CROOKED LAKE AQUATIC PLANT MANAGEMENT PLAN STUDY 2011

Conducted pursuant to
PA 188 of 1954 as amended,
and the rules promulgated thereunder

***Prepared for*:**

Crooked Lake Texas Association
Texas Township
Kalamazoo County, Michigan

LAKESHORE ENVIRONMENTAL, INC.
SCIENTISTS • ENGINEERS • PLANNERS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

NAME	FIGURE

LIST OF TABLES

LIST OF APPENDICES

CROOKED LAKE AQUATIC PLANT MANAGEMENT PLAN STUDY REPORT TEXAS TOWNSHIP, KALAMAZOO COUNTY, MI

OCTOBER, 2011

1.0 EXECUTIVE SUMMARY

Crooked Lake may be classified as a natural lake with an area of approximately 146 acres by the Michigan Department of Natural Resources (MDNR). However, with an augmentation well operational, the water levels may increase the surface area to a digitized area of approximately 171 surface acres (Lakeshore Environmental, Inc., CAD estimates, 2011). Crooked Lake has a shoreline length of approximately 3.8 miles and is fairly elongated in shape. The lake can be geographically sub-divided into four distinctly different "basins" due to markedly unique aquatic vegetation communities that will require different management strategies for optimum success (Main Basin, Middle Basin, North Basin, and Hidden Cove Basin). Observed differences in these aquatic vegetation communities among basins are likely contributed to seed bank stock, sediment nutrition, and water depth. The maximum depth noted during the study was approximately 45 feet in the Main Basin, but a depth of nearly 50 feet has been recorded by the MDNR in the past. The fetch or the greatest distance across the lake has been greatly dissected due to the convoluted shape of the lake and thus the distance is only approximately 0.65 miles at the widest point. Based on the current study, Crooked Lake contains a total of 23 native aquatic plant species and a fair diversity of phytoplankton, which is the primary food source for zooplankton and forms the base of the food chain (i.e. primary producers). The high ratio of green algae (Division: Chlorophyta) and Diatoms (Division: Bacillariophyta) to Blue-Green algae (Division: Cyanophyta) is indicative of clean waters that support a rich fishery with 14 species of fish. Crooked Lake's overall water quality was measured as good.

However, Crooked Lake also contains 5 invasive aquatic plants including Eurasian watermilfoil (*Myriophyllum spicatum* L.), Curly-leaf Pondweed (*Potamogeton crispus*), Yellow iris (*Iris pseudacorus*), Starry stonewort (*Nitellopsis obtusa*), and Purple loosestrife (*Lythrum salicaria*), all of which threaten the biodiversity of the native aquatic macrophyte communities and decrease property values and have other consequences to the lake's ecosystem. In addition to these invasive aquatic plants, Crooked Lake also has the invasive Asian Clam (*Corbicula fluminea*), which is a self-fertilizing species that is small (< 3 cm in size), feeds on organic sediment materials and competes with native clam and snail populations for food resources.

For optimum management of the Crooked Lake ecosystem, Lakeshore Environmental, Inc. recommends that a whole-lake laminar flow aeration system be installed for the following reasons: 1.) the lake was found to have a substantial amount of organic matter that is contributing to the excessive submersed aquatic weed growth problem and increase in Asian Clam population throughout the lake, 2.) the lake exhibits a sharp decline in dissolved oxygen (thermal stratification) over the deep basin of the Main Basin with a dissolved oxygen level of nearly 0.7 mg L^{-1} beyond 25 feet during late summer, which is less than the 5.0 mg L^{-1} needed to sustain a warm-water fishery at depth, 3.) the inherent low dissolved oxygen levels in the deep basin will cause release of phosphorus from the lake bottom (measured to be approximately 50 mg L^{-1} at the bottom during time of sampling) when existing anoxic conditions are present and cause release of phosphorus from lake sediments which further increases submersed plant and planktonic algae growth throughout the lake.

2.0 AQUATIC ECOLOGY BACKGROUND INFORMATION

2.1 Introductory Concepts

Limnology is a multi-disciplinary field which involves the study of the biological, chemical, and physical properties of freshwater ecosystems. A basic knowledge of these processes is necessary to understand the complexities involved and how management techniques are applicable to current lake issues. The following terms will provide the reader with a more thorough understanding of the forthcoming lake management recommendations for Crooked Lake.

2.1.1 Lake Hydrology

Aquatic ecosystems include rivers, streams, ponds, lakes, and the Laurentian Great Lakes. There are thousands of lakes in the state of Michigan and each possesses unique ecological functions and socio-economic contributions (O'Neil and Soulliere 2006). In general, lakes are divided into four categories:

- Seepage Lakes
- Drainage Lakes
- Spring-Fed Lakes
- Drained Lakes

A brief discussion of each follows.

Some lakes (seepage lakes) contain closed basins and lack inlets and outlets, relying solely on precipitation or groundwater for a water source. Seepage lakes generally have small watersheds with long hydraulic retention times which render them sensitive to pollutants. Drainage lakes receive significant water quantities from tributaries and rivers. Drainage lakes contain at least one inlet and an outlet and generally are confined within larger watersheds with shorter hydraulic retention times. As a result, they are less susceptible to pollution. Spring-fed lakes rarely contain an inlet but always have an outlet with considerable flow. The majority of water in this lake type originates from groundwater and is associated with a short hydraulic retention time. Drained lakes are similar to seepage lakes, yet rarely contain an inlet and have a low-flow outlet. The groundwater and seepage from surrounding wetlands supply the majority of water to this lake type and the hydraulic retention times are rather high, making these lakes relatively more vulnerable to pollutants. The water quality of a lake may thus be influenced by the quality of both groundwater and precipitation, along with other internal and external physical, chemical, and biological processes. Crooked Lake receives all of its water from a groundwater source (via an augmentation well) and is considered a closed-basin system.

2.1.2 Biodiversity and Habitat Health

A healthy aquatic ecosystem possesses a variety and abundance of niches (environmental habitats) available for all of its inhabitants. The distribution and abundance of preferable habitat depends on limiting man's influence from man and development, while preserving sensitive or rare habitats. As a result of this, undisturbed or protected areas generally contain a greater number of biological species and are considered more diverse. A highly diverse aquatic ecosystem is preferred over one with less diversity because it allows a particular ecosystem to possess a greater number of functions and contribute to both the intrinsic and socio-economic values of the lake. Healthy lakes have a greater biodiversity of aquatic macro invertebrates, aquatic macrophytes (plants), fishes, phytoplankton, and may possess a plentiful yet beneficial benthic microbial community (Wetzel, 2001).

2.1.3 Watersheds and Land Use

A watershed is defined as an area of land that drains to a common point and is influenced by both surface water and groundwater resources that are often impacted by land use activities. In general, larger watersheds possess more opportunities for pollutants to enter the ecosystem, altering the water quality and ecological communities. In addition, watersheds that contain abundant development and industrial sites are more vulnerable to water quality degradation since from pollution which may negatively affect both surface and ground water. Since many inland lakes in Michigan are relatively small in size (i.e. less than 300 acres), they are inherently vulnerable to nutrient and pollutant inputs, due to the reduced water volumes and small surface areas. As a result, the living (biotic) components of the smaller lakes (i.e. fishery, aquatic plants, macro-invertebrates, benthic organisms, etc.) are highly sensitive to changes in water quality from watershed influences. Land use activities have a dramatic impact on the quality of surface waters and groundwater.

In addition, the topography of the land surrounding a lake may make it vulnerable to nutrient inputs and consequential loading over time. Topography and the morphometry of a lake dictate the ultimate fate and transport of pollutants and nutrients entering the lake. Surface runoff from the steep slopes surrounding a lake will enter a lake more readily than runoff from land surfaces at or near the same grade as the lake. In addition, lakes with steep drop-offs may act as collection basins for the substances that are transported to the lake from the land.

Land use activities, such as residential land use, industrial land use, agricultural land use, water supply land use, wastewater treatment land use, and stormwater management, can influence the watershed of a particular lake. All land uses contribute to the water quality of the lake through the influx of pollutants from non-point sources or from point sources. Non-point sources are often diffuse and arise when climatic events carry pollutants from the land into the lake. Point-source pollutants are discharged from a pipe or input device and empty directly into a lake or watercourse. Residential land use activities involve the use of lawn fertilizers on lakefront lawns, the utilization of septic tank systems for treatment of residential sewage, the construction of impervious (impermeable, hard-surfaced) surfaces on lands within the watershed, the burning of leaves near the lakeshore, the dumping of leaves or other pollutants into storm drains, and removal of vegetation from the land and near the water. In addition to residential land use activities, agricultural practices by vegetable crop and cattle farmers may contribute nutrient loads to lakes and streams. Industrial land use activities may include possible contamination of groundwater through discharges of chemical pollutants.

3.0 CROOKED LAKE PHYSICAL & WATERSHED CHARACTERISTICS

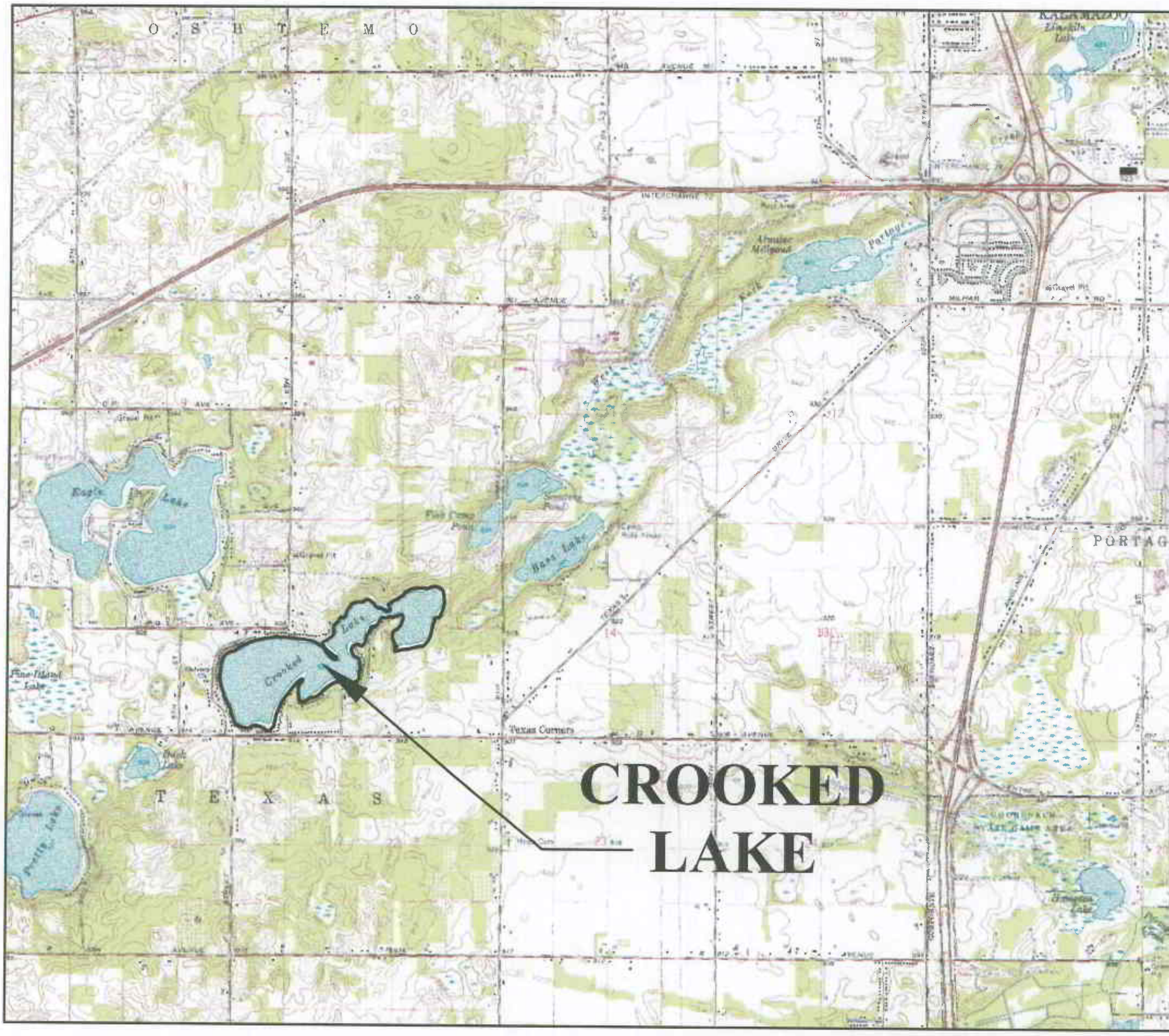
3.1 The Crooked Lake Basin

Crooked Lake is located in Sections 15 and 16 of Texas Township (T.3S, R.12W) in Kalamazoo County, Michigan (Figure 1). The lake has a surface area of approximately 171 acres (Lakeshore Environmental, Inc., 2011) and is classified as a eutrophic aquatic ecosystem with four "basins" (based on submersed vegetation characteristics, Lakeshore Environmental, Inc, 2011) and one deep basin with a maximum depth of approximately 45 feet (Figure 2). Crooked Lake has a lake shoreline of approximately 3.8 miles (Michigan Department of Natural Resources, 1999).

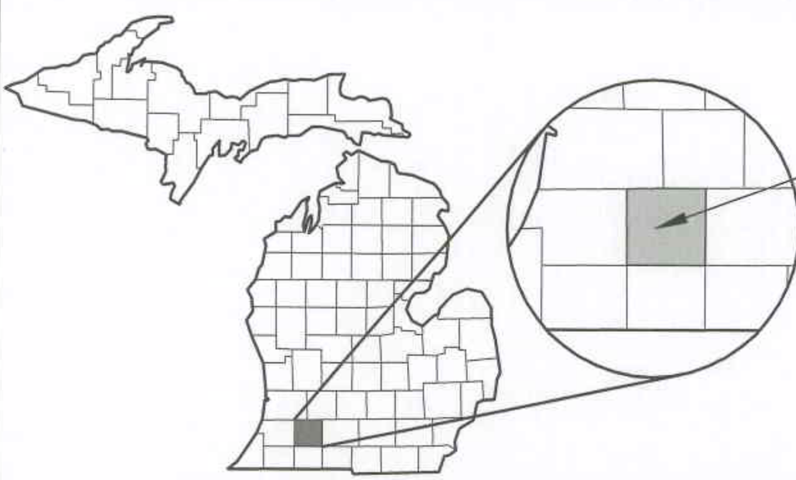
3.2 Crooked Lake Extended and Immediate Watershed

Crooked Lake is located within the Kalamazoo River extended watershed and measures approximately 2,020 mi^2 in area. It encompasses 8 counties including Allegan, Barry, Calhoun, Eaton, Hillsdale, Jackson, Kalamazoo, and Van Buren.

Crooked Lake's immediate watershed consists of the area around the lake which directly drains to the lake and measures approximately 660 acres in size (Figure 3). The immediate watershed is approximately 3.9 times larger than the size of the lake, which indicates the presence of a small watershed. There are no other lakes within Crooked Lake's immediate watershed. The small size of Crooked Lake's watershed means that the majority of the pollutants likely enter from surface runoff from impervious surfaces from lakefront development and also from nutrient inputs from the use of fertilizers or from storm events.



USGS 7.5 MINUTE QUADRANGLE
SCHOOLCRAFT NW, MICHIGAN 1979



0 4000' 8000'

SCALE: 1 INCH = 4000 FEET

LAKESHORE ENVIRONMENTAL, INC.

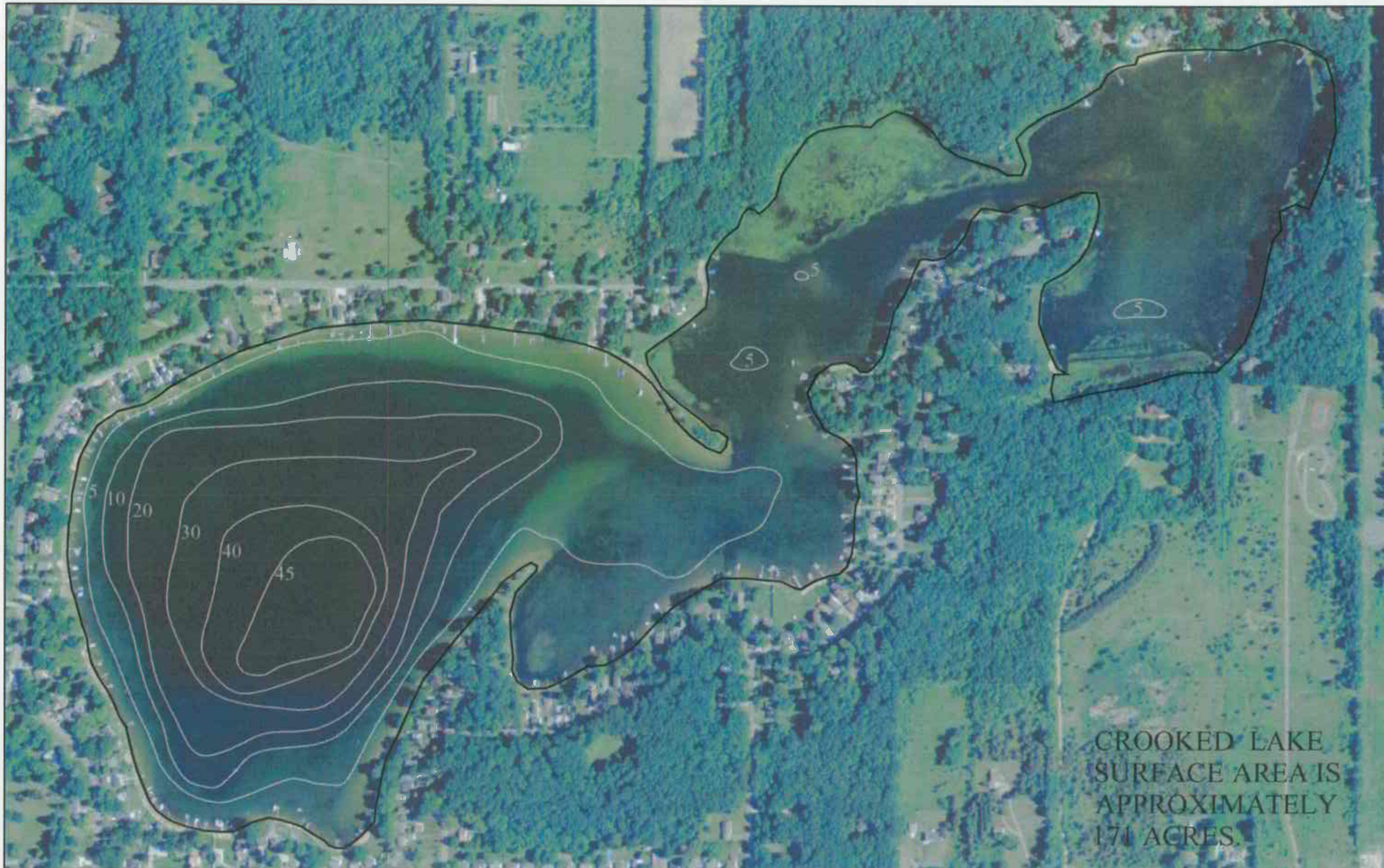
SCIENTISTS · ENGINEERS · PLANNERS

Grand Haven, Michigan | Hudson, Ohio

CROOKED LAKE
LOCATION MAP

TEXAS TOWNSHIP,
KALAMAZOO COUNTY, MICHIGAN

#11-1055	SEPTEMBER 12, 2011	FIGURE 1



ORTHOIMAGERY -
STATE OF MICHIGAN GEOGRAPHIC DATA LIBRARY, 2005.

0' 600' 1200'

SCALE: 1" = 600'

N

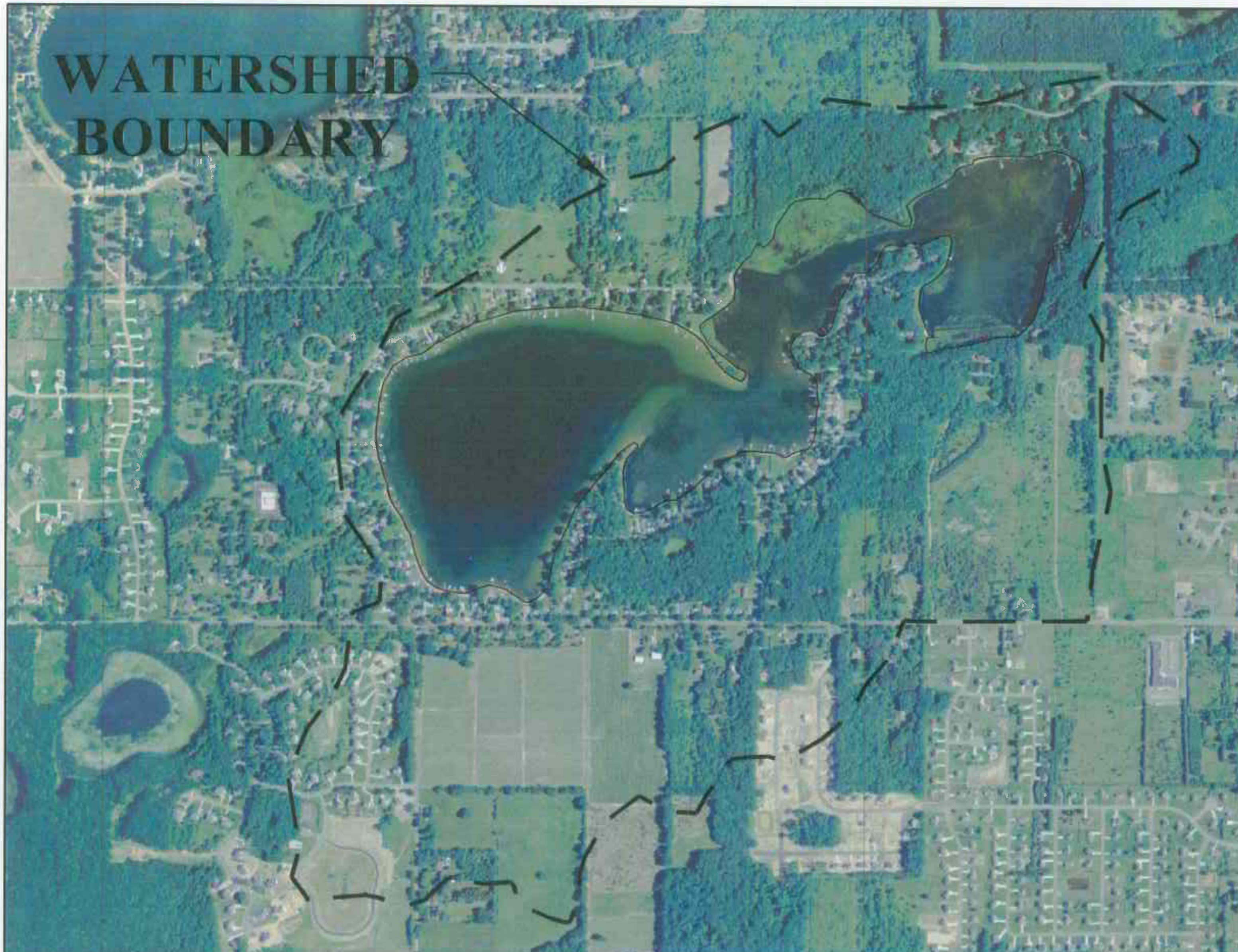
LAKESHORE ENVIRONMENTAL, INC.

SCIENTISTS • ENGINEERS • PLANNERS

CROOKED LAKE
DEPTH CONTOUR MAP

TEXAS TOWNSHIP,
KALAMAZOO COUNTY,
MICHIGAN

11-1055 | SEPTEMBER 20, 2011 | FIGURE 2



CROOKED LAKE WATERSHED IS APPROXIMATELY 660 ACRES.

ORTHOIMAGERY -
STATE OF MICHIGAN GEOGRAPHIC DATA LIBRARY, 2005.

0' 1200' 2400'
SCALE: 1" = 1200'

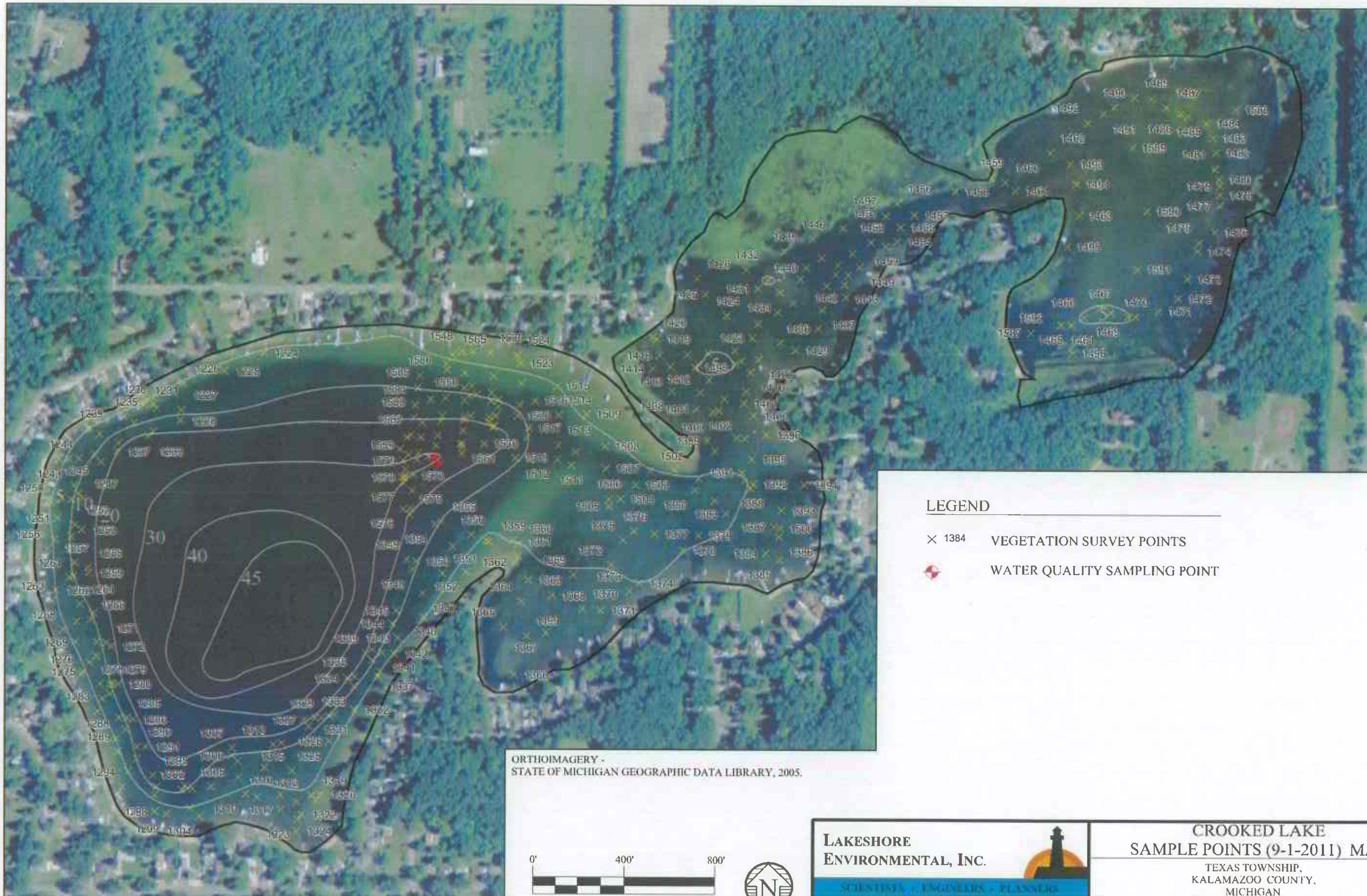
N

LAKESHORE ENVIRONMENTAL, INC.
SCIENTISTS • ENGINEERS • PLANNERS
Grand Haven, Michigan | Hudson, Ohio

CROOKED LAKE
WATERSHED BOUNDARY

TEXAS TOWNSHIP,
KALAMAZOO COUNTY,
MICHIGAN

# 11-1055	SEPTEMBER 20, 2011	FIGURE 3



ORTHOIMAGERY -
STATE OF MICHIGAN GEOGRAPHIC DATA LIBRARY, 2005.

LEGEND

× 1384 VEGETATION SURVEY POINTS

WATER QUALITY SAMPLING POINT

0' 400' 800'
SCALE: 1" = 800'

LAKESHORE ENVIRONMENTAL, INC.
SCIENTISTS · ENGINEERS · PLANNERS

CROOKED LAKE
SAMPLE POINTS (9-1-2011) MAP
TEXAS TOWNSHIP,
KALAMAZOO COUNTY,
MICHIGAN

# 11-1055	SEPTEMBER 20, 2011	FIGURE 4

4.0 CROOKED LAKE WATER QUALITY

Water quality is highly variable among Michigan's inland lakes, although some characteristics are common among particular lake classification types. The water quality of each lake is affected by both land use practices and climatic events. Climatic factors (i.e. spring runoff, heavy rainfall) may alter water quality in the short term; whereas, anthropogenic (man-induced) factors (i.e. shoreline development, lawn fertilizer use) alter water quality over longer time periods. Since many lakes have a fairly long hydraulic residence time, the water may remain in the lake for years and is therefore sensitive to nutrient loading and pollutants. Furthermore, lake water quality helps to determine the classification of particular lakes (Table 1). Lakes that are high in nutrients (such as phosphorus and nitrogen) and chlorophyll-*a*, and low in transparency are classified as **eutrophic**; whereas those that are low in nutrients and chlorophyll-*a*, and high in transparency are classified as **oligotrophic**. Lakes that fall in between these two categories are classified as **mesotrophic**.

Lake Trophic Status	*Total Phosphorus ($\mu g\ L^{-1}$)*	*Chlorophyll-a ($\mu g\ L^{-1}$)*	*Secchi Transparency (feet)*
Oligotrophic	< 10.0	< 2.2	> 15.0
Mesotrophic	10.0 – 20.0	2.2 – 6.0	7.5 – 15.0
Eutrophic	> 20.0	> 6.0	< 7.5

Table 1. Lake Trophic Status Classification Table (MDNR)

4.1 Water Quality Parameters

Parameters such as, but not limited to, dissolved oxygen, water temperature, conductivity, pH, total, total phosphorus, total Kjeldahl nitrogen, algal community (also chlorophyll-*a* concentrations), and Secchi transparency, respond to changes in water quality and consequently serve as indicators of change. During the study, Lakeshore Environmental, Inc. collected a preliminary water sample profile from the Main

Basin of the lake and also collected measurements from the other three "basins" within the lake. The results are discussed below and are presented in Table 2.

4.1.1 Dissolved Oxygen

Dissolved oxygen is a measure of the amount of oxygen that exists in the water column. In general, dissolved oxygen levels should be greater than 5 mg L^{-1} to sustain a healthy warm-water fishery. Dissolved oxygen concentrations may decline if there is a high biochemical oxygen demand (BOD) where organismal consumption of oxygen is high due to respiration. Dissolved oxygen is generally higher in colder waters. Dissolved oxygen is measured in milligrams per liter (mg L^{-1}) with the use of a dissolved oxygen meter and/or through the use of Winkler titration methods. The dissolved oxygen concentrations in Crooked Lake were plentiful in all of the smaller basins, but dropped sharply with depth in the Main Basin. Dissolved oxygen concentrations ranged between 8.7 mg L^{-1} at the surface and 0. 7 mg L^{-1} at the bottom during the early September sampling event. During the summer months, dissolved oxygen at the surface is generally higher due to the exchange of oxygen from the atmosphere with the lake surface, whereas dissolved oxygen is lower at the lake bottom due to decreased contact with the atmosphere and increased biochemical oxygen demand (BOD) from microbial activity. A decline in the dissolved oxygen concentration to near zero may result in an increase in the release rates of phosphorus (P) from lake bottom sediments.

4.1.2 Water Temperature

A lake's water temperature varies within and among seasons, and is nearly uniform with depth under the winter ice cover because lake mixing is reduced when waters are not exposed to the wind. When the upper layers of water begin to warm in the spring after ice-off, the colder, dense layers remain at the bottom. This process results in a "thermocline" that acts as a transition layer between warmer and colder water layers. During the fall season, the upper layers begin to cool and become denser than the warmer layers, causing an inversion known as "fall turnover". In general, shallow lakes will not stratify and deeper lakes may experience single or multiple turnover cycles. Water temperature is measured in degrees Celsius (ºC) or degrees Fahrenheit (ºF) with the use of a submersible thermometer. The water temperatures of Crooked Lake demonstrated the presence of a strong thermocline at a depth of 25.0 On the day of sampling, water temperatures ranged between 54ºF (at the bottom) and 77.5ºF (at the surface) at the main deep basin sampling location.

4.1.3 Conductivity

Conductivity is a measure of the amount of mineral ions present in the water, especially those of salts and other dissolved inorganic substances. Conductivity generally increases with water temperature and the amount of dissolved minerals and salts in a lake. Conductivity is measured in micro ohms per centimeter (μmho cm^{-1}) with the use of a conductivity probe and meter.

Conductivity values for Crooked Lake were consistent among sampling sites and similar to most healthy inland lakes in Michigan. Conductivity was consistent among sites and ranged between 299-358 μmho cm^{-1} for water samples among the sites. Baseline parameter data such as conductivity are important to measure the possible influences of land use activities (i.e. road salt influences) on Crooked Lake over a long period of time, or to trace the origin of a substance to the lake in an effort to reduce pollutant loading.

4.1.4 pH

pH is the measure of acidity or basicity of water. The standard pH scale ranges from 0 (acidic) to 14 (alkaline), with neutral values around 7. Most Michigan lakes have pH values that range from 6.5 to 9.5. Acidic lakes (pH < 7) are rare in Michigan and are most sensitive to inputs of acidic substances due to a low acid neutralizing capacity (ANC). pH is measured with a pH electrode and pH-meter in Standard Units (S.U). The pH of Crooked Lake water ranged from 7.9 – 8.3 during the study. It is not uncommon for lakes in the southern region of Michigan to possess pH values slightly higher than those of northern lakes due to the underlying geological features which help determine pH. From a limnological perspective, Crooked Lake is considered "slightly basic" on the pH scale.

4.1.5 Total Phosphorus

Total phosphorus (TP) is a measure of the amount of phosphorus (P) present in the water column. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. Lakes which contain greater than 0.020 mg L^{-1} of TP are defined as eutrophic or nutrient-enriched. TP concentrations are usually higher at increased depths due to the higher release rates of P from lake sediments under low oxygen (anoxic) conditions. The surface total phosphorus (TP) concentration for the Crooked Lake Deep Basin sampling site was < 0.010 mg L^{-1}. The middle depth total phosphorus concentration was < 0.010 mg L^{-1}. The bottom total phosphorus concentration was < 0.050 mg L^{-1}. Thus, the phosphorus concentrations in Crooked Lake are adequate at the bottom to cause some degree of internal loading and due to the lack of dissolved oxygen at the bottom, create favorable conditions for increased primary production (i.e. increased plant and algae growth).

4.1.6 Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), and organic nitrogen forms in freshwater systems. Much nitrogen (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. Nitrogen originates from atmospheric inputs (i.e. burning of fossil fuels), wastewater sources from developed areas (i.e. runoff from fertilized lawns), agricultural lands, septic systems, and from waterfowl droppings. It also enters lakes through groundwater or surface drainage, drainage from marshes and wetlands, or from precipitation (Wetzel, 2001). In lakes with an abundance of nitrogen (N: P > 15), phosphorus may be the limiting nutrient for phytoplankton and aquatic macrophyte growth. Lakes with a mean TKN value of 0.66 mg L^{-1} may be classified as oligotrophic, those with a mean TKN value of 0.75 mg L^{-1} may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg L^{-1} may be classified as eutrophic. Crooked Lake contains highly variable values for TKN (0.45 – 1.1 mg L^{-1}), although only the bottom of the main deep basin contained a TKN concentration of 1.1 mg L^{-1}. The N: P ratio for the main deep basin was 110 and thus would indicate that water column phosphorus was a limiting nutrient for phytoplankton or macrophyte growth at the time of sampling. In fact, most rooted aquatic plant communities derive the majority of their nutrients from the sediments and sediment pore water.

4.1.7 Algal Communities

The algal flora of the Crooked Lake ecosystem consisted primarily of the Chlorophyta (green algae), and the Bascillariophyta (diatoms). The waters of Crooked Lake are rich in the Chlorophyta (green algae), which are indicators of good water quality and also support a robust fishery. By contrast, blue-green algae (Cyanophyta) such as *Oscillatoria* sp., and *Microcystis* sp., are capable of producing microtoxins (Rinehart et *al*. 1994) that can cause neurologic or hepatic (liver) dysfunction in animals or humans if ingested in large quantities. Blue-green blooms are usually visible as a bluish tinted surface "scum layer" on lake waters when they are a threat and these areas should be avoided when obvious surface layer blooms are present. Fortunately, the quantity of these cells appeared low in the sample collected during the September 2011 study.

4.1.8 Secchi Transparency

Secchi transparency is a measure of the clarity or transparency of lake water, and is measured with the use of an 8-inch diameter standardized Secchi disk. Secchi disk transparency is measured in feet (ft) or meters (m) by lowering the disk over the shaded side of a boat around noon and taking the mean of the measurements of disappearance and reappearance of the disk. Elevated Secchi transparency readings allow for more aquatic plant and algae growth. Eutrophic systems generally have Secchi disk transparency measurements less than 7.5 feet due to turbidity caused by excessive planktonic algae growth. The Secchi transparency of Crooked Lake was approximately 10.5 feet over the main deep basin during the study which was collected during calm wind conditions under sunny skies at noon. This transparency is adequate to allow abundant growth of algae and aquatic plants in the majority of the littoral zone of the lake. Secchi transparency is variable and depends on the amount of suspended particles in the water (often due to windy conditions of lake water mixing) and the amount of sunlight present at the time of measurement.

4.1.9 Oxidative Reduction Potential

The oxidation-reduction potential (E_h) of lake water describes the effectiveness of certain atoms to serve as potential oxidizers and indicates the degree of reductants present within the water. In general, the Eh level (measured in millivolts) decreases in anoxic (low oxygen) waters. Low E_h values are therefore indicative of reducing environments where sulfates (if present in the lake water) may be reduced to hydrogen sulfide (H_2S). Decomposition by microorganisms in the hypolimnion may also cause the E_h value to decline with depth during periods of thermal stratification. The E_h (ORP) values for Crooked Lake ranged between 12.0 mV (at the bottom) and 131.6 mV (at the surface) throughout the depths of the Main Basin, and thus were within a normal range for Michigan lakes. Values were significantly lower (< 12 mV) near the sediments in the other three shallow basins, likely due to reduced conditions from microbial activity in thick organic deposits.

4.1.10 Sediment Organic Matter

Organic matter (OM) contains a high amount of carbon which is derived from biota such as decayed plant and animal matter. Detritus is the term for all dead organic matter which is different than living organic and inorganic matter. OM may be autochthonous or allochthonous in nature where it originates from within the system or external to the system, respectively. A total of 15 sediment OM samples were collected with an Ekman dredging sampler among the 4 basin sites and preserved on ice and taken to the laboratory for analysis with the ASTM D2974 method. The mean OM concentration (in %) for each basin is presented in Table 3 below. The quantity of organic matter was lowest in the Main Basin (mean value of 1.4%) and highest in Hidden Cove (mean value of 52.8%). The North Basin also contained a high mean percentage of 46.5% and the Middle Basin had a mean value of 12.5% which is average for most inland lakes. An example of sediments collected from a sandy lake would be that of White Lake (Muskegon County, Michigan) which had mean organic matter values of < 0.8% (Jermalowicz-Jones, MS thesis, *unpublished data, 2005*). Alternatively, Austin Lake in Kalamazoo County, was recently found to have a mean organic matter value of 46.9% in its South Basin (Lakeshore Environmental, Inc., November, 2010 study) which will be utilizing laminar flow aeration and bioaugmentation to reduce excessive layers of organic matter and reduce excessive submersed aquatic plant growth. Many factors affect the degradation of organic matter including basin size, water temperature, thermal stratification, dissolved oxygen concentrations, particle size, and quantity and type of organic matter present. There are two major biochemical pathways for the reduction of organic matter to forms which may be purged as waste. First, the conversion of carbohydrates and lipids via hydrolysis are converted to simple sugars or fatty acids and then ferment to alcohol, CO_2, or CH_4. Second, proteins may be proteolyzed to amino acids, deaminated to NH_3+, nitrified to NO_2- or NO_3-, and denitrified to N_2 gas.

Depth ft	*Water Temp °F*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*ORP mV*	*Total Kjeldahl Nitrogen mg L^{-1}*	*Total Phos. mg L^{-1}*
0	77.5	8.7	8.3	300	108.4	0.45	<0.010
15	75.9	7.8	8.2	299	131.6	0.69	<0.010
30	59.0	0.7	8.1	358	114.3	0.68	<0.020
45	54.0	0.7	7.9	342	12.0	1.1	<0.050

Table 2. Crooked Lake water quality parameter data collected over the Main Basin during September, 2011.

Crooked Lake Basin Site	*Sample Size (n)*	*Sediment Organic Matter %*
Main Basin	4	1.4
Middle Basin	4	12.5
North Basin	2	46.5
Hidden Cove Basin	5	52.8

Table 3. Crooked Lake organic matter data collected from The four "basins" during September, 2011.

4.2 Crooked Lake Fish Community

The Crooked Lake fishery has been previously documented (Michigan Department of Natural Resources, 2001) as a diverse warm-water fishery due to the single deep basin and overall shallow mean depth of the lake. The fish community consists of 14 species including Yellow Perch (*Perca flavescens*), Bluegill (*Lepomis macrochirus*), Pumpkinseed Sunfish (*Lepomis gibbosus*), Largemouth Bass (*Micropterus salmoides*), Northern Pike (*Esox lucius*), Rock Bass (*Ambloplites rupestris*), Bullhead Catfishes (*Ameiurus* spp.), Common Shiner (*Notropis cornutus*), Black Crappie (*Pomoxis nigromaculatus*), Golden Shiner (*Notemigonus crysoleucas*), Green Sunfish (*Lepomis cyanellus*), Lake Chubsucker (*Erimyzon sucetta*), the Creek Chubsucker (*Erimyzon sucetta*), and the Warmouth (*Lepomis gulosus*).
The Crooked Lake fishery will benefit from a diverse (yet balanced) native aquatic plant community, control of invasive aquatic plant and animal species, improvements to water quality, and abundance of submerged habitats (i.e. wood structures and native weed beds).

4.3 Crooked Lake Aquatic Vegetation Communities

An Aquatic Vegetation Assessment Site (AVAS) survey was conducted on Crooked Lake using the methods as defined by the Michigan Department of Environmental Quality (MDEQ). The AVAS Survey method was developed by the MDEQ to assess the presence and relative abundance of submersed, floating-leaved, and emergent aquatic vegetation within and around the littoral zones of Michigan lakes. With this survey method, the littoral zone areas of the lake are divided into lakeshore sections approximately 100 - 300 feet in length. The species of aquatic macrophytes present and relative abundance of each macrophyte are recorded onto an MDEQ AVAS data sheet. Each macrophyte species corresponds to an assigned number designated by the MDEQ. In addition to the particular species observed (via assigned numbers), a relative abundance scale is used to estimate the percent coverage of each species within the AVAS site (Table 4). If shallow areas are present in the open waters of the lake, then individual AVAS segments can be sampled at those locations to assess the macrophyte communities in offshore locations. Since many shallow areas were noted in the other three smaller basins, the GPS Point-Intercept survey designed by the U.S. Army Corps of Engineers (1999) was utilized for the Main Basin as well as the other three basins along with the AVAS survey method for vegetation analysis with the modification that points were selected in the field. All of the AVAS data sheets for all of the 4 "basins" can be found in Appendix A along with a map showing the delineation of each distinct "basin".

MDEQ Species Abundance Code	*Abundance Meaning Interpretation*	*% Coverage of AVAS Surface Area*
a	**Found**	**< 2**
b	**Sparse**	**2 - 20**
c	**Common**	**21 – 60**
d	**Dense**	**> 60**

Table 4. MDEQ AVAS species relative abundance codes used in AVAS surveys.

For reference, a map of all aquatic vegetation sampling points can be found in Figure 4. The four "basins" of Crooked Lake were named as follows (from west to east): 1.) Crooked Lake Drive Main Basin (Figure 5), 2.) Crooked Lake Middle Basin (Figure 6), 3.) North Crooked Lake Drive Basin (Figure 6), and 4.) Hidden Cove Basin (Figure 7).

Figure 5. Main Basin of Crooked Lake

Figure 6. Middle Basin of Crooked Lake

Figure 7. North Basin of Crooked Lake

Figure 8. Hidden Cove Basin of Crooked Lake

Each of the "basins" contained significantly different submersed aquatic vegetation communities both in terms of quantity and in terms of species composition. In the Main Basin of Crooked Lake, the cumulative cover score of the littoral zone was 91.9 and the most abundant native species was Thinleaf pondweed (29.0% cover), followed by Illinois pondweed (19.0 % cover), and Southern naiad (8.7% cover). Of particular interest, was the discovery of the unique variety (sub-species) of Large-leaf pondweed (*Potamogeton amplifolius* var. *ovalifolius*), which bears conspicuous oval floating leaves below the surface and is a rarer genotype but still found in northern temperate waters. There were a total of 18 native species found in the Main Basin of Crooked Lake and a total of 4 exotic aquatic plant species noted (with Curly-leaf pondweed absent at the time of sampling). The Main Basin portion of the lake also contained low quantities of exotic species such as Eurasian watermilfoil (8.5 % cover), Starry stonewort (1.7% cover), Purple loosestrife (0.4% cover), and Yellow iris (0.1% cover).

The Middle Basin contained a cumulative littoral zone cover of 125.3 and the most abundant species was Illinois pondweed (37.5% cover), followed by both Thinleaf pondweed and Southern naiad (both at 15.9% cover), and Large-leaf pondweed at 12.8% cover. In addition, there was a problematic area of dense Yellow waterlily growth (4.4% cover) at the southernmost section of the Middle Basin as noted in Figure 6. This section of the lake contained a total of 14 native aquatic plant species and 4 exotic species (with Curly-leaf pondweed also absent at the time of sampling). The Middle Basin portion of the lake also contained low quantities of exotic species such as Eurasian watermilfoil (4.3 % cover), Starry stonewort (0.9% cover), Purple loosestrife (0.8% cover), and Yellow iris (0.6% cover).

The North Basin of Crooked Lake contained a cumulative littoral zone cover score of 198.5, which is significantly higher than the other two basins. The North Basin contained a total of 21 native aquatic plant species and 3 exotic aquatic plant species. The most abundant native aquatic plant species were Large-leaf pondweed (33.6% cover), Illinois pondweed (20.6% cover), and Elodea at 19.6% cover. Of particular interest and also dominant, was the submersed waterbulrush (*Scirpus subterminalis*), which was present at 19.0% cover. Thick beds of *Chara* sp. were found in the northwest corner and were identified as true *Chara* and not *Nitellopsis* (Starry stonewort) in that region of the lake. Eurasian watermilfoil occupied 1.8% cover, Purple loosestrife 2.6% cover, and Yellow iris 0.4% cover in this region of the lake.

The Hidden Cove section of the lake is the eastern most region which contains a littoral zone score of 290.3 that is substantially higher than those of the rest of the lake. Most areas of this cove were barely navigable at the time of the study and sampling was a challenge. This area contains 14 native aquatic plant species and 4 exotic species. The decline in native species is likely due to the excessive overgrowth of a few dominant native species that are shading light from other lower growing native species that would otherwise germinate and flourish. Illinois pondweed was found to occupy nearly 69.3% of the littoral zone, followed by Small-leaf pondweed (*Potamogeton pusillus*) at 38.6% and Thin-leaf pondweed (*Potamogeton pectinatus*) at 34.1%. The exotic Eurasian watermilfoil was prevalent at 11.6% and Curly-leaf pondweed at 20.5%, followed by Starry stonewort at 4.3%, and Purple loosestrife at 0.7%. This region of the lake is the most impaired with excessive quantities of aquatic plant growth that impede navigation and greatly threaten all Crooked lakefront property values. The sediment organic matter underlying the aquatic vegetation in this region was also the highest and may explain the dense plant growth. Similarly, the dense growth noted in the North Basin was also accompanied by high values of organic matter compared to the other two basins of the lake which contained more sparse vegetation communities.

Aquatic Plants in Crooked Lake: Their Role and Importance

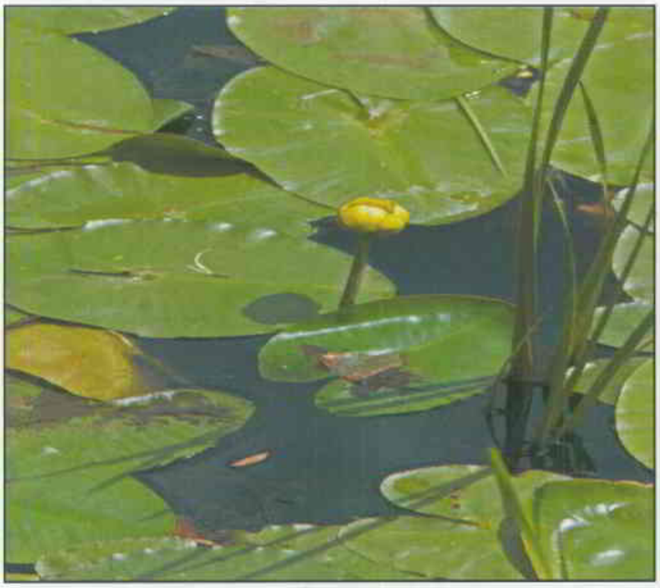
Aquatic plants (macrophytes) are an essential component in the littoral zones (shallow areas) of most lakes in that they serve as suitable habitat and food for macro invertebrates, contribute oxygen to the surrounding waters through photosynthesis, stabilize bottom sediments (if in the rooted growth form), and contribute to the cycling of nutrients such as phosphorus and nitrogen upon decay. In addition, decaying aquatic plants contribute organic matter to lake sediments which further supports the growth of successive aquatic plant communities that are necessary for a balanced aquatic ecosystem. However, an overabundance of aquatic vegetation may cause organic matter to accumulate on the lake bottom faster than it can break down. Aquatic plants generally consist of rooted submersed (Figures 9 and 10), free-floating submersed (Figures 11 and 12), floating-leaved (Figures 13 and 14), and emergent (Figures 15 and 16) growth forms. The emergent growth forms are critical for the diversity of insects onshore and for the health of nearby wetlands. There is evidence that the diversity of submersed aquatic macrophytes can greatly influence the diversity of macro invertebrates associated with aquatic plants of different structural morphologies (Parsons and Matthews, 1995). Therefore, it is possible that declines in the biodiversity and abundance of submersed aquatic plant species and associated macro invertebrates, could negatively impact the fisheries of inland lakes. Alternatively, the overabundance of aquatic vegetation can compromise recreational activities, aesthetics, and property values.

© Superior Photique, 2009
Figure 9. Illinois pondweed (*Potamogeton illinoensis*)

© Superior Photique, 2009
Figure 10. Southern naiad (*Najas guadalupensis*)

© Superior Photique, 2009
Figure 11. Bladderwort (*Utricularia vulgaris*)

© Superior Photique, 2009
Figure 12. Coontail (*Ceratophyllum demersum*)



© Superior Photique, 2007
Figure 13. Yellow water lily (*Nuphar variegata*)

© Superior Photique, 2007
Figure 14. White water lily (*Nymphaea odorata*)

© Superior Photique, 2007
Figure 15. Bulrushes (*Scirpus acutus*)

© Superior Photique, 2011
Figure 16. Cattails (*Typha latifolia*)

4.3.1 Crooked Lake Exotic Aquatic Macrophytes

Exotic aquatic plants (macrophytes) are not native to a particular site, but are introduced by some biotic (living) or abiotic (non-living) vector. Such vectors include the transfer of aquatic plant seeds and fragments by boats and trailers (especially if the lake has public access sites), waterfowl, or by wind dispersal. In addition, exotic species may be introduced into aquatic systems through the release of aquarium or water garden plants into a water body. An aquatic exotic species may have profound impacts on the aquatic ecosystem. Eurasian Watermilfoil (*Myriophyllum spicatum*; Figure 17) is an exotic aquatic macrophyte first documented in the United States in the 1880's (Reed 1997), although other reports (Couch and Nelson 1985) suggest it was first found in the 1940's. *M. spicatum* has since spread to thousands of inland lakes in various states through the use of boats and trailers, waterfowl, seed dispersal, and intentional introduction for fish habitat. *M. spicatum* is a major threat to the ecological balance of an aquatic ecosystem through causation of significant declines in favorable native vegetation within lakes (Madsen et al. 1991), and may limit light from reaching native aquatic plant species (Newroth 1985; Aiken et al. 1979). Additionally, *M. spicatum* can alter the macro invertebrate populations associated with particular native plants of certain structural architecture (Newroth 1985).

Starry stonewort (*Nitellopsis obtusa*; Figure 18) is an invasive macro alga that has invaded many inland lakes of Michigan and was originally discovered in the St. Lawrence River. The "leaves" appear as long, smooth, angular branches of differing lengths. The alga has been observed in dense beds at depths beyond several meters and can grow to heights in excess of a few meters. It prefers clear alkaline waters and has been shown to cause significant declines in water quality and fishery spawning habitat (Crawford, *personal communication*). Management options for the plant are provided in the management recommendations section of the report.

Curly-leaf pondweed (*Potamogeton crispus*; Figure 19) is an exotic, submersed, rooted aquatic plant that was introduced into the United States in 1807 but was abundant by the early 1900's. *P. crispus* is easily distinguished from other native pondweeds by its wavy leaf margins. *P. crispus* grows early in the spring and as a result may prevent other favorable native aquatic species from germinating. The plant reproduces by the formation of fruiting structures called turions. The plant does not reproduce by fragmentation as *M. spicatum* does; however, the turions may be deposited in the lake sediment and germinate in following seasons. Fortunately, the plant usually declines around mid-July in most lakes and thus is not likely to be prolific throughout an entire growing season. *P. crispus* is a pioneering aquatic plant species and specializes in colonizing disturbed habitats. It is highly invasive in aquatic ecosystems with low biodiversity and unique sediment characteristics.

Purple loosestrife (*Lythrum salicaria*; Figure 20) is an invasive (i.e. exotic) emergent aquatic plant that inhabits wetlands and shoreline areas. *L. salicaria* has showy magenta-colored flowers that bloom in mid-July and terminate in late September. The seeds are highly resistant to tough environmental conditions and may reside in the ground for extended periods of time. It exhibits rigorous growth and may out-compete other favorable native emergents such as cattails (*Typha latifolia*) or native swamp loosestrife (*Decodon verticillatus*) and thus reduce the biological diversity of localized ecosystems. The plant is spreading rapidly across the United States and is converting diverse wetland habitats to monocultures with substantially lower biological diversity. Management options for the plant are provided in the management recommendations section of the report.

Yellow iris (*Iris pseudacorus*; Figure 21), although aesthetically pleasant, contains significantly deeper root systems than the native Blueflag iris (*Iris versicolor*) and thus can out-compete and displace native shoreline species over time. Yellow iris is capable of forming long underground rhizomes that crowd out native vegetation and consume nutrients and moisture from adjacent native shoreline vegetation communities. Management options for the control of this plant are provided in the recommendations section of this report.

Figure 17. A photograph of Eurasian watermilfoil showing the prominent seed head, lateral branches, and abundant leaflets
© Superior Photique, 2007

Figure 18. A photograph of Starry stonewort, an invasive macro alga

Figure 19. A photograph of Curly-leaf pondweed showing the distinctive wavy leaf margin and red mid-vein
© Superior Photique, 2007

Figure 20. A photograph of Purple loosestrife showing prominent magenta flowers
© Superior Photique, 2009

Figure 21. A photograph of Yellow iris showing the prominent yellow flower and long green leaves
© Superior Photique, 2008

5.0 CROOKED LAKE MANAGEMENT IMPROVEMENT METHODS

Improvement strategies, including the management of exotic aquatic plants, control of nuisance native aquatic vegetation growth, and reduction of excessive organic matter are available and recommended for the Crooked Lake ecosystem. The increase in developmental pressures and increased use of the Crooked Lake aquatic ecosystem necessitates the implementation of inland lake management practices to preserve and maintain balance within the Crooked Lake ecosystem. Long-term improvement strategies may involve both within-lake (basin) and around-lake (watershed) solutions to protect and restore complex aquatic ecosystems. However, the purpose of this study is to investigate specific methods for the management of nuisance aquatic vegetation noted throughout the four distinct "basins" of Crooked Lake. Regardless of the management goals, all management decisions must be site-specific and should consider the socio-economic, scientific, and environmental components of a lake management program.

5.1 Crooked Lake Aquatic Plant Management

The management of submersed, floating-leaved and emergent aquatic plants is necessary in nutrient-enriched aquatic ecosystems due to their accelerated growth and distribution. Management options should be environmentally and ecologically sound and financially feasible. Options for control of aquatic plants are limited yet are capable of achieving strong results when used properly. Protection of favorable native aquatic plants (especially the low growing submersed plants and *Chara*) in Crooked Lake to provide for a balanced fishery is strongly recommended. However, exotic aquatic plant species should be managed with solutions that will yield long-term results. **It was duly noted during this study that Purple loosestrife around the perimeter of the lake was being treated with the biological control agent beetle, *Galerucella* sp., as numerous damage was noted to leaf and floral structures. Continued stocking of beetles for control of the invasive Purple loosestrife population around Crooked Lake is strongly encouraged. Furthermore, the invasive Yellow iris should be hand-removed with a shovel from all riparian properties where it exists and replaced with a native substitute such as native Blueflag iris, which can be purchased from specialized nurseries.**

5.1.1 Laminar Flow Lake Aeration

Laminar flow aeration systems are retrofitted to a particular site and account for variables such as water depth and volume, contours, water flow rates, and thickness and composition of lake sediment. The systems are designed to completely mix the surrounding waters and evenly distribute dissolved oxygen throughout the lake sediments for efficient microbial utilization.

A laminar flow aeration system utilizes diffusers which are powered by onshore air compressors. The diffusers are connected via extensive self-sinking airlines which help to purge the lake water of benthic carbon dioxide (CO_2), which is a primary nutrient necessary aquatic plant photosynthetic growth and productivity and is also a byproduct of microbial metabolism. Other gasses such as H_2S are also purged out from the sediments. In addition to the placement of the diffuser units, the concomitant use of bacteria and enzymatic treatments to facilitate the microbial breakdown of organic sedimentary constituents is also used as a component of the treatment. Beutel (2006) found that lake oxygenation eliminates release of NH_3+ from sediments through oxygenation of the sediment-water interface. Allen (2009) demonstrated that NH_3+ oxidation in aerated sediments was significantly higher than that of control mesocosms with a relative mean of 2.6 ± 0.80 mg N g dry wt day^{-1} for aerated mesocosms and 0.48 ± 0.20 mg N g dry wt day^{-1} in controls. Although this is a relatively new area of research, recent case studies have shown promise on the positive impacts of laminar flow aeration systems on aquatic ecosystem management with respect to organic matter degradation and resultant increase in water depth, and rooted aquatic plant management in eutrophic ecosystems (Lakeshore Environmental, Inc., 2010, results being submitted for peer review). Toetz (1981) found evidence of a decline in *Microcystis* algae (toxin-producing blue - green algae) in Arbuckle Lake in Oklahoma. Other studies (Weiss and Breedlove, 1973; Malueg et *al.*, 1973) have also shown declines in overall algal biomass.

Conversely, a study by Engstrom and Wright (2002) found no significant differences between aerated and non-aerated lakes with respect to reduction in organic sediments. This study was however limited to one sediment core per lake and given the high degree of heterogeneous sediments in inland lakes may not have accurately represented the conditions present throughout much of the lake bottom. The philosophy and science behind the laminar flow aeration system is to reduce the organic matter layer in the sediment so that a significant amount of nutrient is removed from the sediments and excessive sediments are reduced to yield a greater water depth.

Benefits and Limitations of the Laminar Flow System

In addition to the reduction in toxic blue-green algae (such as *Microcystis* sp.) as described by Toetz (1981), aeration and bioaugmentation in combination have been shown to exhibit other benefits for the improvements of water bodies. Laing (1978) showed that a range of 49-82 cm of organic sediment was removed annually in a study of nine lakes which received aeration and bioaugmentation. It was further concluded that this sediment reduction was not due to re-distribution of sediments since samples were collected outside of the aeration "crater" that is usually formed. A detailed study by Lakeshore Environmental, Inc. of Indian Lake (Van Buren County, Michigan) during 2010 also indicated a significant reduction of organic sediments in bioaugmented/aerated regions, as well as a decline in the relative proportion of blue-green algae and the presence of the rooted, submersed, exotic aquatic plant, Eurasian Watermilfoil (*Myriophyllum spicatum*). A study by Turcotte et *al*. (1988) analyzed the impacts of bioaugmentation on the growth of *M. spicatum* and found that during two four-month studies, the growth and re-generation of this plant was reduced significantly with little change in external nutrient loading. Currently, it is unknown whether the reduction of organic matter for rooting medium or the availability of nutrients for sustained growth is the critical growth limitation factor and these possibilities are being researched. A reduction of *M. spicatum* is desirable for protection of native plant biodiversity, recreation, water quality, and reduction of nutrients such as nitrogen and phosphorus upon decay (Ogwada et *al*., 1984).

Furthermore, bacteria are the major factor in the degradation of organic matter in sediments (Fenchel and Blackburn, 1979) so the concomitant addition of microbes to lake sediments will accelerate that process. A reduction in sediment organic matter would likely decrease *M. spicatum* growth as well as increase water depth and reduce the toxicity of ammonia nitrogen to overlying waters. A study by Verma and

Dixit (2006) evaluated aeration systems in Lower Lake, Bhopal, India, and found that the aeration increased overall dissolved oxygen, and reduced biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total coliform counts.

The Laminar Flow Aeration system has some limitations including the inability to degrade mineral sediments, the requirement of a constant Phase I electrical energy source to power the units and unpredictable response by various species of rooted aquatic plants. In other systems installed within Michigan during 2009-2010, it was observed that Curly-leaf pondweed did not show a marked decline in biomass relative to *M. spicatum*.

Design of the Crooked Lake Whole-Lake Laminar Flow System

The design of a laminar flow system will be retrofitted to circulate the entire Crooked Lake water volume. This means that the Laminar Flow Aeration system will completely mix the entire water volume of Crooked Lake with the number of diffusers proposed and the power supplied. The system has several components which consist of in-water components such as 22 micro-porous ceramic diffusers, 18,750 feet of self-sinking airline, and bacteria and enzyme treatments which consist of 200 gallons of Lake Clear bacteria for nitrogen reduction, 150 gallons of Clean and Clear Enzyme as a catalyst for organic matter reduction, and 150 lbs of Clean-Flo bacteria for organic matter reduction. On-land components consist of 3 locally-sourced sheds and 5.4HP rotary claw compressors along with cooling fans and ventilation. Once the system has been installed, the MDEQ has instituted a required minimum sampling protocol to monitor the efficacy of the system for the intended purposes as determined by the Crooked Lake Texas Association Board. In addition, once a whole-lake Laminar Flow Aeration system is installed, the MDEQ may necessitate that no aquatic herbicides be used in order to properly monitor the efficacy of the system.

5.1.2 Aquatic Herbicides and Algaecides

Aquatic herbicides are generally applied via an application boat (Figure 22) or through the use of a small back-mounted back-pack for small remote shoreline areas. The use of aquatic chemical herbicides is regulated by the MDEQ under Part 33 (Aquatic Nuisance) of the Natural Resources and Environmental Protection Act, P.A. 451 of 1994, and requires a permit from the Michigan Department of Environmental Quality (MDEQ). The permit contains a list of approved herbicides for a particular body of water, as well as dosage rates, treatment areas, and water use restrictions. Furthermore, residents that reside within 100 feet of the proposed treatment area must be notified at least seven days, but not more than forty-five days prior to the initial treatment date. A certified herbicide applicator usually notices the residents in advance of the proposed treatment date, and during the day of treatment. Contact and systemic aquatic herbicides are the two primary herbicide types used in aquatic systems. Contact herbicides cause damage to leaf and stem structures; whereas systemic herbicides are assimilated by the plant roots and are lethal to the entire plant. Wherever possible, it is preferred to use a systemic herbicide for longer-lasting aquatic plant control. There are often restrictions with usage of some systemic herbicides around shoreline areas that contain shallow drinking wells. Systemic herbicides such as 2,4-D and Triclopyr could be used to successfully treat localized or widely dispersed beds of Eurasian watermilfoil. Triclopyr should be used with an adjuvant to increase its ability to adhere to the aquatic plants. **If a whole-lake Laminar Flow Aeration system is not installed and relief from the dense pondweeds in all of the basins is desired, then biomass could be treated with contact herbicides such as diquat or hydothol. Both of these treatments options are temporary and re-growth of the pondweeds will occur. Treatment costs for 2012 will be approximately $290 per acre for these herbicides and thus a 38 acre treatment area would cost approximately $11,020 for the use of contact herbicides. Due to the robustness of Illinois pondweed, this treatment may need to be re-applied twice in a single growing season.**

Fluridone (trade name, SONAR®) is a systemic whole-lake herbicide treatment that is applied to the entire lake volume in the spring. The objective of a fluridone treatment is to selectively control the growth of Eurasian watermilfoil in order to allow other native aquatic plants to germinate and create a more diverse aquatic plant community. **A whole-lake treatment of fluridone is <u>not</u> recommended for Crooked Lake due to the localized areas of *M. spicatum* that would be best controlled with granular aquatic herbicides that would have minimal impact on the rest of the lake area that does not contain the milfoil. Currently, there is approximately 15 acres of Eurasian watermilfoil throughout the lake that could be spot-treated with Triclopyr (Renovate OTF) if Laminar Flow Aeration is not installed or in**

the season prior to installation to systemically kill the plants (Lakeshore Environmental, Inc. currently has the locations of all EWM areas). All herbicides should be applied during calm weather conditions to minimize drift of the chemical from the treatment site. Algae treatments through the use of algaecides should be limited to extremely dense filamentous algal blooms and are only recommended if efforts to reduce planktonic algae though a whole lake laminar flow system are not successful. Overuse of algal treatments may lead to the selection for non-preferred algal types. **The cost to treat the milfoil systemically with Triclopyr OTF at the recommended dose of 120 lbs per acre for 2012 would be approximately $7,350.**

Figure 22. An aquatic herbicide application boat on a Michigan lake.

5.1.3 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting (Figure 23) machine. The mechanical harvester collects numerous loads of aquatic plants as they are cut near the lake bottom. The plants are off-loaded onto a conveyor and then into a dump truck. Harvested plants are then taken to an offsite landfill or farm where they can be used as fertilizer. Mechanical harvesting is preferred over chemical herbicides when primarily native aquatic plants exist, or when excessive amounts of plant biomass need to be removed. Mechanical harvesting is usually not recommended for the removal of Eurasian watermilfoil since the plant may fragment when cut and re-grow on the lake bottom. **Due to the current infestation of *M. spicatum* scattered throughout the littoral zone of Crooked Lake, mechanical harvesting is not recommended until the milfoil has been treated or a Laminar Flow Aeration system has been installed.** Mechanical harvesting does not require a permit from the Michigan Department of Environmental Quality (MDEQ); however, some counties require a launch site use permit from the Michigan Department of Natural Resources (MDNR) if a public access launch site is present. At this time, mechanical harvesting may be used to remove some of the excessive pondweed biomass in Hidden Cove prior to the installation of the Laminar Flow Aeration system and also in the Middle Basin where the Yellow waterlilies are problematic in the southernmost corner. Although there are some aquatic herbicides that could be used to treat the Yellow water lilies (i.e. glyphosate, triclopyr), the MDEQ may not allow use once the Laminar Flow Aeration system is installed and a mechanical method of removal may be necessary. Laminar Flow Aeration has also shown some promise on water lily control in some other projects due to breakdown of organic matter and loss of organic matter rooting medium. **If the 38 acres of nuisance pondweed growth located throughout Crooked Lake and 2 acres of Yellow water lilies in the Middle Basin were to be harvested at a 2012 cost of $400 per acre, then the cost per year would be approximately $15,200.**

Figure 23. A mechanical harvester on a Michigan lake.

5.1.4 Mechanical, Hydraulic, and Suction Dredging

Dredging is a lake management option used to remove accumulated lake sediments to increase accessibility for navigation and recreational activities. Dredging is regulated pursuant to provisions of Part 301 (Inland Lakes and Streams) of the Natural Resources and Environmental Protection Act, P.A. 451 of 1994, as amended, and requires a joint permit through both the Michigan Department of Environmental Quality (MDEQ) and the U.S. Army Corps of Engineers (USACE). The two major types of dredging include hydraulic and mechanical. A mechanical dredge utilizes a backhoe and requires that the disposal site be adjacent to the lake. In contrast, a hydraulic dredge removes sediments in an aqueous slurry and the wetted sediments are transported through a hose to a confined disposal facility (CDF). Selection of a particular dredging method and CDF should consider the environmental, economical, and technical aspects involved. The CDF must be chosen to maximize retention of solids and accommodate large quantities of water from the dewatering of sediments. It is imperative that hydraulic dredges have adequate pumping pressure which can be achieved by dredging in waters greater than 3 foot of depth. Dredge spoils cannot be emptied into wetland habitats; therefore a large upland area is needed for lakes that are surrounded by wetland habitats. In addition, proposed sediment for removal must be tested for metal contaminants before being stored in a CDF. If the sediment is not contaminated, it could be used for habitat restoration, landfill cover, agriculture, strip mine reclamation, or in other industrial or construction uses (U.S. EPA/USACE 2004).

Large-scale dredging is a very expensive operation (typically costing approximately $20 per cubic yard), requires a dredging feasibility study, and is usually cost prohibitive. Funding for dredging projects is usually limited and thus an additional Special Assessment District (SAD) would be needed to fund the project.

Suction Dredging (Figure 24) involves removal of selected areas of lake bottom sediment with the use of a hand-operated suction hose. Dredged spoils are dewatered on land or removed via fabric bags to an offsite location. This method is generally recommended for spot-dredging of sediments and vegetation since it does not remove sediment as rapidly as the standard mechanical and hydraulic dredging methods.

Furthermore, dredging may cause re-suspension of sediments (Nayar et *al*., 2007) which may lead to increased turbidity and reduced clarity of the water. Suction dredging may be another alternative for the removal of the Yellow waterlilies in the southern corner of the Middle Basin. **Costs for this service vary but generally exceed $1,000 per acre.**

Figure 24. A suction dredging apparatus. © Superior Photique, 2009

5.1.5 Biological Control

The use of the aquatic weevil, *Euhrychiopsis lecontei* (Figure 25) to control *M. spicatum* has been used in some inland lakes throughout Michigan (locally, Eagle Lake in Van Buren County), and in many lakes nationally. The weevil naturally exists in many lakes; however, the lack of adequate populations requires that they be implanted and augmented for successful control of *M. spicatum*. The weevil feeds almost entirely on milfoils and will leave other native aquatic plant genera unharmed. The weevil burrows into the stems of *M. spicatum* and damages the vascular tissue, thereby reducing the plant's ability to store carbohydrates (Newman et *al*. 1996). Eventually, the *M. spicatum* stems lose buoyancy and the plant decomposes on the lake bottom.

Figure 25. The milfoil weevil grazing on a milfoil leaf.
From: Dr. Ray Newman, *used with permission.*

Recent research has shown that the weevils require a substantial amount of aquatic plant biomass for successful control of *M. spicatum*. In addition, the weevils require adequate over-wintering habitat since they overwinter within shoreline vegetation. Lakes with sparse *M. spicatum* distribution and abundant metal and concrete seawalls are not ideal candidates for the milfoil weevil. Due to the low amount of milfoil biomass and sparse distribution throughout Crooked Lake, weevils are not recommended as the primary treatment for the control of the milfoil found in the lake.

5.1.6 Integrated Management

Integrated management combines the use of chemical, biological, and/or mechanical methods to control aquatic plant growth. Integrated management is becoming increasingly common since aquatic ecosystems are multi-dimensional and have different vegetation communities in certain lake areas and thus may show variable responses to specific treatments. The ultimate recommendation for a whole-lake laminar flow aeration system in Crooked Lake combined with periodic spot harvests or treatments with aquatic herbicides and continued use of biological controls for Purple loosestrife is indicative of an Integrated Management Program (IMP). Staff from Lakeshore Environmental, Inc. will make integration recommendations, as within this report and will work with the Crooked Lake stakeholders to ascertain a successful outcome.

5.2 Invasive Aquatic Species Prevention

An exotic species is a non-native species that does not originate from a particular location. When international commerce and travel became prevalent, many of these species were transported to areas of the world where they did not originate. Due to their small size, insects, plants, animals, and aquatic organisms may escape detection and be unknowingly transferred to unintended habitats. The first ingredient to successful prevention of unwanted transfer of exotic species to Crooked Lake is awareness and education. More information on invasive species prevention is available at: www. miseagrant.umich.edu. In addition to the invasive aquatic plant species found throughout Crooked Lake as described above, the Asian Clam (*Corbicula fluminea*) was also discovered in all of the 4 basins, but was most prevalent in the Main Basin and Middle Basin.

5.2.1 The Asian Clam

The Asian clam (*Corbicula fluminea*) is native to southern and eastern Asia, Australia, and Africa, but was first noted in North America in the 1920's (Counts 1986). The bivalve is usually less than 3 cm in size, colonizes lake sediments, and feeds on organic matter. The clam has the ability to cross and self-fertilize which creates a high reproduction rate and colonization density of > 1000 m^2 (McMahon and Williams 1986) under some environmental conditions. Fortunately, the adult clam may only live for up to 3 years and thus are not likely to persist if water quality conditions are less than ideal. Reproduction generally occurs when the water temperature is around 15°C (59°F), with more than one annual brood in the late spring and fall. Like zebra mussels, the Asian Clam, may also result in blue-green algae blooms because they compete with native clams for food by filtering favorable green algae from the water (along with the benthic organic matter) and this results in a disproportionate quantity of blue-green algae in the

water column relative to green algae which results in a "bloom". Such declines in favorable algae can decrease zooplankton populations and ultimately the biomass of planktivorous fish populations
The recommended prevention protocols for introduction of all invasive clams and mussels includes steam-washing all boats, boat trailers, jet-skis, and floaters prior to placing them into Crooked Lake. Boat transom wells must always be steam-washed and emptied prior to entry into the lake. Excessive waterfowl should also be discouraged from the lake since they are a natural transportation vector of the microscopic clam or mussel larvae or mature adults. Fishing poles, lures, and other equipment used in other lakes (and especially the Great Lakes) should also be thoroughly steam-washed before use in Crooked Lake. Additionally, all solid construction materials (if recycled from other lakes) must also be steam-washed.

6.0 PROJECT RECOMMENDATIONS AND FINANCING

It is highly recommended that the members of the Crooked Lake Texas Association and the residents around Crooked Lake adopt the aquatic vegetation guidelines suggested in this vegetation management plan. To protect the biodiversity of native aquatic plants within Crooked Lake, aquatic herbicides should be minimized and used primarily for exotic species, except where an occasional mechanical harvest may be needed for dense biomass removal. With removal of the sediment organic matter and whole lake aeration program, nuisance aquatic vegetation should diminish in problematic areas of the lake over time.
In summary, Lakeshore Environmental, Inc. scientists recommend the use of laminar flow aeration to improve multiple aspects of the lake at a feasible cost over time. The integrated approach would therefore consist of: 1.) laminar flow aeration, and 2.) Purple Loosestrife beetles.

6.1 Recommendations for the Crooked Lake Texas Association

Every aquatic vegetation management plan should offer solutions that are ecologically sound, practical, and economically feasible. Since funds for the suggested management improvements and oversight are limited, it was suggested that the Crooked Lake Texas Association utilize a Special Assessment District

(SAD) under P.A. 188 of 1954 to fund the suggested improvements. The SAD should include all riparian properties around Crooked Lake and back lot properties which would derive benefit from the intended improvements mentioned in the management plan (i.e. deeded and dedicated accesses). Under P.A. 188 of 1954, it is critical that the properties within the SAD be equitable to properties within a particular category. Furthermore, it is suggested that the Township work closely with the Crooked Lake Texas Association on this project as both as important stakeholders for this unique water resource. If aquatic herbicides are to be used in Crooked Lake they must be registered by the United States Environmental Protection Agency (EPA) and also must be used according to the safety guidelines listed for that particular herbicide on the MSDS sheet. The aquatic herbicide registration process requires that intense studies on human exposure and health, effects on fisheries and wildlife, biopersistance, and analysis of chemical breakdown products all be assessed to determine if these substances are safe to use in aquatic habitats for the control of nuisance aquatic vegetation.

Furthermore, a professional limnologist/aquatic botanist should perform regular GPS-guided whole-lake surveys each spring and fall to monitor the growth and distribution of all aquatic vegetation communities to measure responses of such communities to the selected management program. Additionally, the lake manager should oversee all management activities and would be responsible for the creation of aquatic plant management survey maps, direction of all management contractors to target-specific areas of aquatic vegetation for removal, administrative duties such as the processing of contractor invoices, and the education of lakefront owners through an educational newsletter and through attending meetings at the request of the Crooked Lake Texas Association Board. It is critical that the professional limnologist be familiar with the baseline monitoring requirements and appropriate water quality analyses for evaluation of the laminar flow aeration technology.

6.1.1 Cost Estimates for Crooked Lake Improvements

The proposed Integrated Management treatment program for the control of nuisance native and exotic aquatic plant species in Crooked Lake would begin during the 2012 season. A breakdown of costs associated with Crooked Lake improvements is presented in Table 5 (a chemical and mechanical) and Table 6 (laminar flow) approach. It should be noted that proposed costs are estimates and may change in response to changes in environmental conditions (i.e. increases in aquatic plant growth or distribution, or changes in treatment costs).

Proposed Crooked Lake Improvement Item	**Estimated 2012 Cost**	**Estimated 2013 Cost[1]**	**Estimated 2014-2016 Cost[2]**
Professional Limnologist[2] and Certified Watershed Manager/Lake surveys/Water quality sampling/Contractor oversight/	$5,500	$6,000	$6,000
Aquatic herbicide treatment of 15 acres of EWM with Triclopyr @$490 per acre	$7,350	$4,000	$4,000
Aquatic herbicide treatment[3] of 38 acres of nuisance Pondweeds @$290 per acre	$22,040	$24,000	$26,000
Suction Harvesting of Yellow Water lilies for 2 acres @ $1,000 per acre	$2,000	N/A	N/A
Contingency[4]	$3,689	$3,400	$3,600
Total Annual Estimated Cost	$40,579	$37,400	$39,600

Table 5. Crooked Lake proposed lake improvement program costs (2012-2014).

[1] Herbicide treatment acreage is predicted to decline by half for second year, but cost of product is predicted to increase by 10%.

[2] Professional services includes two annual GPS-guided, aquatic vegetation surveys, pre and post-treatment surveys for aquatic plant control methods, oversight and management of the aquatic plant control program, processing of all invoices from contractors and others billing for services related to the improvement program, education of local riparians through the development and publication of a high-quality, scientific newsletter, and attendance at up to 3 scheduled Crooked Lake Texas Association Board meetings. Also, preparation and dissemination of all bidding documents and analysis of bidding documents, and recommendations to the Crooked Lake Texas Association Board on contractors if

requested. Retention of a non-biased scientific firm is advised for neutral oversight of all management activities.

[3] Nuisance pondweed growth treated with contact herbicides will have to be done twice per season and thus is costed twice per season. Costs will increase each year due to rise in herbicide cost. **Note: mechanical harvesting may be replaced for cost similar to that of contact herbicides once the EWM has been treated with systemic herbicides and fragmentation is not a threat.**

[4] Contingency is 10% of the total project cost, to assure that extra funds are available for unexpected expenses. Note: Contingency may be advised and/or needed for future treatment years.

Proposed Crooked Lake Improvement Item	**Estimated 2012 Cost**	**Estimated 2013 Cost**	**Estimated 2014-2016 Cost**
Professional Limnologist[1] and Certified Watershed Manager/Lake surveys/Water quality sampling/Contractor oversight/	$5,000	$5,000	$5,000
Laminar Flow Aeration system	$49,296	$34,450	$33,850
Total Annual Estimated Cost	$54,296	$39,450	$38,850

Table 6. Crooked Lake proposed lake improvement program costs with a whole lake Laminar Flow Aeration system (2012-2014).

[1]Professional services includes two annual GPS-guided, aquatic vegetation surveys, pre and post-treatment surveys for aquatic plant control methods, oversight and management of the aquatic plant control program, processing of all invoices from contractors and others billing for services related to the improvement program, education of local riparians through the development and publication of a high-quality, scientific newsletter, and attendance at up to 3 scheduled Crooked Lake Texas Association Board

meetings. Also, preparation and dissemination of all bidding documents and analysis of bidding documents, and recommendations to the Crooked Lake Texas Association Board on contractors if requested. Retention of a non-biased scientific firm is advised for neutral oversight of all management activities.

7.0 LITERATURE CITED

Aiken, S.G., P.R. Newroth, and I. Wile. 1979. The biology of Canadian weeds. 34. *Myriophyllum spicatum* L. *Can. J. Plant Sci.* 59: 201-215.

Blackburn, R.D., L.W. Weldon, R.R. Yeo, and T.M. Taylor. 1969. Identification and distribution of certain similar-appearing submersed aquatic weeds in Florida. *Hyacinth Contr. J.* 8:17-23.

Blossey, B., Schroeder, D., Hight, S.D., and Malecki, R.A. (1994) Host specificity and environmental impact of two leaf beetles (*Galerucella calmariensis* and *G. pusilla*) for biological control of purple loosestrife (*Lythrum salicaria*). Weed Sci., 42: 134-140.

Bowes, G.A., S. Holaday, T.K. Van, and W.T. Haller. 1977. Photosynthetic and photorespiratory carbon metabolism in aquatic plants. *In* Proceedings 4th Int. Congress of Photosynthesis, Reading (UK) pp. 289-298.

Cooke, G. D. 2007. Lake level drawdown as a macrophyte control technique. J. Amer. Wat. Res. Assoc. 16: 317-322.

Couch, R., and E. Nelson 1985. *Myriophyllum spicatum* in North America. Pp. 8-18. In: Proc. First Int. Symp. On Watermilfoil (*M. spicatum*) and related Haloragaceae species. July 23-24, 1985. Vancouver, BC, Canada. Aquatic Plant Management Society, Inc.

Counts, C.L., 1986. The zoogeography and history of the invasion of the United States by *Corbicula fluminea* (Bivalvia: Corbiculidae). Am. Malacol. Bill. Spec. ed.No. 2:7-39.

Doyle, R.D., and Smart, R.M. 2001. Effects of drawdowns and desiccation on tubers of *Hydrilla*, an exotic aquatic weed. Weed Science, 49: 135-140.

Henderson, C.L., C. Dindorf, and F. Rozumalski. 1998. Lakescaping for Wildlife and Water Quality. Minnesota Department of Natural Resources, 176 pgs.

Herbert, P.D.N., B.W. Muncaster, and G.L. Mackie. 1989. Ecological and genetic studies on *Dreissena polymorpha* (Pallas) a new mollusk in the Great Lakes. *Can. J. Fish and Aquat. Sci.* 46: 1587-1591.

Herrick, B.M., and Wolf, A.T. 2005. Invasive plant species in diked vs. undiked Great Lakes wetlands. J. Great Lakes Res., Internat. Assoc. Great. Lakes. Res. 31(3): 277-287.

Holland, R.E. 1993. Changes in planktonic diatoms and water transparency in Hatchery Bay, Bass Island Area, Western Lake Erie since the establishment of the zebra mussel, *Journal of Great Lakes Research*, 19:617-624.

Mackie, G.L., and D.W. Schlosser. 1996. Comparative biology of zebra mussels in Europe and North America: an overview, *American Zoologist*. 36: 244-258.

Madsen, J.D., J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, and C.W. Boylen. 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies, *Journal of Aquatic Plant Management* 29, 94-99.

Malecki, R.A., Blossey, B., Hight, S.D., Schroeder, D., Kok, L.T., and Coulson, J.R. (1993) Biological control of purple loosestrife: a case for using insects as control agents, after rigorous screening, and for integrating release strategies with research. BioSci., 43: 680-686.

Manny, B.A., and R.G. Wetzel. 1982. Allochthonous dissolved organic and inorganic nitrogen budget of a marl lake. (Unpublished manuscript).

McMahon, R.F., and C.J. Williams. 1986. A reassessment of growth rate, life span, life cycles, and population dynamics in a natural population dynamics in a natural population and field caged individuals of Corbicula fluminea (Müller) (Bivalvia: Corbicula). Am. Malacol. Bull. Spec. ed. No. 2:151-166.

McMahon, R.F. 1996. The physiological ecology of the zebra mussel, *Dreissena polymorpha*, in North America and Europe, *American Zoologist*. 36: 339-363

Newroth, P.R. 1985. A review of Eurasian watermilfoil impacts and management in British Columbia. Pp. 139-153. In: Proc. First Int. Symp. On watermilfoil (*M. spicatum*) and related Haloragaceae species. July 23-24, 1985. Vancouver, BC, Canada. Aquatic Plant Management Society, Inc.

Parsons, J.K., and R.A. Matthews. 1995. Analysis of the associations between macroinvertebrates and macrophytes in a freshwater pond. *Northwest Science*, 69: 265-275.

Peavy, H.S. 1978. Groundwater pollution from septic tank drainfields, June 1978, Montana State University, Montana.

Reed, C.G. 1977. History and disturbance of Eurasian milfoil in the United States and Canada. *Phytologia* 36: 417-436.

Rinehart, K.L., M. Namikoshi, and B. W. Choi. 1994. Structure and biosynthesis of toxins from blue-green algae (cyanobacteria). Journal of Applied Phycology 6: 159-176.

Verkleij, J.A.C., A.H. Pieterse, G.J.T. Horneman, and M. Torenbeek. 1983. A comparative study of the morphology and isoenzyme patterns of *Hydrilla verticillata* (L.f.) Royle. Aquat. Bot. 17: 43-59.

Wang, Q., Wang., C.H., Zhao, B., Ma, Z.J., Luo, Y.Q., Chen, J.K., and Li, B., 2006. Effects of growing conditions on the growth of and interactions between salt marsh plants: implications for invasability of habitats. Biological Invasions, 8: 1547-1560.

Wetzel, R. G. 2001. Limnology: Lake and River Ecosystems. Third Edition. Academic Press, 1006 pgs.

APPENDIX A

CROOKED LAKE AQUATIC VEGETATION SURVEY AVAS SURVEY DATA TABLES SEPTEMBER, 2011

LAKE NAME- North Crooked Lake Drive Basin **COUNTY- Kalamazoo** **SURVEY DATE: September 1, 2011**

Standard Aquatic Vegetation Summary Sheet SURVEY BY: JLJ, SJC

		Total number of AVASS = 50 for each Density Catagory				Calculations				Sum of Previous Four Columns	Total Number of AVAS's	Quotient of Column 9 divided by Column 10		
		A	B	C	D	Catagory A x 1	Catagory B x10	Catagory C x 40	Catagory D x 80					
Code No	Plant Name	1	2	3	4	5	6	7	8	9	10	11	Code No	Plant Name
1	Eurasian watermilfoil	2	5	1		2	50	40	0	92	50	1.8	1	Eurasian watermilfoil
2	Curlyleaf pondweed					0	0	0	0	0	50	0.0	2	Curlyleaf pondweed
3	Chara vulgaris		27	6	3	0	270	240	240	750	50	15.0	3	Chara vulgaris
4	Thinleaf pondweed		7	7	1	0	70	280	80	430	50	8.6	4	Thinleaf pondweed
5	Flatstem pondweed		1	6		0	10	240	0	250	50	5.0	5	Flatstem pondweed
6	Robbins pondweed					0	0	0	0	0	50	0.0	6	Robbins pondweed
7	Variable-leaf pondweed		17	3	3	0	170	120	240	530	50	10.6	7	Variable-leaf pondweed
8	Whitestem pondweed					0	0	0	0	0	50	0.0	8	Whitestem pondweed
9	Richardsons pondweed					0	0	0	0	0	50	0.0	9	Richardsons pondweed
10	Illinois pondweed		19	11	5	0	190	440	400	1030	50	20.6	10	Illinois pondweed
11	Large-leaf pondweed		4	17	12	0	40	680	960	1680	50	33.6	11	Large-leaf pondweed
12	American pondweed					0	0	0	0	0	50	0.0	12	American pondweed
13	Floating leaf pondweed		2		2	0	20	0	160	180	50	3.6	13	Floating leaf pondweed
14	Water stargrass		1			0	10	0	0	10	50	0.2	14	Water stargrass
15	Wild celery		1			0	10	0	0	10	50	0.2	15	Wild celery
16	Large-leaf Pondweed (var. ovalifolius)					0	0	0	0	0	50	0.0	16	Large-leaf Pondweed (var. ovalifolius)
17	Northern milfoil					0	0	0	0	0	50	0.0	17	Northern milfoil
18	Whorled watermilfoil	1	4	1		1	40	40	0	81	50	1.6	18	Whorled watermilfoil
19						0	0	0	0	0	50	0.0	19	
20	Coontail		9	1		0	90	40	0	130	50	2.6	20	Coontail
21	Elodea		2		12	0	20	0	960	980	50	19.6	21	Elodea
22	Bladderwort		22	2	1	0	220	80	80	380	50	7.6	22	Bladderwort
23						0	0	0	0	0	50	0.0	23	
24						0	0	0	0	0	50	0.0	24	
25	Southern naiad	1	23	11	2	1	230	440	160	831	50	16.6	25	Southern naiad
26	Water bulrush		3	3	10	0	30	120	800	950	50	19.0	26	Water bulrush
27						0	0	0	0	0	50	0.0	27	
28						0	0	0	0	0	50	0.0	28	
29	Small-leaf pondweed		6	3		0	60	120	0	180	50	3.6	29	Small-leaf pondweed
30	White waterlily		4		5	0	40	0	400	440	50	8.8	30	White waterlily
31	Yellow waterlily		2		8	0	20	0	640	660	50	13.2	31	Yellow waterlily
32	Watershield					0	0	0	0	0	50	0.0	32	Watershield
33	Duckweed					0	0	0	0	0	50	0.0	33	Duckweed
34						0	0	0	0	0	50	0.0	34	
35	Watermeal					0	0	0	0	0	50	0.0	35	Watermeal
36	Arrowhead					0	0	0	0	0	50	0.0	36	Arrowhead
37	Pickerelweed		2	2		0	20	80	0	100	50	2.0	37	Pickerelweed
38						0	0	0	0	0	50	0.0	38	
39	Cattails					0	0	0	0	0	50	0.0	39	Cattails
40	Bulrushes		7			0	70	0	0	70	50	1.4	40	Bulrushes
41						0	0	0	0	0	50	0.0	41	
42	Swamp loosestrife					0	0	0	0	0	50	0.0	42	Swamp loosestrife
43	Purple loosestrife		1	3		0	10	120	0	130	50	2.6	43	Purple loosestrife
44	Yellow iris	2	2			2	20	0	0	22	50	0.4	44	Yellow iris
45	Phragmites					0	0	0	0	0	50	0.0	45	Phragmites
46						0	0	0	0	0	50	0.0	46	
50	Emergent smartweed		1			0	10	0	0	10	50	0.2	50	Emergent smartweed
												198.5		

LAKE NAME- Hidden Cove Basin **COUNTY- Kalamazoo** **SURVEY DATE: September 1, 2011**

Standard Aquatic Vegetation Summary Sheet SURVEY BY: JLJ, SJC

		Total number of AVASS = 44 for each Density Catagory					Calculations				Sum of Previous Four Columns	Total Number of AVAS's	Quotient of Column 9 divided by Column 10		
		A	B	C	D		Catagory A x 1	Catagory B x10	Catagory C x 40	Catagory D x 80					
Code No	Plant Name	1	2	3	4		5	6	7	8	9	10	11	Code No	Plant Name
1	Eurasian watermilfoil	2	7	3	4		2	70	120	320	512	44	11.6	1	Eurasian watermilfoil
2	Curlyleaf pondweed		2	10	6		0	20	400	480	900	44	20.5	2	Curlyleaf pondweed
3	Chara vulgaris		3	10	11		0	30	400	880	1310	44	29.8	3	Chara vulgaris
4	Thinleaf pondweed	2	14	10	12		2	140	400	960	1502	44	34.1	4	Thinleaf pondweed
5	Flatstem pondweed	1	2	7	2		1	20	280	160	461	44	10.5	5	Flatstem pondweed
6	Robbins pondweed						0	0	0	0	0	44	0.0	6	Robbins pondweed
7	Variable-leaf pondweed	2	8	4	1		2	80	160	80	322	44	7.3	7	Variable-leaf pondweed
8	Whitestem pondweed						0	0	0	0	0	44	0.0	8	Whitestem pondweed
9	Richardsons pondweed						0	0	0	0	0	44	0.0	9	Richardsons pondweed
10	Illinois pondweed	1	1	6	35		1	10	240	2800	3051	44	69.3	10	Illinois pondweed
11	Large-leaf pondweed			4	6		0	0	160	480	640	44	14.5	11	Large-leaf pondweed
12	American pondweed						0	0	0	0	0	44	0.0	12	American pondweed
13	Floating leaf pondweed		2	1			0	20	40	0	60	44	1.4	13	Floating leaf pondweed
14	Water stargrass						0	0	0	0	0	44	0.0	14	Water stargrass
15	Wild celery						0	0	0	0	0	44	0.0	15	Wild celery
16	Large-leaf Pondweed (var. ovalifolius)						0	0	0	0	0	44	0.0	16	Large-leaf Pondweed (var. ovalifolius)
17	Northern milfoil						0	0	0	0	0	44	0.0	17	Northern milfoil
18	Whorled watermilfoil						0	0	0	0	0	44	0.0	18	Whorled watermilfoil
19							0	0	0	0	0	44	0.0	19	
20	Coontail		2	5			0	20	200	0	220	44	5.0	20	Coontail
21	Elodea		4	7			0	40	280	0	320	44	7.3	21	Elodea
22	Bladderwort						0	0	0	0	0	44	0.0	22	Bladderwort
23							0	0	0	0	0	44	0.0	23	
24							0	0	0	0	0	44	0.0	24	
25	Southern naiad		4	12	4		0	40	480	320	840	44	19.1	25	Southern naiad
26	Water bulrush	2	5	4	2		2	50	160	160	372	44	8.5	26	Water bulrush
27	Starry stonewort	1	3	4			1	30	160	0	191	44	4.3	27	Starry stonewort
28							0	0	0	0	0	44	0.0	28	
29	Small-leaf pondweed		2	8	17		0	20	320	1360	1700	44	38.6	29	Small-leaf pondweed
30	White waterlily	1		4			1	0	160	0	161	44	3.7	30	White waterlily
31	Yellow waterlily		2	4			0	20	160	0	180	44	4.1	31	Yellow waterlily
32	Watershield						0	0	0	0	0	44	0.0	32	Watershield
33	Duckweed						0	0	0	0	0	44	0.0	33	Duckweed
34							0	0	0	0	0	44	0.0	34	
35	Watermeal						0	0	0	0	0	44	0.0	35	Watermeal
36	Arrowhead						0	0	0	0	0	44	0.0	36	Arrowhead
37	Pickerelweed						0	0	0	0	0	44	0.0	37	Pickerelweed
38							0	0	0	0	0	44	0.0	38	
39	Cattails						0	0	0	0	0	44	0.0	39	Cattails
40	Bulrushes						0	0	0	0	0	44	0.0	40	Bulrushes
41							0	0	0	0	0	44	0.0	41	
42	Swamp loosestrife						0	0	0	0	0	44	0.0	42	Swamp loosestrife
43	Purple loosestrife		3				0	30	0	0	30	44	0.7	43	Purple loosestrife
44	Yellow iris						0	0	0	0	0	44	0.0	44	Yellow iris
45	Phragmites						0	0	0	0	0	44	0.0	45	Phragmites
46							0	0	0	0	0	44	0.0	46	
50	Emergent smartweed						0	0	0	0	0	44	0.0	50	Emergent smartweed
													290.3		

LAKE NAME- Crooked Lake Long Point Middle Basin **COUNTY- Kalamazoo** **SURVEY DATE: September 1, 2011**

Standard Aquatic Vegetation Summary Sheet SURVEY BY: JLJ, SJC

		Total number of AVAS'S = 36 for each Density Catagory				Calculations				Sum of Previous Four Columns	Total Number of AVAS's	Quotient of Column 9 divided by Column 10		
		A	B	C	D	Catagory A x 1	Catagory B x10	Catagory C x 40	Catagory D x 80					
Code No	Plant Name	1	2	3	4	5	6	7	8	9	10	11	Code No	Plant Name
1	Eurasian watermilfoil	4	7	2		4	70	80	0	154	36	4.3	1	Eurasian watermilfoil
2	Curlyleaf pondweed					0	0	0	0	0	36	0.0	2	Curlyleaf pondweed
3	Chara vulgaris	1	21	3		1	210	120	0	331	36	9.2	3	Chara vulgaris
4	Thinleaf pondweed	1	17	6	2	1	170	240	160	571	36	15.9	4	Thinleaf pondweed
5	Flatstem pondweed		2			0	20	0	0	20	36	0.6	5	Flatstem pondweed
6	Robbins pondweed					0	0	0	0	0	36	0.0	6	Robbins pondweed
7	Variable-leaf pondweed		14	3	1	0	140	120	80	340	36	9.4	7	Variable-leaf pondweed
8	Whitestem pondweed					0	0	0	0	0	36	0.0	8	Whitestem pondweed
9	Richardsons pondweed					0	0	0	0	0	36	0.0	9	Richardsons pondweed
10	Illinois pondweed		3	9	12	0	30	360	960	1350	36	37.5	10	Illinois pondweed
11	Large-leaf pondweed		14	8		0	140	320	0	460	36	12.8	11	Large-leaf pondweed
12	American pondweed					0	0	0	0	0	36	0.0	12	American pondweed
13	Floating leaf pondweed					0	0	0	0	0	36	0.0	13	Floating leaf pondweed
14	Water stargrass	2	7			2	70	0	0	72	36	2.0	14	Water stargrass
15	Wild celery					0	0	0	0	0	36	0.0	15	Wild celery
16	Large-leaf Pondweed (var. ovalifolius)					0	0	0	0	0	36	0.0	16	Large-leaf Pondweed (var. ovalifolius)
17	Northern milfoil					0	0	0	0	0	36	0.0	17	Northern milfoil
18	Whorled watermilfoil					0	0	0	0	0	36	0.0	18	Whorled watermilfoil
19						0	0	0	0	0	36	0.0	19	
20	Coontail	3	11			3	110	0	0	113	36	3.1	20	Coontail
21	Elodea		1	1		0	10	40	0	50	36	1.4	21	Elodea
22	Bladderwort	1				1	0	0	0	1	36	0.0	22	Bladderwort
23						0	0	0	0	0	36	0.0	23	
24						0	0	0	0	0	36	0.0	24	
25	Southern naiad	1	13	9	1	1	130	360	80	571	36	15.9	25	Southern naiad
26	Water bulrush					0	0	0	0	0	36	0.0	26	Water bulrush
27	Starry stonewort	4	3			4	30	0	0	34	36	0.9	27	Starry stonewort
28						0	0	0	0	0	36	0.0	28	
29	Small-leaf pondweed		13	2		0	130	80	0	210	36	5.8	29	Small-leaf pondweed
30	White waterlily					0	0	0	0	0	36	0.0	30	White waterlily
31	Yellow waterlily				2	0	0	0	160	160	36	4.4	31	Yellow waterlily
32	Watershield					0	0	0	0	0	36	0.0	32	Watershield
33	Duckweed					0	0	0	0	0	36	0.0	33	Duckweed
34						0	0	0	0	0	36	0.0	34	
35	Watermeal					0	0	0	0	0	36	0.0	35	Watermeal
36	Arrowhead					0	0	0	0	0	36	0.0	36	Arrowhead
37	Pickerelweed					0	0	0	0	0	36	0.0	37	Pickerelweed
38						0	0	0	0	0	36	0.0	38	
39	Cattails	1				1	0	0	0	1	36	0.0	39	Cattails
40	Bulrushes		1			0	10	0	0	10	36	0.3	40	Bulrushes
41						0	0	0	0	0	36	0.0	41	
42	Swamp loosestrife					0	0	0	0	0	36	0.0	42	Swamp loosestrife
43	Purple loosestrife		3			0	30	0	0	30	36	0.8	43	Purple loosestrife
44	Yellow iris	1	2			1	20	0	0	21	36	0.6	44	Yellow iris
45	Phragmites					0	0	0	0	0	36	0.0	45	Phragmites
46						0	0	0	0	0	36	0.0	46	
50	Emergent smartweed		1			0	10	0	0	10	36	0.3	50	Emergent smartweed
												125.3		

Standard Aquatic Vegetation Summary Sheet SURVEY BY: JLJ, SJC

		Total number of AVASS = 77 for each Density Catagory					Calculations				Sum of Previous Four Columns	Total Number of AVAS's	Quotient of Column 9 divided by Column 10		
		A	B	C	D		Catagory A x 1	Catagory B x10	Catagory C x 40	Catagory D x 80					
Code No	Plant Name	1	2	3	4		5	6	7	8	9	10	11	Code No	Plant Name
1	Eurasian watermilfoil	2	29	9			2	290	360	0	652	77	8.5	1	Eurasian watermilfoil
2	Curlyleaf pondweed						0	0	0	0	0	77	0.0	2	Curlyleaf pondweed
3	Chara vulgaris	1	47	1			1	470	40	0	511	77	6.6	3	Chara vulgaris
4	Thinleaf pondweed		11	33	10		0	110	1320	800	2230	77	29.0	4	Thinleaf pondweed
5	Flatstem pondweed		7				0	70	0	0	70	77	0.9	5	Flatstem pondweed
6	Robbins pondweed						0	0	0	0	0	77	0.0	6	Robbins pondweed
7	Variable-leaf pondweed	1	20				1	200	0	0	201	77	2.6	7	Variable-leaf pondweed
8	Whitestem pondweed		1	1			0	10	40	0	50	77	0.6	8	Whitestem pondweed
9	Richardsons pondweed						0	0	0	0	0	77	0.0	9	Richardsons pondweed
10	Illinois pondweed		26	22	4		0	260	880	320	1460	77	19.0	10	Illinois pondweed
11	Large-leaf pondweed	2	14	2			2	140	80	0	222	77	2.9	11	Large-leaf pondweed
12	American pondweed						0	0	0	0	0	77	0.0	12	American pondweed
13	Floating leaf pondweed			1			0	0	40	0	40	77	0.5	13	Floating leaf pondweed
14	Water stargrass		18				0	180	0	0	180	77	2.3	14	Water stargrass
15	Wild celery						0	0	0	0	0	77	0.0	15	Wild celery
16	Large-leaf Pondweed (var. ovalifolius)		5				0	50	0	0	50	77	0.6	16	Large-leaf Pondweed (var. ovalifolius)
17	Northern milfoil						0	0	0	0	0	77	0.0	17	Northern milfoil
18	Whorled watermilfoil						0	0	0	0	0	77	0.0	18	Whorled watermilfoil
19							0	0	0	0	0	77	0.0	19	
20	Coontail	5	26				5	260	0	0	265	77	3.4	20	Coontail
21	Elodea		1				0	10	0	0	10	77	0.1	21	Elodea
22	Bladderwort	3	3				3	30	0	0	33	77	0.4	22	Bladderwort
23							0	0	0	0	0	77	0.0	23	
24							0	0	0	0	0	77	0.0	24	
25	Southern naiad		35	6	1		0	350	240	80	670	77	8.7	25	Southern naiad
26	Water bulrush						0	0	0	0	0	77	0.0	26	Water bulrush
27	Starry stonewort	2	5		1		2	50	0	80	132	77	1.7	27	Starry stonewort
28							0	0	0	0	0	77	0.0	28	
29	Small-leaf pondweed		9				0	90	0	0	90	77	1.2	29	Small-leaf pondweed
30	White waterlily						0	0	0	0	0	77	0.0	30	White waterlily
31	Yellow waterlily			1	1		0	0	40	80	120	77	1.6	31	Yellow waterlily
32	Watershield						0	0	0	0	0	77	0.0	32	Watershield
33	Duckweed						0	0	0	0	0	77	0.0	33	Duckweed
34							0	0	0	0	0	77	0.0	34	
35	Watermeal						0	0	0	0	0	77	0.0	35	Watermeal
36	Arrowhead						0	0	0	0	0	77	0.0	36	Arrowhead
37	Pickerelweed						0	0	0	0	0	77	0.0	37	Pickerelweed
38							0	0	0	0	0	77	0.0	38	
39	Cattails						0	0	0	0	0	77	0.0	39	Cattails
40	Bulrushes		4				0	40	0	0	40	77	0.5	40	Bulrushes
41							0	0	0	0	0	77	0.0	41	
42	Swamp loosestrife						0	0	0	0	0	77	0.0	42	Swamp loosestrife
43	Purple loosestrife		3				0	30	0	0	30	77	0.4	43	Purple loosestrife
44	Yellow iris		1				0	10	0	0	10	77	0.1	44	Yellow iris
45	Phragmites						0	0	0	0	0	77	0.0	45	Phragmites
46							0	0	0	0	0	77	0.0	46	
50	Emergent smartweed		1				0	10	0	0	10	77	0.1	50	Emergent smartweed
													91.9		

APPENDIX B

CROOKED LAKE SOILS MAP
NRCS-USDA

Soil Map—Kalamazoo County, Michigan
(Crooked Lake Soils)

Map Scale: 1:12,900 if printed on A size (8.5" x 11") sheet.

Meters	0	150	300	600	900
Feet	0	500	1,000	2,000	3,000

N

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Units

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other

Special Line Features
- Gully
- Short Steep Slope
- Other

Political Features
- Cities

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

MAP INFORMATION

Map Scale: 1:12,900 if printed on A size (8.5" × 11") sheet.

The soil surveys that comprise your AOI were mapped at 1:15,840.

Please rely on the bar scale on each map sheet for accurate map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: UTM Zone 16N NAD83

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Kalamazoo County, Michigan
Survey Area Data: Version 7, Jun 17, 2009

Date(s) aerial images were photographed: 6/22/2005

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Kalamazoo County, Michigan (MI077)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
CoB	Coloma loamy sand, 0 to 6 percent slopes	46.3	6.1%
CoC	Coloma loamy sand, 6 to 12 percent slopes	10.4	1.4%
CoD	Coloma loamy sand, 12 to 18 percent slopes	49.8	6.6%
Hs	Houghton and Sebewa soils, ponded	7.3	1.0%
OsB	Oshtemo sandy loam, 1 to 6 percent slopes	115.1	15.2%
OsC	Oshtemo sandy loam, 6 to 12 percent slopes	147.0	19.4%
OsD	Oshtemo sandy loam, 12 to 18 percent slopes	25.5	3.4%
OsE	Oshtemo sandy loam, 18 to 35 percent slopes	0.1	0.0%
SpB	Spinks loamy sand, 0 to 6 percent slopes	31.4	4.2%
SpC	Spinks loamy sand, 6 to 12 percent slopes	142.8	18.9%
SpD	Spinks loamy sand, 12 to 18 percent slopes	9.3	1.2%
W	Water	171.8	22.7%
Totals for Area of Interest		**756.8**	**100.0%**