing in the wetlands along the shoreline of Little Pigeon Lake should be removed by hand pulling and spot treatment with Rodeo then reseeded with valuable wetland plants. Developing the wooded areas west of Pigeon Lake would also have negative effects on water quality, and should be discouraged. An option is to zone the land as "conservancy" so that the land is taxed less and the owner has less incentive to develop the land. Purchasing of sensitive areas would be eligible for 75 percent project funding up to $100,000.00 under the WDNR Lake Protection Grants. An assessment could be performed to determine the exact size and functional values of the land. This assessment would be used to supplement the application for the grant. Because these sensitive areas provide protection of water quality, compliments BMPs in the watershed, and protects the natural ecosystem, this project is a good candidate for a grant. The 1994-95 fiscal budget for this grant program is over $1.3 million (Reference 14).

A WDNR publication titled *Life on the Edge...Owning Waterfront Property* should be distributed to all Pigeon Lake home owners. This publication describes to the layperson terms, issues, and regulations regarding purchasing and owning waterfront property. It also provides information on improving shoreline habitat and water quality for new and existing homes. At a cost of about $5.00 per publication, all lake home owners could receive a copy for about $400.00.

6.2 In-Lake Management Techniques

Mechanically harvesting aquatic plants (i.e., Milfoil) is one short-term management techniques. Harvesting reduces the amount of nutrients being recycled in the lake over winter. This management technique provides only a temporary solution to the aquatic plant problem. One

TABLE 4

LAKE MANAGEMENT PLAN

I. WATERSHED MANAGEMENT TECHNIQUES

Implement Best Management Practices

Sensitive Area Preservation

Distribute Educational Materials: *Life of the Edge* (WDNR Publication)

II. IN-LAKE MANAGEMENT TECHNIQUES

Physical:

- Assess feasibility of aquatic plant harvesting
- Experimental sediment covers
- Create fish management plan: Survey and Assessment
- Appoint a volunteer to monitor Pigeon Lake's physical parameters
- Improve swim areas: pea gravel blankets (WDNR permits)
- Create boat traffic lanes with buoys and Boat Launch Education Board
- Purple loosestrife control program

Policy:

- Form recreational use committee
- Form exotic species control committee
- Create zoning committee

Table 5 Wisconsin Best Management Practices (from NR 120)

Cropland Practices:

- Change in crop rotations
- Change from cropland to grassland
- Contour cropping
- Strip cropping
- Field diversions
- Terraces
- Grassed waterways
- Reduced tillage
- Nutrient management
- Pesticide management

Cropland, Urban, and Other Area Practices:

- Critical area stabilization
- Grade stabilization structures
- Shoreline and streambank protection (including fish structures)
- Shoreline buffers
- Wetland restoration
- Livestock exclusion from woodlots
- Well abandonment

Animal Waste Management Practices:

- Manure spreading management
- Barnyard runoff management
- Animal lot relocation
- Manure storage facilities
- Roofs for barnyard runoff management and manure storage facilities
- Manure storage ordinances

Urban Practices:

- Street sweeping
- Leaf collection
- Pet waste ordinances
- Construction site erosion control ordinance
- Infiltration basins
- Infiltration trenches
- Porous pavement
- Grassed swales
- Wet basins
- Detention basins
- Wetland basins
- Covering materials being stored

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goal of implementing this technique is to reduce the total biomass in the lake prior to ice over. The most beneficial effect of harvesting is increased aesthetics. A study should be performed to determine the feasibility of implementing mechanical harvesting.

Sediment covers are a longer term management technique for controlling aquatic plant growth and reducing sediment disruption. Sediment covers are placed on the bottom of the lake to prevent aquatic plants from rooting by limiting sediment exposure to sunlight. Sediment covers are most effective in shallow lake areas such as Little Pigeon Lake. A one-acre test plot should be set up using a polypropyl synthetic material (trade name Typar) at a cost of $3,500.00 an acre for materials, and about $1,500.00 for installation. The cost of dredging about three feet of sediment over an acre of the lake would cost about $190,000.00 (not including dredge disposal costs), while the cost of sediment covers for eight acres would be about $30,000.00 (not including installation cost). Large sediment covers projects may have a negative effect on the ecology of the lake and as a result, Northern Environmental would recommend that the covered area be limited to exclude near shore areas. Both dredging and covering can be considered effective for about ten years (Reference 13). The cost of mechanical harvesting about eight acres for ten years is approximately $10,000.00, not including the $75,000.00 cost of the harvester or the cost of completing a WDNR required aquatic plant management plan.

Fisheries are an important part of lake systems. Not only do they provide recreation as sport fishing, but they also directly relate to a lake's productivity. More eutrophic lakes have larger fish populations but also have more rough fish, like carp. The first step in a fish management plan is to conduct a survey of the fish population so that it can be assessed. The United States Fish and Wildlife Service and the WDNR should be contacted for information on funding. Fish survey techniques like shocking and netting can be used to sample the population, and after an assessment and plan is approved, management implementation can proceed. In the past, Pigeon Lake was stocked with a number of different species. A fish management plan would select one specie to stock that is the most viable. A fish management plan for mesotrophic lakes, like Pigeon Lake, may involve hypolimnetic aeration, artificial reefs, aquatic plant control, and fish removal or stocking. The survey could be funded by a grant under a second Lake Management Planning Grant.

The PLA should appoint a lake monitor volunteer to routinely monitor the lake's physical water quality. The WDNR can provide information and equipment for the volunteer through the WDNR Self-Help Lake Monitoring Program. This will provide long-term data which helps evaluate the effectiveness of management techniques.

Pea gravel blankets are used to improve a streambank or lake shoreline conditions under Chapter 30 of the WDNR Natural Resource law. Each riparian land owner can apply for a permit to place a maximum of six-inches of pea gravel in a 1250-foot square area on the bed of a navigable waterway. Areas which have emergent vegetation, fish spawning habitat, or more than six inches of muck, will not be issued permits by the WDNR.

Installing buoys and establishing boat traffic lanes would further reduce recreational use conflicts. Traffic lanes would also identify priority areas which need to be managed for aquatic plant growth and sediment disturbance to maximize recreational boating. Boating lanes would foster access to deep water areas reducing sediment disturbance from boating in shallow areas. Detailed information regarding Eurasian milfoil, Zebra mussels, and purple loosestrife should be displayed at the public boat landing. Funding would be provided by the PLA and the Pigeon Lake Sanitary District (PLSD) or could be incorporated to the second Lake Management Planning Grant as part of an educational program.

A purple loosestrife, Lythrum salicaria, control program should be implemented to stop the spread of the existing plants and reduce the existing population. Hand spraying with herbicide and hand pulling of entire plants will, if implemented properly, effectively reduce the population of purple loosestrife in Little Pigeon Lake. The type, rate, time of year, and method of herbicide application is critical to the success of the program.

The Sanitary District should create committees to address recreational use, exotic species control, and county zoning laws. All committees should be composed of volunteers with an appointed non-paid committee chairperson. The recreational use committee can produce a lake-use map and monitor disputes between lake users, in an effort to reduce conflict. The exotic species control committee should monitor progress of purple loosestrife control, the eurasian milfoil population, and monitor for the presence of zebra mussels. Non-native species can cause serious ecologic problems for lakes, like purple loosestrife is doing in Little Pigeon Lake. The sooner populations are identified, the better the chance to control them. Zoning changes can be monitored by a land use committee that attends county zoning meetings and rezoning cases. Monitoring policy issues in a lake community is important for understanding, implementing, and assessing management techniques.

6.3 Funding

Funding for BMPs will be available through the Pigeon River Priority Watershed Project on a cost share basis if the project is successfully petitioned during the 1996 through 1997 grant year. The PLA should apply for a second Lake Management Planning Grant to complete an aquatic management plan and perform limited chemical analysis of the water quality. The sanitary district should also apply for the WDNR Lake Protection Grant. Lake Protection Grants are available for purchasing land or easements, restoring wetlands, and developing local regulations to protect water quality. Purchasing the western woodlands, experimenting with sediments covers, forming boating lanes, and enhancing the educational information at the boat launch could all be funded under a Lake Protection Grant. Protection grants fund 75 percent of project costs up to $100,000.00. Costs for distributing WDNR educational materials, totaling $400.00, should be covered by the PLSD.

Pea gravel blankets are low-cost small-scale methods to enhance shorelines. Many residents use them to improve swimming areas. Permits must be obtained by the WDNR to install a pea gravel blanket. There are no WDNR grants available to fund pea gravel blankets. All costs incurred must be paid by the land owner applying for the permit.

Funding for the purple loosestrife control program could be raised through donations, a fund raiser, or a special fee attached to annual dues for members of the PLA. Northern Environmental can provide services and technical expertise for the program if the PLA or PLSD chooses to implement this management technique.

The remaining management techniques are volunteer positions. The volunteer lake monitor will be a part of the WDNR Self-Help Lake Monitoring Program. Equipment for monitoring is provided by the WDNR. Volunteer committees should be formed to monitor issues in the watershed. Both the lake monitor and the volunteer committees should be lake enthusiasts and members of the PLA. This may increase membership and strengthen the association by having members more involved and by addressing recreational use and zoning issues.

Northern Environmental can provide services to apply for another Lake Management Grant and for a Lake Protection Grant. Both grant programs are WDNR funded.

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APPENDIX A

INVESTIGATIVE METHODS

Investigative Methods

Chemical and Physical Analysis

All water samples for chemical analysis were collected with a Kemmerer sampling bottle. Laboratory tests were performed by the Wisconsin Department of Natural Resources (WDNR) certified State Lab of Hygiene to meet requirements prescribed in the lake planning grant. Samples were taken one meter below the lake's surface and one meter above the lake's bottom in the deepest portion of the lake. Sample depths and location were chosen to reflect the entire water column, including the photic and anoxic zones. Chemical parameters for sampling are listed and described below.

A. Phosphorous: Phosphorous is usually the compound regulating algae and aquatic macrophyte growth. Phosphorous is available in two forms, soluble and particulate (total phosphorous). The soluble form is dissolved and readily available for uptake by floating and suspended plants. Total phosphorous is useful to plants with root systems absorbing nutrients from the sediments. Total phosphorous is considered a better indicator of a lake's nutrient status than soluble phosphorous because its level is more stable than soluble reactive phosphorous, which can vary in concentration over short time periods.

B. Nitrogen: Nitrogen is another nutrient limiting the growth of aquatic plants, second in importance to phosphorous. Nitrogen can be found in lakes in many forms including nitrate, nitrite, ammonium, and Kjeldahl nitrogen. Nitrite is usually present in trace quantities, and is readily transformed to nitrate in oxygenated water. The inorganic nitrate and ammonium forms are most beneficial to plants and algae. Sources from which nitrogen can enter a lake include precipitation, which can have concentrations of nitrogen as high as 0.5 milligrams per liter (mg/l), and breakdown of organic tissues. However, concentrations of nitrogen found in surface waters are usually related to human activities within the watershed. Manmade sources of nitrogen include agricultural wastes, fertilizers, and human sewage. If the ratio of total phosphorous to total nitrogen is more than 15 to 1, the nutrient system is considered phosphorous limited.

C. Chlorophyll *a*: Chlorophyll *a* is a green pigment present in all green plant life which is vital for photosynthesis. The levels of chlorophyll *a* relate directly to the amount of algae present. The concentrations are expected to be highest during summer months with increased photosynthesis. High chlorophyll *a* results are associated with algae blooms and eutrophic lakes.

D. Alkalinity: Alkalinity is an indicator of the buffering capacity and susceptibility to acid rain. Laboratory analysis quantifies carbonates (HCO_3) and bicarbonates (CO_3) present in the water. Most Northern Wisconsin lakes are set in glacial deposits composed of quartz, sand, and other insoluble minerals which contain little limestone resulting in low alkalinity, while Southeastern lakes have higher alkalinity levels due to the dolomite bedrock.

E. pH: pH is an expression of the negative logarithm of hydrogen ion (H^+) concentration. pH is measured on a scale of 1 to 14 with pH values above 7 considered alkaline (less H^+ ions), below 7 acidic (more H^+ ions), and 7 neutral. Alkaline waters buffer against acid rain. Acid rain entering the lake will have the effect of lowering the lake's pH level, bringing it closer to neutral and thus reducing the lake's acid rain buffering capacity. pH was measured using a Cole-Parmer hand held pH meter, calibrated to pH ten and pH seven. Measurements were taken one meter below the surface and one meter above the bottoms.

Physical analysis parameters include dissolved oxygen content, temperature, conductivity, and transparency. Dissolved oxygen and temperature profiles were gathered using a Yellow Springs Instrument Model 59 meter. Measurements were recorded at one foot intervals in the deepest part of the lake. Conductivity readings were taken from samples one meter below the surface and one meter above the bottom using a Cole-Parmer hand held TDS Test-3™ calibrated to 700 μohms per centimeter (μohms/cm). Transparency was measured using a standard secchi disk or the shaded side of the sampling boat. Readings are an average of the depth at which the disk disappeared and reappeared.

Watershed Analysis

A watershed boundary was delineated using a United States Geological Survey (USGS) 7.5 minute topographic map and the quarter-quarter section direction of flow method. Information was compared with soils data from the Soil Conservation Service's soil survey of Manitowoc County and confirmed in the field. Field investigations were also performed to identify areas of steep slopes, non-point source pollution, and wetlands.

Vegetation Surveys

The vegetation survey of Pigeon and Little Pigeon Lake was performed using the Jensen and Loud method for surveying aquatic plants. The actual survey was completed during August 1994. A representative specimen was collected and placed on ice in a cooler for transportation. Each specimen was identified to specie level and mounted and preserved on herbarium paper for future reference. Various dichotomous keys and technical publications were used to classify the specimens.

With the information gathered from the preliminary inventory, the actual aquatic macrophyte survey was conducted on August 3 and 4, 1994. A base map was developed with twenty transects distributed around the perimeter of Pigeon Lake and Little Pigeon Lake. The transects extended perpendicular to the shoreline a distance calculated by dividing the total shoreline length by the number of established transects. The length of each transect was either the calculated distance or near the distance from the shoreline to the maximum rooting depth determined by the following equation:

$$\text{maximum rooting depth (feet)} = 2.73 + 1.22\ (\text{means secchi disk depth in feet})$$

The latitude and longitude at the intersection of the shoreline and transect were measured with a Magellan Global Position System. A Silva compass was used to determine transect bearings. The transects proceeded in the direction of the established bearing. The following measurements were recorded at the end point of each transect:

- Distance to the starting point (the shoreline)
- Latitude and longitude
- A compass bearing back to the starting point

Along each transect, a ten-foot diameter circle was randomly selected in each of the corresponding depth ranges:

Depth Code	Actual Depth Range (ft)
1	0.0 - 1.75
2	1.76 - 5.0
3	5.1 - 10.0
4	10.1 - 20.0
5	>20.1

The circle was subdivided into four quadrants. A density rating was determined for each quadrant visually or with a modified rake. In areas where the bottom could be clearly observed (i.e., in water less than 1.75 feet), visual means were used. A dragging test was necessary to correlate visual and rake density ratings. The test was performed in shallow water to determine how much plant matter would be collected by the teeth of the rake. A rake with an extended handle was used in depths too great for visual observations. The rake was thrown into each quadrant, allowed to settle, and was slowly retrieved with a rope. A density rating, based on the following criteria, and observations regarding substrate type, were recorded along with the depth in feet.

Bathymetric Map Revision

During June 1995, depths to bottom in Pigeon Lake were measured. Depths were measured using a grid method and two sonar depth finders.

Depths measured were compared to the WDNR Lake Survey Map for Pigeon Lake. The boat was driven along transects and differences noted between the sonar read out and the existing WDNR bathymetric map. Significant differences were noted and changes made to the bathymetry. The sonar's precision was checked with a standard 100 foot tape measurer at the deepest point of Pigeon Lake. The sonar read 68 feet and the tape measurer read 68 feet.

Public Opinion Survey

During 1993, a public opinion survey was conducted by Northern Environmental Technologies, Incorporated (Northern Environmental). All Pigeon Lake residents were sent a questionnaire. The survey was intended to produce results which would reveal local issues regarding Pigeon Lake and the surrounding environment. Thirty-five questions were asked pertaining to perceived water quality, recreational activities, access, lake use patterns, and opinions on problems facing the lake.

Lake Management Plan

The Lake Management Plan was created by comparing public opinion with physical characteristics of the lake. A plan of the lake should set goals for preserving the natural integrity of the lakes without limiting, and even enhancing, expectations or use by the local residents. Goals were selected and ranked by weighing the cost of implementation against local support for or against a given goal.

APPENDIX B

PIGEON AND LITTLE PIGEON LAKE AQUATIC MACROPHYTE SURVEYS

AQUATIC PLANT SPECIES PRESENT IN PIGEON LAKE
AUGUST 3 and 4, 1994 AQUATIC MACROPYHTE SURVEY

COMMON NAME	SCIENTIFIC NAME
HARD-STEM BULRUSH	SCIRPUS ACUTUS
THREE-SQUARE RUSH	SCIRPUS AMERICANUS
WHITE WATER LILY	NYMPHAEA ODORATA
YELLOW WATER LILY	NUPHAR VARIEGATA
BROAD LEAVED CATTAIL	TYPHA LATIFOLIA
LARGE LEAVED PONDWEED	POTAMOGETON AMPLIFOLIUS
RICHARDSON'S PONDWEED	POTAMOGETON RICHARDSONII
SAGO PONDWEED	POTAMOGETON PECTINATUS
CRISPY LEAVED PONDWEED	POTAMOGETON CRISPUS
COMMON PONDWEED	POTAMOGETON NATANS
NORTHERN WATER MILFOIL	MYRIOPHYLLUM EXALBESCENS
EURASIAN WATER MILFOIL	MYRIOPHYLLUM SPICATUM
WATER CELERY	VALLISERIA AMERICANA
SLENDER NAIAD	NAJAS FLEXILIS
FILAMENTOUS ALGAE	(CLADOPHORA, SPIROGYRA)
MUCKGRASS	CHARA JULGARIS
STONEWORT	NITELLA FLEXILIS

▲ Northern Environmental℠
Hydrologists • Engineers • Geologists

AQUATIC PLANT SPECIES PRESENT IN LITTLE PIGEON LAKE AUGUST 3 and 4, 1994 AQUATIC MACROPYHTE SURVEY

COMMON NAME	SCIENTIFIC NAME
HARD-STEM BULRUSH	SCIRPUS ACUTUS
WHITE WATER LILY	NYMPHAEA ODORATA
YELLOW WATER LILY	NUPHAR VARIEGATA
BROAD LEAVED CATTAIL	TYPHA LATIFOLIA
SAGO PONDWEED	POTAMOGETON PECTINATUS
CRISPY LEAVED PONDWEED	POTAMOGETON CRISPUS
FLAT-STEMMED PONDWEED	POTAMEGETON ZOSTERIFORMIS
NORTHERN WATER MILFOIL	MYRIOPHYLLUM EXALBESCENS
PURPLE LOOSESTRIFE	LYTHRUM SALICARIA
COONTAIL	CERATOPHYLLUM DEMERSUM
BLADDERWORT	URTICULARIA VULGARIS
PICKERELWEED	PONTEDERIA CORDATA
SHORT-BEAKED ARROWHEAD	SAGITARIA ENGELMANNIANA
FILAMENTOUS ALGAE	(ELADOPHORA, SPIROGYRA)