Limnological Assessment

Gravel Lake Limnological Assessment

Prepared for:
Gravel Lake Association
P.O. Box 531
Lawton, MI 49065

Prepared by:
Progressive AE
1811 4 Mile Road, NE
Grand Rapids, MI 49525-2442
616/361-2664

and

Freshwater Physicians
5293 Daniel Dr.
Brighton, MI 48114

March 2016

Project No: 74590001

progressive|ae

Gravel Lake Limnological Assessment

Prepared for:
Gravel Lake Association
P.O. Box 531
Lawton, MI 49065

Prepared by:
Progressive AE
1811 4 Mile Road, NE
Grand Rapids, MI 49525-2442
616/361-2664

and

Freshwater Physicians
5293 Daniel Dr.
Brighton, MI 48114

March 2016

Project No: 74590001

We thank Craig DeSimone and Suzanne Reed from the Gravel Lake Association for providing valuable historical information. Thanks also to Andy Tomaszewski and Jaimee Conroy at PLM Lake and Land Management Corp. for providing historical information and insights on Gravel Lake aquatic plants, aquatic plant control, and water chemistry. Dean Rucinski and James Opoka were our on-site guardian angels and provided invaluable assistance with lake sampling, access and captaining of his boat, expertise in choosing sites for net deployment, arranging for collection of fish samples (thank you Matt Small and other fishers who donated fish samples), and most importantly congeniality. We thank the able-bodied assistant James Hart for enthusiasm, attention to detail in data entry, observations, and help with the sampling. Jason Jude provided help with some of the figures. Kevin Wehrly provided historical data from IFR files.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

Introduction

PROJECT BACKGROUND

Gravel Lake is located in Sections 31 and 32 in Porter Township in Van Buren County, Michigan (T4S, R13W; Figure 1). In April of 2015, Progressive AE and Freshwater Physicians were retained by the Gravel Lake Association to conduct a limnological assessment of Gravel Lake. The purpose of this report is to discuss study findings, conclusions, and recommendations.

Figure 1. Gravel Lake location map.

LIMNOLOGICAL ASSESSMENT

Limnology is the study of the physical, chemical, and biological characteristics of a lake (Figure 2). Many of Michigan's lakes were formed thousands of years ago when glaciers scraped the landscape. The size and shape of the water-filled holes left behind by the glaciers often determines a lake's physical characteristics. Lakes can be large or small, deep or shallow, round or convoluted. Size and shape can greatly impact a lake's chemical and biological characteristics. Lake water chemistry can also be influenced by conditions outside of the lake, that is, in the lake's watershed. Given the wide array of physical and chemical conditions that can occur in a lake, a variety of plants and animals have adapted to living in lake environments. As such, each lake contains a unique combination of limnological characteristics.

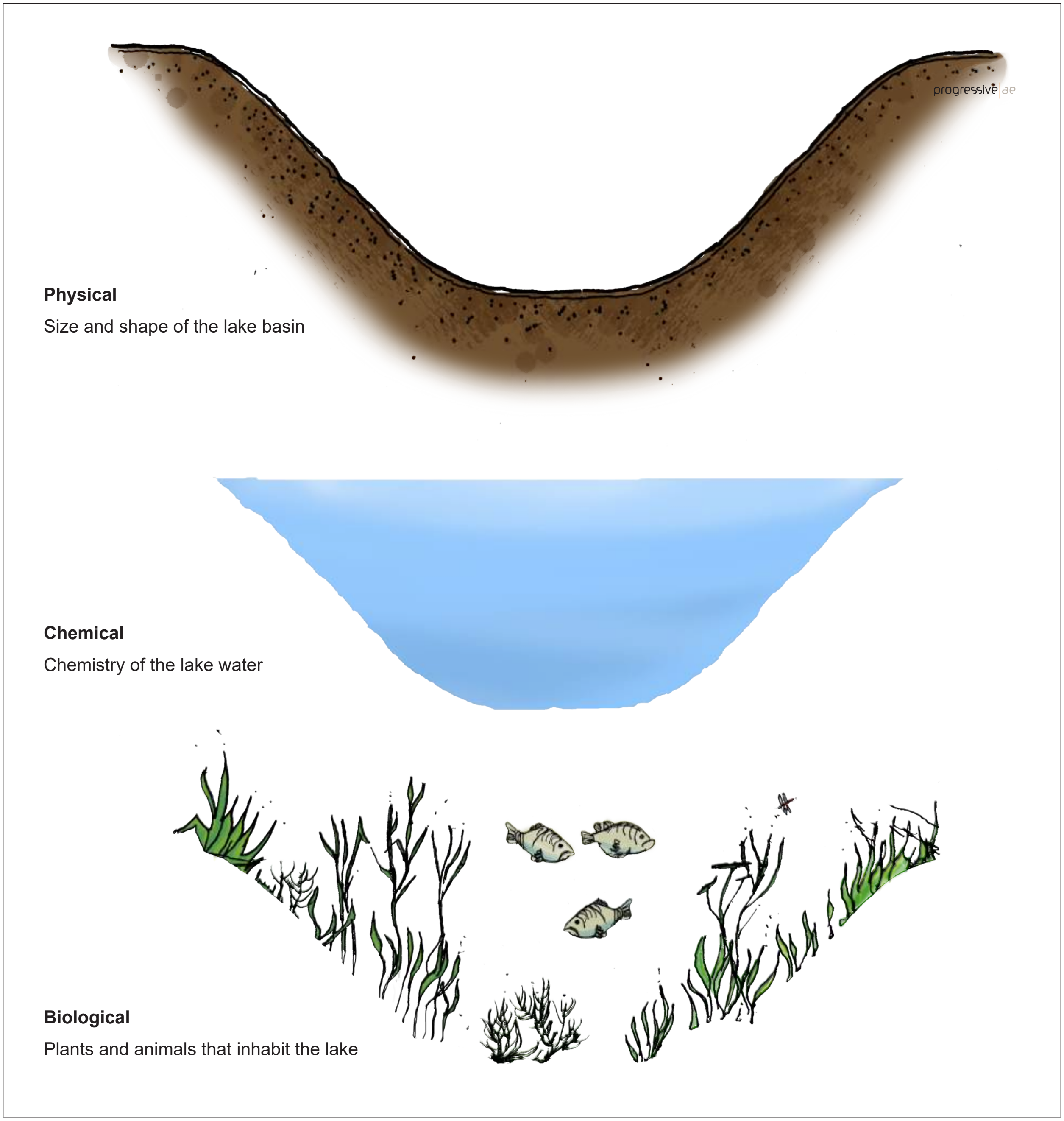

Figure 2. Limnological characteristics of a lake.

The physical, chemical, and biological characteristics of Gravel Lake were measured in order to determine the current condition of the lake. One way to classify a lake's condition is to determine its "trophic state," that is, how biologically productive the lake is. Lakes can be categorized as “oligotrophic,” “mesotrophic,” or “eutrophic” (Figure 3).

Oligotrophic lakes are generally deep and clear with little aquatic plant growth. These lakes maintain sufficient dissolved oxygen in the cool, deep bottom waters during late summer to support cold-water fish such as trout and whitefish.

Eutrophic lakes have poor clarity and support abundant aquatic plant growth. In deep eutrophic lakes, the cool bottom waters usually contain little or no dissolved oxygen. Therefore, these lakes can only support warm-water fish such as bass and bluegill.

Lakes that fall between the two extremes of oligotrophic and eutrophic are called mesotrophic lakes.

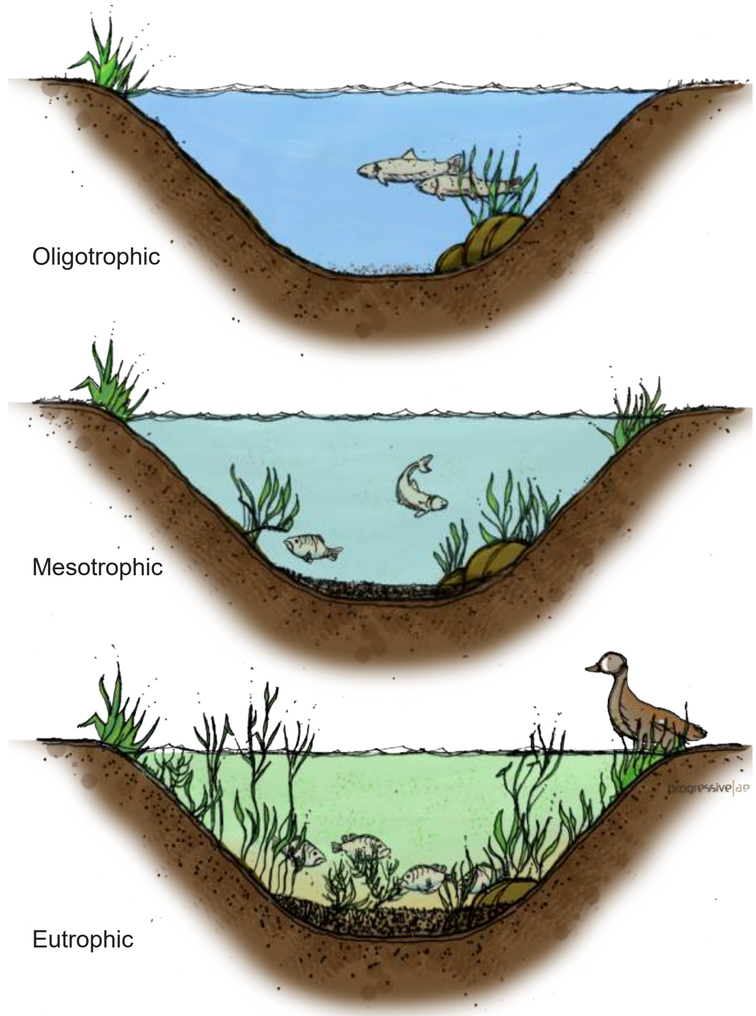

Figure 3. Lake classification.

Under natural conditions, most lakes will ultimately evolve to a eutrophic state as they gradually fill with sediment and organic matter transported to the lake from the surrounding watershed. The natural lake aging or eutrophication process takes many thousands of years. However, the natural aging process can be greatly accelerated if excessive amounts of sediment and nutrients (which stimulate aquatic plant growth) enter the lake from the surrounding watershed. Because these added inputs are usually associated with human activity, this accelerated lake aging process is often referred to as cultural eutrophication. Recent sampling of 729 lakes across Michigan indicates that, of the lakes sampled, about 15% of lakes are oligotrophic, about 55% are mesotrophic, and about 30% are eutrophic (Fuller and Taricska 2012).

Recent sampling of 729 lakes across Michigan indicates that, of the lakes sampled, about 15% of lakes are oligotrophic, about 55% are mesotrophic, and about 30% are eutrophic (Fuller and Taricska 2012).

In addition to examining the current limnological condition of Gravel Lake, the present study also included a review of historical information. Historical mapping and other data help to place the current information in context.

GRAVEL LAKE HISTORICAL MAPPING

Porter Township was originally mapped in December of 1829 and January of 1830 by Edward H. Sytle as part of the General Land Office survey when Michigan was still a territory (Figure 4). At that time, Gravel Lake was known as Round Lake.

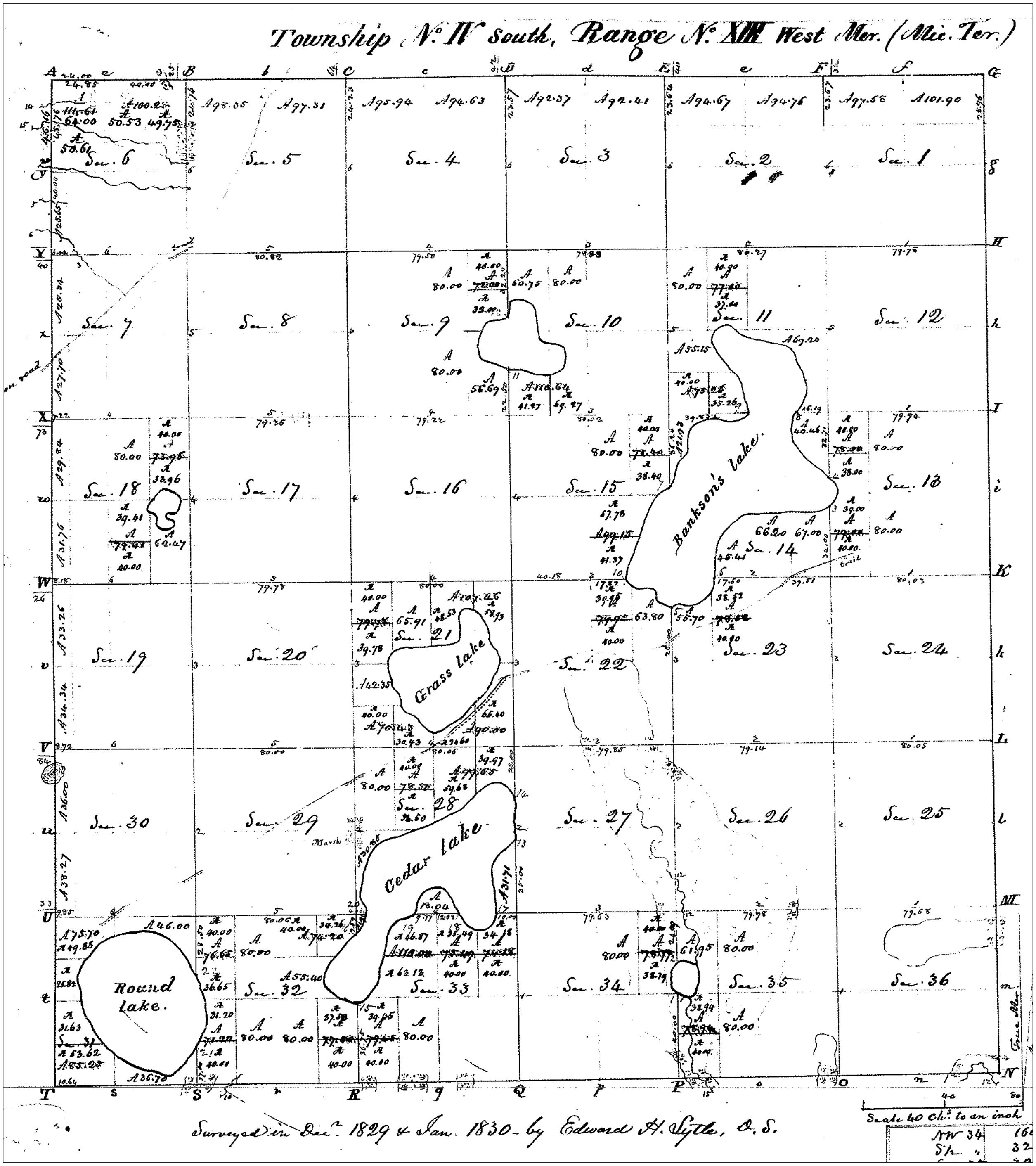

Figure 4. General Land Office plat of Township 4 South, 8 West, Michigan Territories, 1829-1830.

The oldest subdivisions around Gravel Lake, Streeter Beach and Winkler's, were platted in 1921 (Figure 5) and are visible on the east and south sides of the lake, respectively, in 1938 aerial photography (Figure 6) and 1944 topographic mapping (Figure 7). The remaining subdivisions were platted between 1945 and 1969.

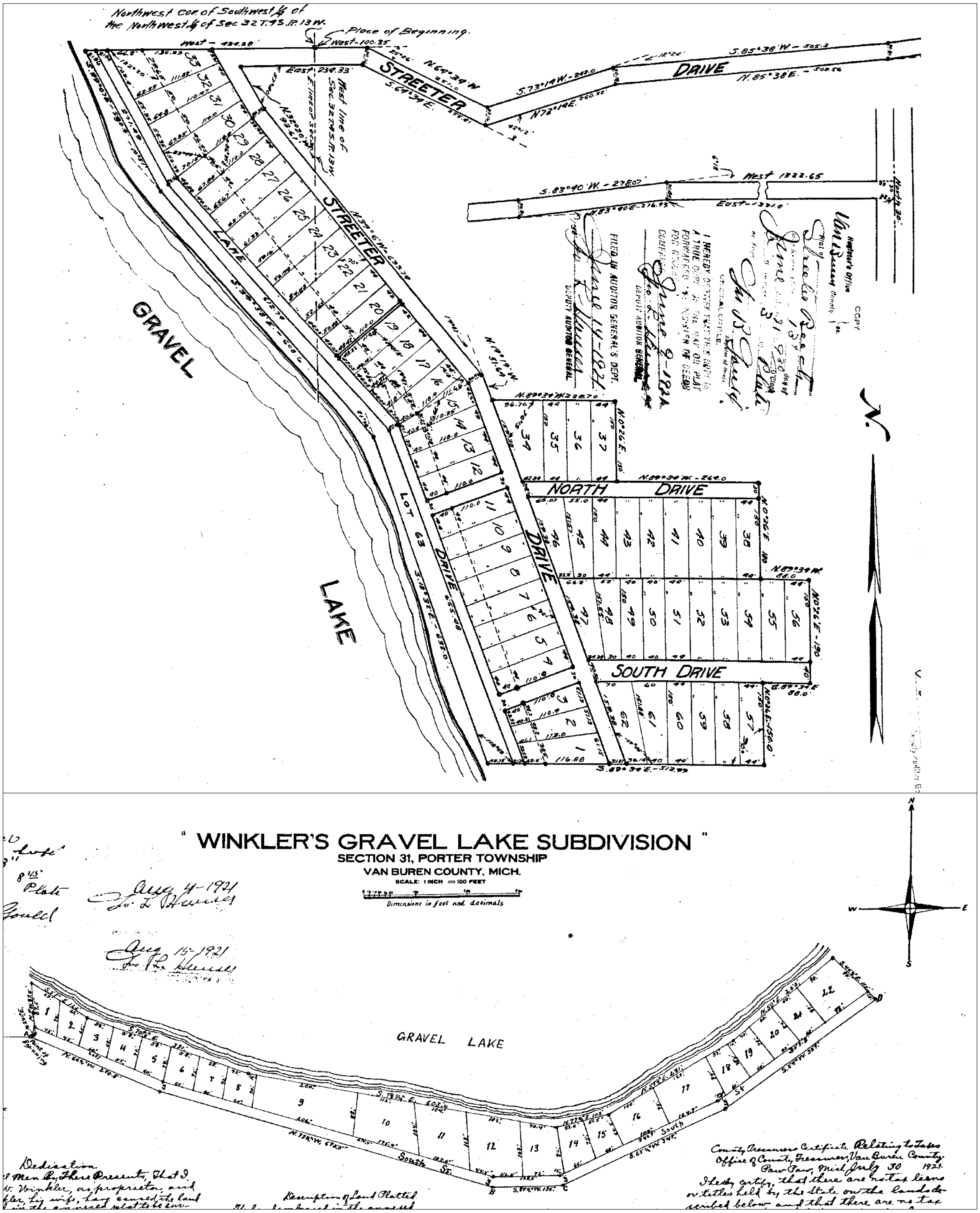

Figure 5. Streeter Beach (top) and Winkler's Gravel Lake Subdivision plat maps.

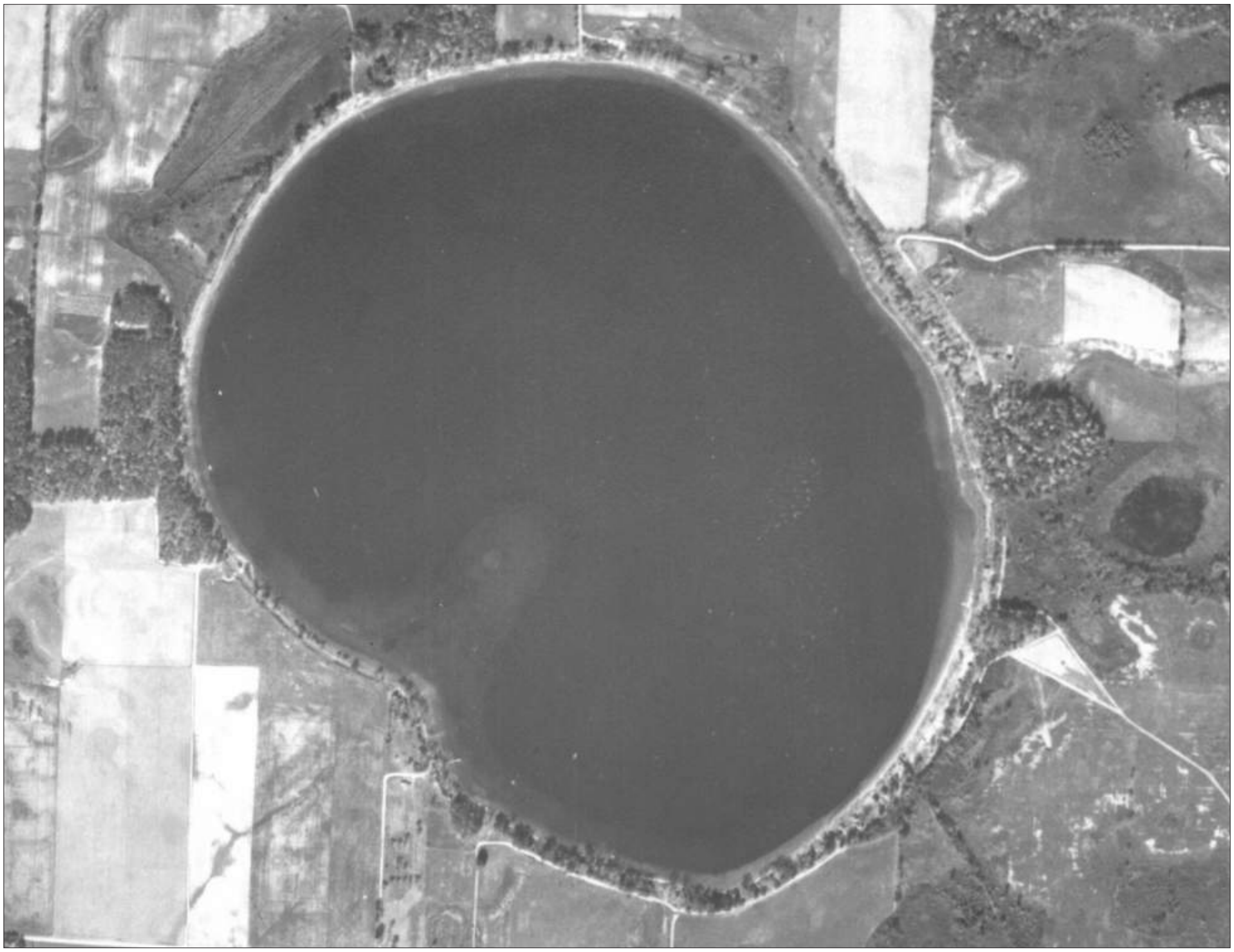

Figure 6. Gravel Lake aerial photograph, 1938. Source: USDA.

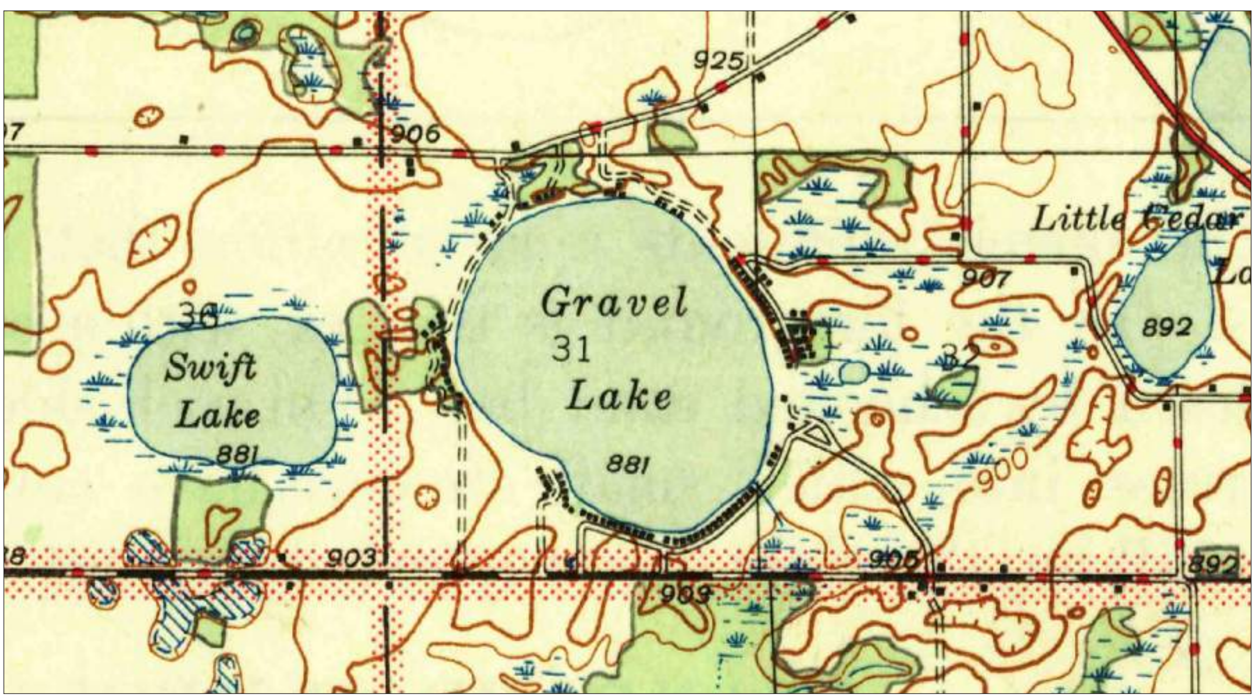

Figure 7. Gravel Lake area topography, 1946. Source: USGS 15 minute series topographic map, Marcellus, Mich. quadrangle (1946).

HISTORICAL DATA

Over the years, various groups and individuals have collected information about water quality, aquatic plants, and other related aspects of Gravel Lake that helped to inform the current study. Historical data is included in Appendix A and is summarized as follows:

1976: Kalamazoo Nature Center

1978: Western Michigan University study

1995: Water Quality Investigators report

1980-2015: Cooperative Lakes Monitoring Program (CLMP) Secchi transparency measurements

1993-2015: CLMP total phosphorus measurements

2001, April and August: Michigan Department of Natural Resources water quality sampling

2001, October 4: Michigan Department of Environmental Quality plant survey

2004-2015 PLM Lake and Land Management Corp. water quality sampling

2012: PLM Lake and Land Management Corp. lake management plan

2013, 2014: PLM Lake and Land Management Corp. aquatic vegetation assessment site surveys

1886-1979: Institute for Fisheries Research records

HISTORICAL LAKE MANAGEMENT ACTIVITIES

Residents have managed the growth of nuisance plants in Gravel Lake by contracting with companies for aquatic plant harvesting and herbicide applications since at least 1983:

1983, 1985: Maney's Aquatic Weed Harvesting Corp.: Harvesting in channel

1997, 1999: PLM Lake and Land Management Corp. harvesting

2000 (or earlier) - 2015: Herbicide treatments

In 2004, residents formed a special assessment district (SAD) for Porter Township to collect funds for the control of nuisance aquatic plants in Gravel Lake. The assessment district has been periodically renewed and is still currently in place.

In 2011, construction of a sewer system around Gravel Lake was completed. Construction was financed by the establishment of a separate SAD.

2007-2009, 2011-2014: Approximately 1,000 walleye in the 5- to 8-inch size range were stocked in Gravel Lake each year by the lake association.

Study Methods

PHYSICAL

The Gravel Lake shoreline was digitized from 2014 USDA FSA aerial orthodigital photography using ArcGIS software. A GPS-guided hydro-acoustic survey of Gravel Lake was conducted on July 10, 2015, in which transects were established at 100-foot intervals across the lake and the lake bottom was scanned along each transect using high-definition SONAR (Lowrance HDS 9). Hydro-acoustic data was uploaded to Navico BioBase for a kriging analysis to create interpolated mapping. Lake volume was calculated using the conical frustrum method (Wetzel and Likens 2010). Lake volume was divided by surface area to calculate mean depth. Shoreline development factor was calculated from shoreline length and surface area (Wetzel and Likens 2010). Shallowness ratio was calculated from the area less than five feet in depth divided by the total lake area (Wagner 1991).

CHEMICAL

Water quality sampling was conducted in the spring and late summer of 2015 at the two deep basins and the channel within Gravel Lake (Figure 8). Temperature was measured using a YSI Model 550A probe. Samples were collected at 10-foot intervals with a Van Dorn bottle to be analyzed for dissolved oxygen, total phosphorus, pH, and total alkalinity. Dissolved oxygen samples were fixed in the field and then transported to Progressive AE for analysis using the modified Winkler method (Standard Methods procedure 4500-O C). pH was measured in the field using a YSI EcoSense pH meter. Total phosphorus and total alkalinity samples were placed on ice and transported to Prein and Newhof and to Progressive AE, respectively, for analysis. Total phosphorus was analyzed at Prein and Newhof using Standard Methods procedure 4500-P E, and total alkalinity was titrated at Progressive AE using Standard Methods procedure 2320 B. In addition to the depth-interval samples at each deep basin, Secchi transparency was measured and composite chlorophyll-*a* samples were collected from the surface to a depth equal to twice the Secchi transparency. Chlorophyll-*a* samples were analyzed by Prein and Newhof using Standard Methods procedure 10200 H.

Sediment samples were collected during late summer from the two deep basins of the lake. The presence of a thick mat of starry stonewort (*Nitellopsis obtusa*) prevented staff from collecting a sediment sample from the channel. Samples were analyzed by Materials Testing Consultants for sediment composition using ASTM D422 and by Prein and Newhof for organic content using EPA Method 160.4.

Samples were collected during spring and late summer from the inlet and the outlet to Gravel Lake (Figure 8). Samples were analyzed for total phosphorus, total solids, and total suspended solids at Prein and Newhof. Total solids and total suspended solids were analyzed using EPA Method 160.3 and Standard Methods procedure 2540 D, respectively.

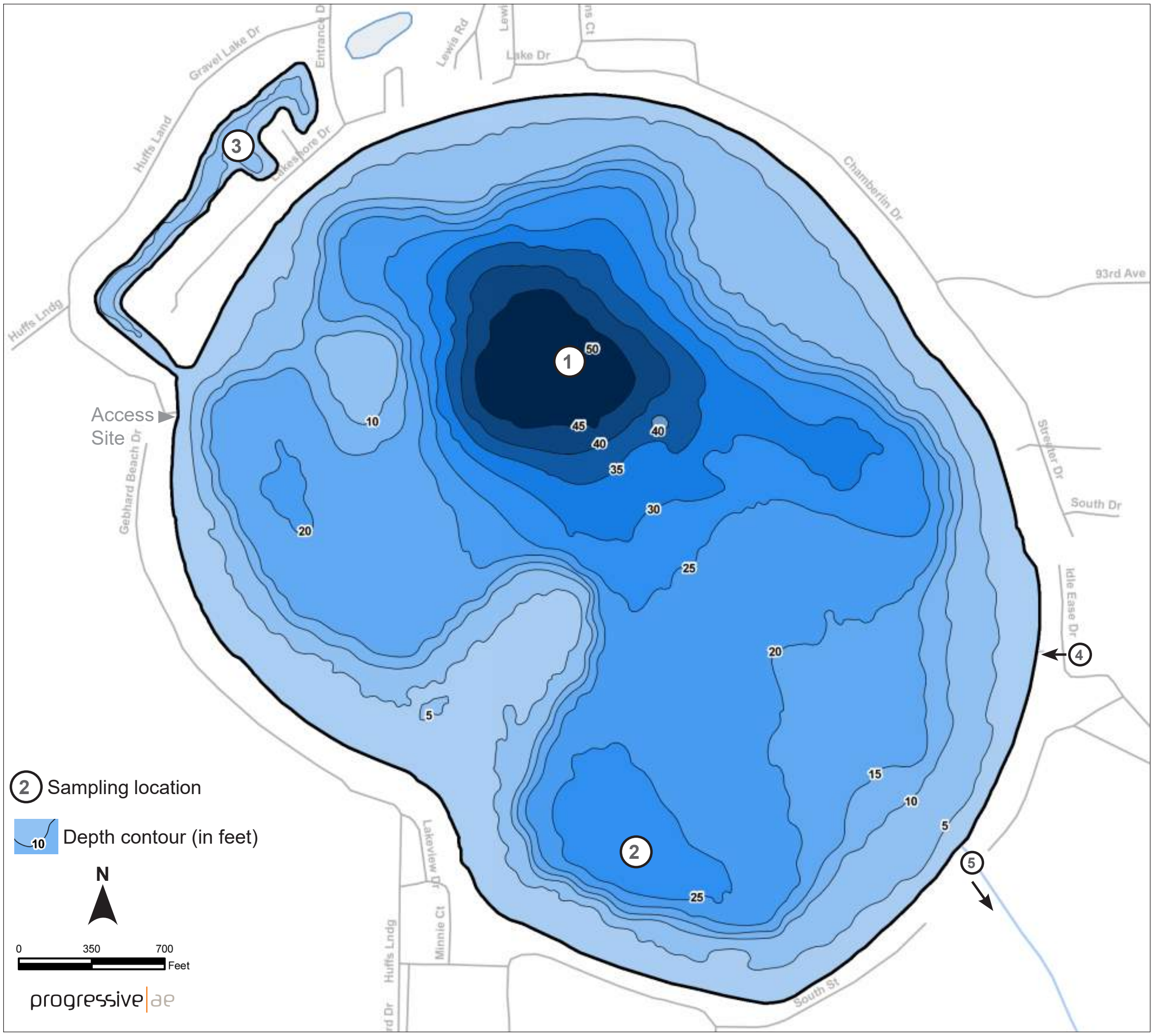

Figure 8. Gravel Lake water and sediment sampling location map.

BIOLOGICAL

Aquatic Vegetation Surveys

The plant survey of Gravel Lake was conducted in general conformance with Michigan Department of Environmental Quality (MDEQ) Procedures for Aquatic Vegetation Surveys (2016). GPS reference points were established at one-acre grid intervals throughout the vegetated portions of the lake based on hydro-acoustic survey data and at 300-foot intervals along the shoreline (Figure 9). At each reference point, an assessment was made of the type and relative abundance of all plant species present. Plant densities were recorded in accordance with MDEQ procedures as follows: (a) = found: one or two plants of a species found at a site, equivalent to less than 2% of the total site surface area; (b) = sparse: scattered distribution of a species at a site, equivalent to between 2% and 20% of the total site surface area; (c) = common: common distribution of a species where the species is easily found at a site, equivalent to between 21% and 60% of the total site surface area; (d) = dense: dense distribution of a species where the species is present in considerable quantities throughout a site, equivalent to greater than 60% of the total site surface area. Data for each individual assessment site was then recorded, compiled and tabulated to evaluate the relative abundance of all plant species in Gravel Lake.

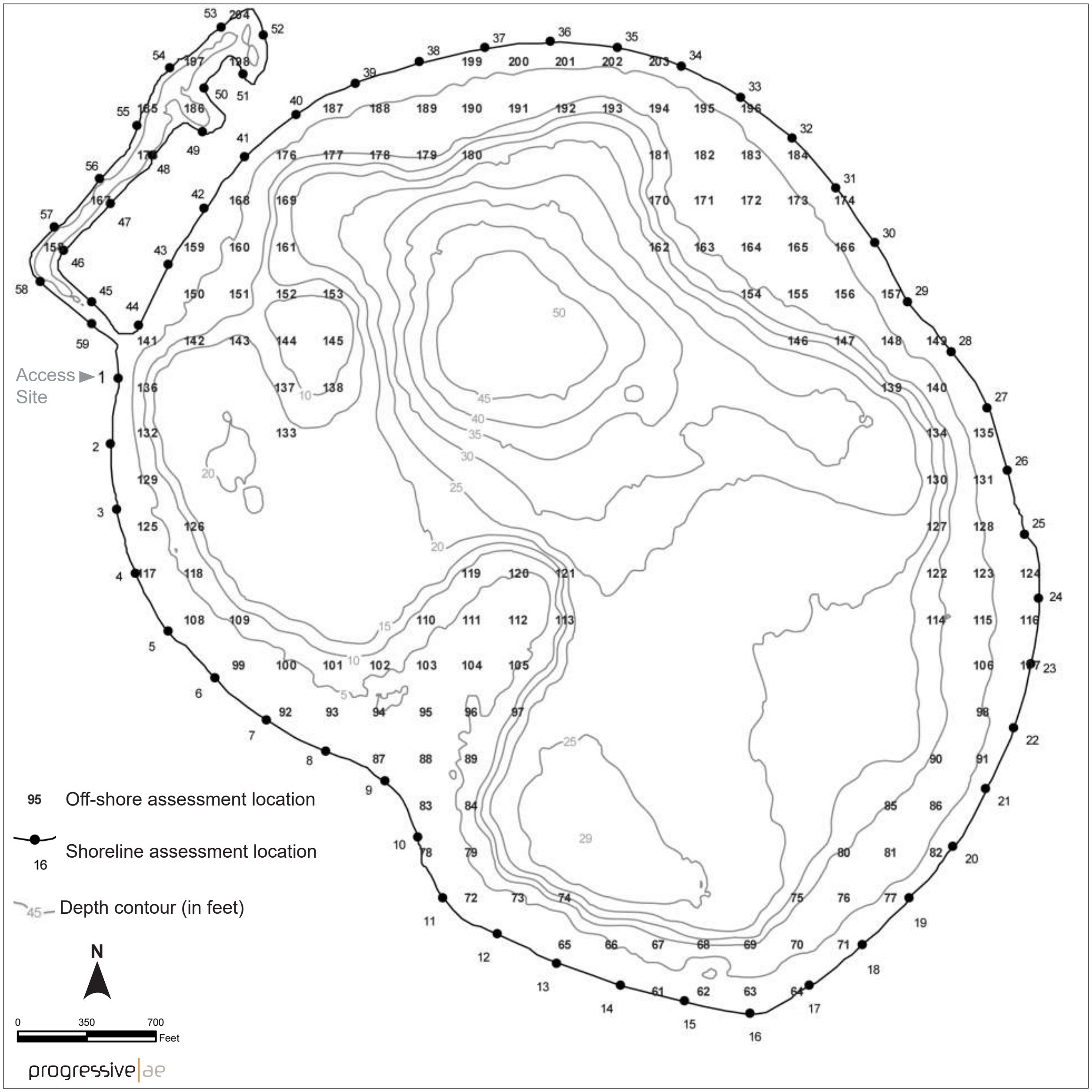

Figure 9. Gravel Lake aquatic plant survey location map.

Non-native Milfoil Genetic Analysis

Three samples of non-native milfoil were collected from each of two sites (#41 and #77) for genetic analysis to determine whether hybrid milfoil is present in Gravel Lake. Tissue samples were transported to AquaGen[1] laboratory and genetically identified using an Internal Transcribed Spacer (ITS) restriction analysis (Moody and Les. 2002; Thum et al. 2006; Moody and Les 2007; Zuellig and Thum 2012; Grafé et al. 2015).

Fish Habitat

Gravel Lake was examined for sediment type (is there gravel for sunfish and bass spawning available), abundance and diversity of aquatic plants, depth contours, and wetlands/streams that could be used for spawning.

1 Robert B. Annis Water Resources Institute, 740 West Shoreline Drive, Muskegon, MI 49441.

Fish Population Assessment

We collected fish using three trap nets at six stations; a 50-foot seine at three stations; and two gill nets at four stations (Figures 10 through 13). Nets were deployed at various times and depths from July 29 to 31, 2015 (Table 1). The gill nets were used during the daytime only and checked often to reduce deaths of large predators. The gill nets were picked up and reset the same day, while trap nets were left overnight and reset the next day for two consecutive days. Seining was done at three sites on the lake in different habitats. Most fish were released; we kept enough for an adequate sample for ageing and diet analyses. We never want to kill too many fish, especially top predators, as they are so important to fish community balance in a lake. We could have used a few more large fish (especially largemouth bass), but the ones we did catch and those that were donated by fishers provided a fairly good sample for some basic information on the lake. We are grateful for fisherman who helped us.

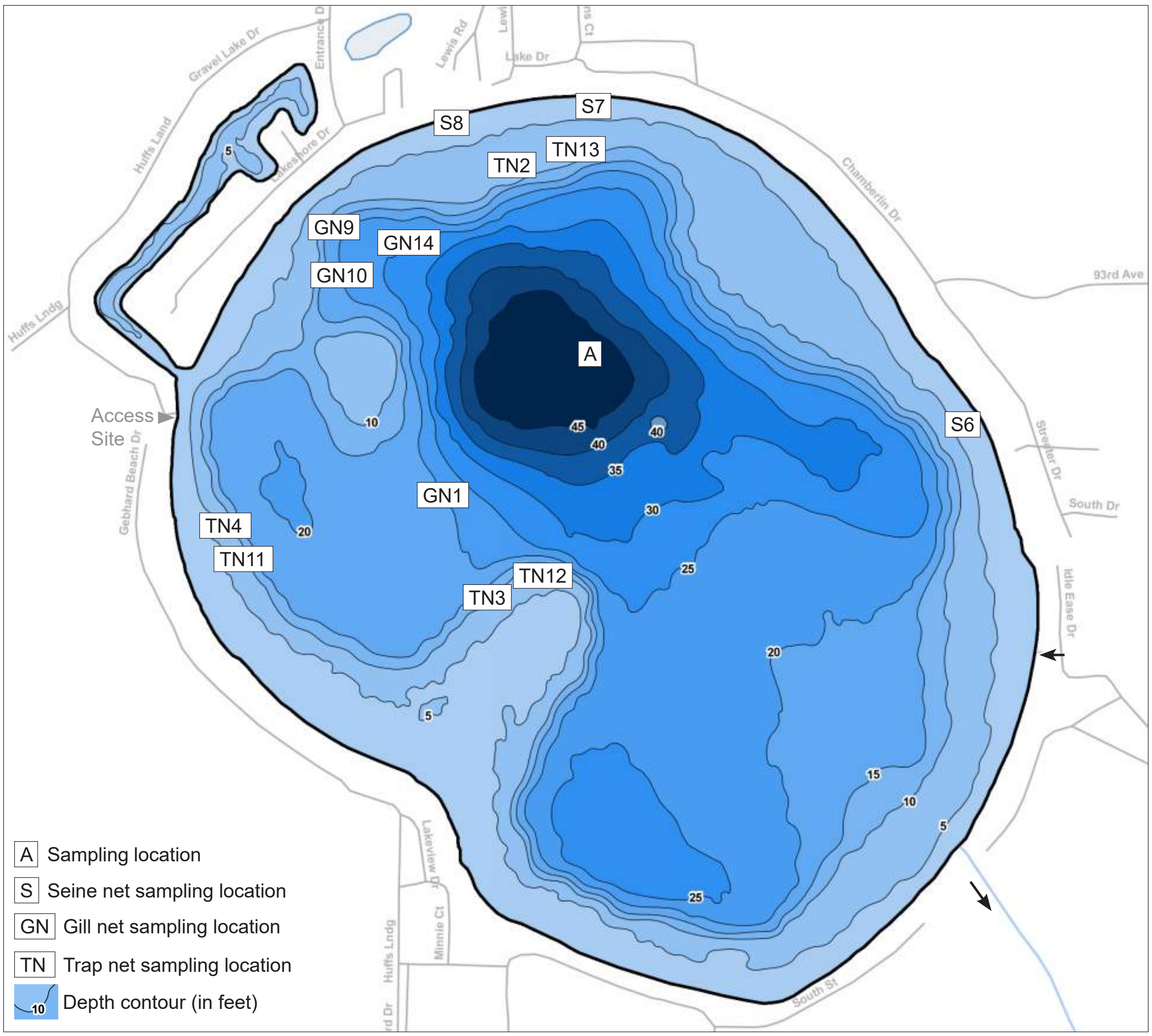

Figure 10. Gravel Lake fish sampling location map.

Figure 11. Trap net with fish.

Figure 12. Seining with the 50-foot seine.

Figure 13. Gill net being retrieved with fish.

TABLE 1
GRAVEL LAKE FISH SAMPLING STATION DESCRIPTIONS

	Set		Retrieved			Depth
Station	**Date**	**Time**	**Date**	**Time**	**Latitude and Longitude**	**(feet)**
GN1	29-Jul-15	1038	29-Jul-15	1405	42.077153N -85.869468W	18-25
GN9	29-Jul-15	1415	29-Jul-15	1702	42.080387N -85.871523W	15-23
GN10	30-Jul-15	1047	30-Jul-15	1429	42.079996N -85.871363W	18-20
GN14	30-Jul-15	1428	30-Jul-15	1835	42.080838N -85.869172W	18-20
TN2	29-Jul-15	1113	30-Jul-15	1055	42.081214N -85.868562W	9-14
TN3	29-Jul-15	1123	30-Jul-15	1133	42.076076N -85.868373W	9-25
TN4	29-Jul-15	1135	30-Jul-15	1157	42.075738N -85.872610W	9
TN11	30-Jul-15	1105	31-Jul-15	1010	42.075394N -85.872058W	9-10
TN12	30-Jul-15	1123	31-Jul-15	948	42.076090N -85.867830W	6-10
TN13	30-Jul-15	1139	31-Jul-15	957	42.081618N -85.867172W	5-20
S6	29-Jul-15	1229	29-Jul-15	1235	42.080569N -85.862516W	1-5
S7	29-Jul-15	1290	29-Jul-15	1301	42.082464N -85.867022W	1-5
S8	29-Jul-15	1312	29-Jul-15	1338	42.082209N -85.869275W	1-4

Fishes were placed on ice and processed in the laboratory as follows: Each fish was weighed to the nearest 0.01 gram, measured to the nearest 1 millimeter (mm). Data was converted to the English system for the report. If there were large numbers of some species or sizes, a special sub-sampling technique was used that calculates the lengths and weights of the fish not weighed or measured. Fish were aged from scale samples collected when measured and average lengths at age compared with Michigan state averages. Diets were analyzed to determine what the various fishes are eating. Any large sport fishes captured alive were measured and a scale sample taken and then released. Sport fishers were requested to save a scale sample of top predators that fishers intended to release; and to save the stomachs and a scale sample of top predators that were not released.

Zooplankton

Zooplankton were collected by towing a No. 10 plankton net (mesh size of 153 microns) through the water and the resulting sample was preserved with 10% formaldehyde and then examined microscopically in the laboratory.

Results and Discussion

PHYSICAL CHARACTERISTICS

Gravel Lake was originally mapped by the Michigan Conservation Department (MCD) Institute for Fisheries Research from January 19 to 22 in 1949 (Figure 14). Many of the early MCD lake surveys were conducted during the winter months. Holes were drilled through the ice and water depths were measured with weighted drop lines.

Figure 14. Gravel Lake 1949 depth contour map. Source: Michigan Conservation Department Institute for Fisheries Research.

At that time, most of the lake bottom in the near-shore areas was sandy; deep areas contained pulpy peat; and the intermediate areas contained marl, which is a naturally-occurring calcium carbonate substance similar to finely graded limestone. The maximum depth of the lake was 51 feet with a 22-foot basin at the northwest end and a 30-foot basin at the south end of the lake.

With the exception of the channel excavation at the northwest end of the lake, there has been very little change in Gravel Lake since 1949; the Department of Conservation map is very similar to the map prepared during the current study (Figure 15). The maximum depths are nearly identical, and the size and location of the deep holes and shallow regions are largely unchanged. Hydro-acoustic soundings conducted during the study indicate that much of the near-shore sediments in the lake remain firm.

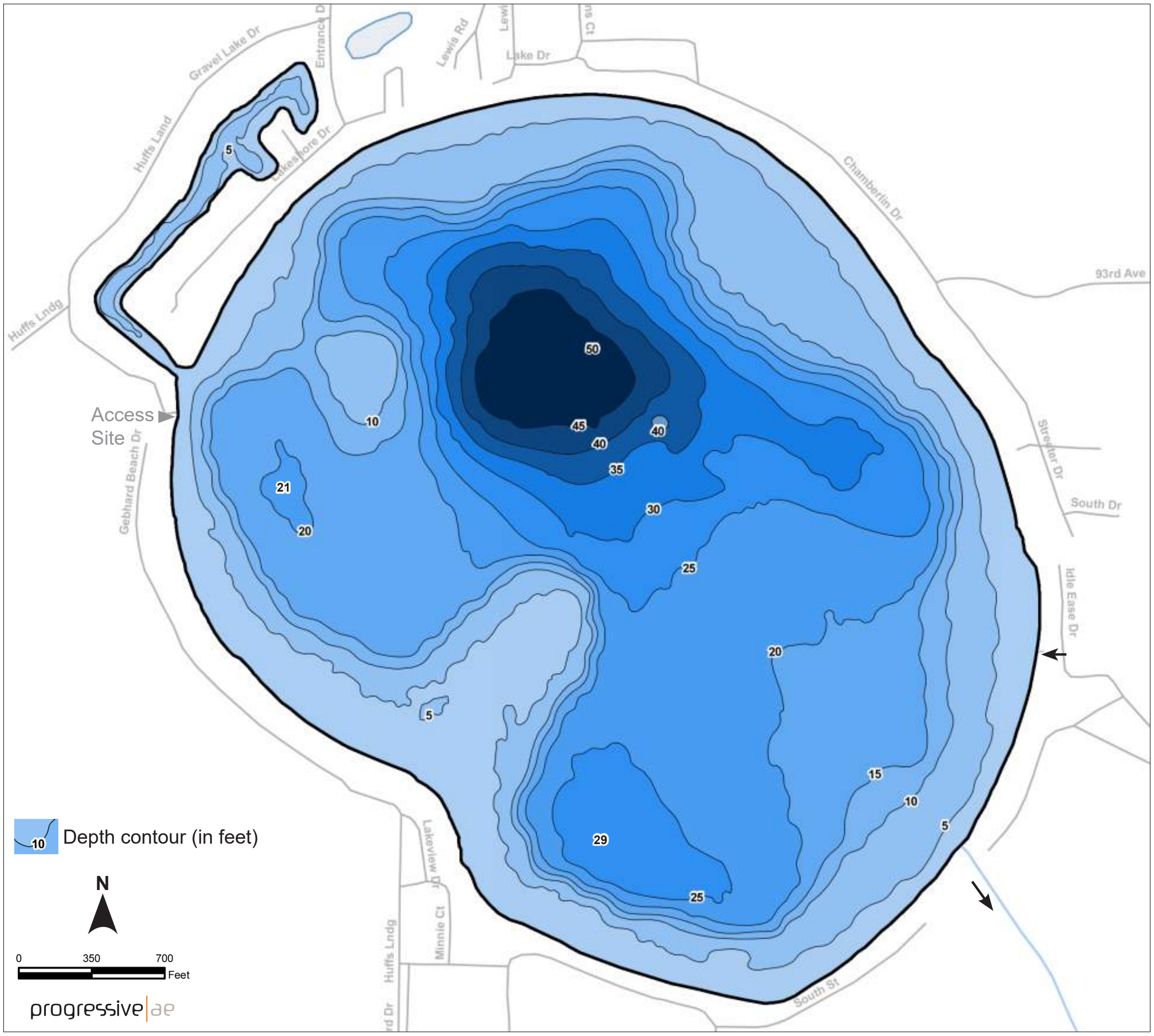

Figure 15. Gravel Lake 2015 depth contour map. Hydro-acoustic data collected on July 10, 2015 and processed by Navico. Lake shoreline digitized from 2014 aerial orthodigital photography (Source: USDA FSA).

A summary of the physical characteristics of Gravel Lake and its watershed is provided in Table 2. The Department of Conservation measured the surface area of Gravel Lake at 296 acres. Based on recent aerial photography, the shoreline was measured at 302 acres during the current study. Using information available from the State's GIS Open Data, Gravel Lake is the 387th largest inland lake in Michigan. With 10,031 lakes that are 5 acres in size or larger, Gravel Lake is in the top 4 percent of Michigan inland lakes by surface area.

TABLE 2
GRAVEL LAKE AND WATERSHED PHYSICAL CHARACTERISTICS

Lake Surface Area	302	acres
Maximum Depth	50	feet
Mean Depth	17.1	feet
Lake Volume	5,178	acre-feet
Shoreline Length	3.4	miles
Shoreline Development Factor	1.4	
Shallowness Factor	0.2	
Legal Lake Level	881.3	feet
Lake Residence Time	0.9	years
Watershed Area	1,830	acres
Ratio of Lake Area to Watershed Area	6.1	

The mean, or average, depth of Gravel Lake is 17.1 feet. Since aquatic plants can grow to a depth of about 20 feet, a significant portion of the lake bottom is shallow enough for plants to grow. However, depths in Gravel Lake are sufficient to allow navigation throughout most of the lake.

Gravel Lake contains 5,178 acre-feet of water, a volume which would cover an area just over 8 square miles to a depth of 1 foot.

Shoreline development factor is a measure of the irregularity of the shoreline. A lake with a perfectly circular shoreline would have a shoreline development factor of 1.0. Shoreline development factor increases as the shoreline becomes more convoluted. In Michigan, shoreline development factor ranges from 1.0 to 13.5 (Figure 16). The lakes with the highest shoreline development factors are usually impoundments, i.e., reservoirs. Shoreline development factor is significant because lakes with more irregular shorelines can accommodate more buildings and other development, which can lead to greater pollution runoff and lake overcrowding. In addition, more convoluted shorelines can support more aquatic plant growth. Wagner (1991) noted:

> The ratio of the length of shoreline around the lake to the circumference of a circle with the same area as the lake [shoreline development factor] provides a size-independent measure of the lake shape and indicates much about how motorized watercraft could affect the water body. Higher ratios suggest irregular shorelines with more waterfront per unit area than smaller ratios. Numerous coves may serve to isolate impacts, but there is a greater potential for the shoreline to be affected. High ratios also imply greater safety risks as well as ecological consequences.

Gravel Lake has a relatively low shoreline development factor of 1.4.

The shallowness ratio compares the area of the lake less than 5 feet deep to the total lake area, and indicates the degree to which the lake bottom area is likely to be directly affected by motorized watercraft. Impacts of primary concern include sediment suspension, turbidity, and destruction of fish habitat. Shallowness ratios range from low (less than 0.10) for lakes unlikely to be impacted to high (greater than 0.50) for lakes with a high potential for impact. Gravel Lake has a shallowness ratio of 0.2 which indicates that the potential impact of motorized watercraft on the lake is moderate.

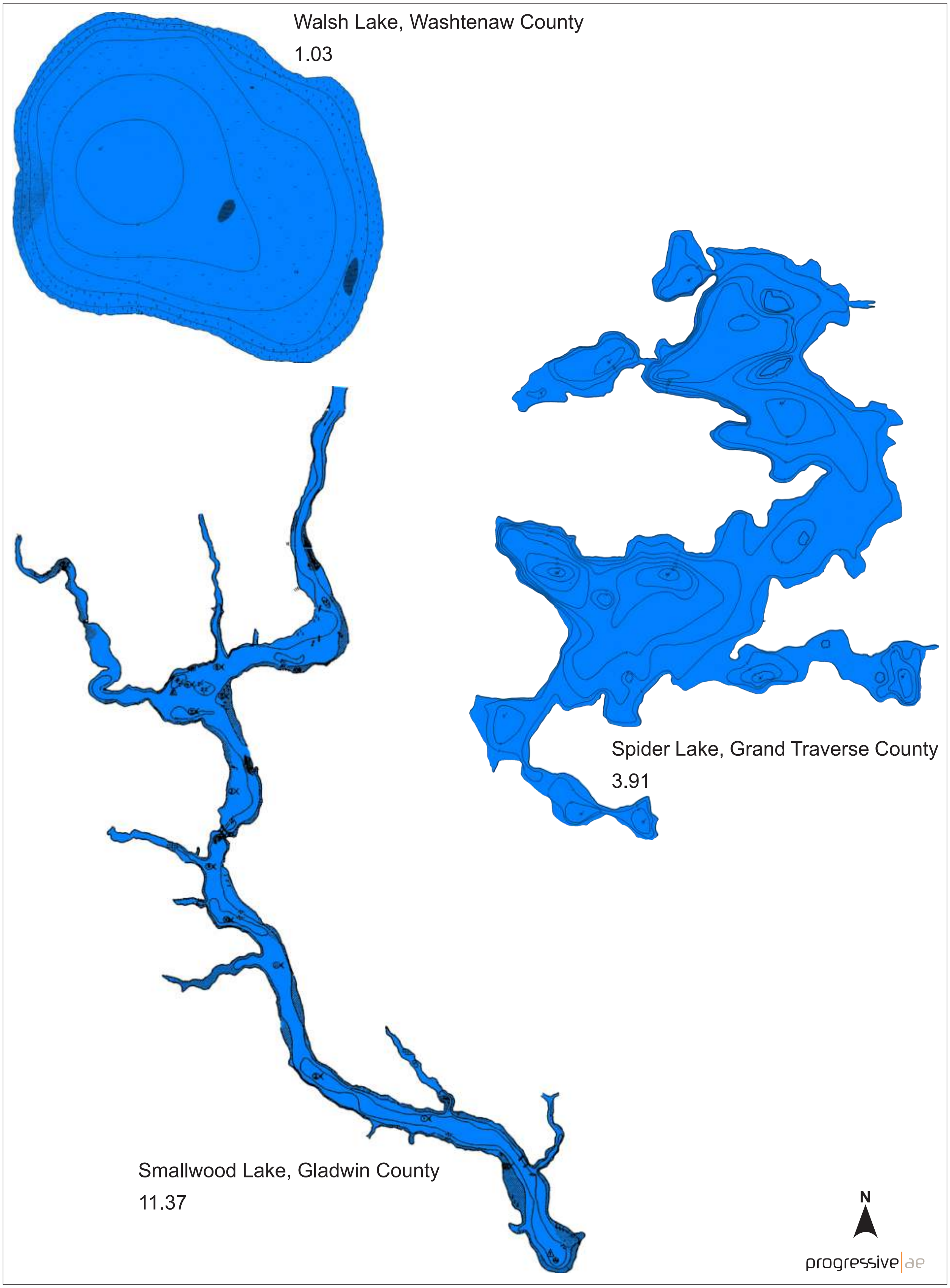

Figure 16. Shoreline development factor of select Michigan inland lakes. Base maps prepared by Michigan Department of Natural Resources, or predecessor agencies. Shoreline development factor calculations based on surface area and shoreline length data from Michigan GIS Open Data.

Currently, approximately 275 seasonal and year-round homes border Gravel Lake. With 3.4 miles of shoreline, the average lot width is 64 feet, excluding vacant lots. Only about 5 percent of the Gravel Lake shoreline is "natural," meaning that it contains trees, shrubs, or other native plants (Figure 17). The remainder of the shoreline contains turf grass, beach, seawalls or other hardened surfaces (Figure 18).

Natural shoreline is important for habitat and water quality protection. In the first-ever nationwide assessment of lakes, the U.S. Environmental Protection Agency evaluated several stressors of lakes. Of the factors evaluated, lack of shoreline vegetation was the biggest problem facing the nation's lakes. Lakes with poor shoreline habitat were three times more likely to be in poor biological condition (U.S. EPA 2009).

Figure 17. Natural shoreline on Gravel Lake.

Figure 18. Disturbed shoreline on Gravel Lake.

Gravel Lake's legal level of 881.3 feet was set by Circuit Court order on July 25, 1949 and is controlled by a sheet-pile structure constructed in 1950 (Figures 19 and 20; Appendix B). The outlet flows south to Saddlebag, Fish, Finch, and Bunker Lakes in Cass County, then to Dowagiac Creek, Pokagon Creek, the Dowagiac River, and the St. Joseph River where it flows into Lake Michigan at the cities of St. Joseph and Benton Harbor. Gravel Lake is about 300 feet higher in elevation than Lake Michigan. Based on outflow estimates from the Michigan Department of Environmental Quality (Appendix C), it takes just under one year for all the water in Gravel Lake to be flushed out and replaced with incoming water, a factor known as the lake residence time or flushing rate. By comparison, some impoundments can be flushed in a matter of hours while the water residence time for Higgins Lake in Roscommon County is approximately 10 years.

Figure 19. Gravel Lake level control structure and adjacent embankment sheet piling.

Figure 20. Close-up of Gravel Lake level control structure.

The land area surrounding a lake that drains to the lake is called its watershed or drainage basin. The watershed boundary is determined by examining a topographic map that shows elevation of the surrounding land area to determine direction of flow to and away from the lake (Figure 21).

Figure 21. USGS topographic map of Gravel Lake area. Base map: USGS 7.5 minute series topographic maps, Decatur quadrangle (1981) and Marcellus quadrangle (1981).

Based on USGS topographic mapping alone, the Gravel Lake watershed includes drainage from Little Cedar Lake and Cedar Lake which lie to the east of Gravel Lake. However, the Cedar Lake intercounty drain bypasses Gravel Lake and routes drainage to the Gravel Lake outlet stream (Figure 22).

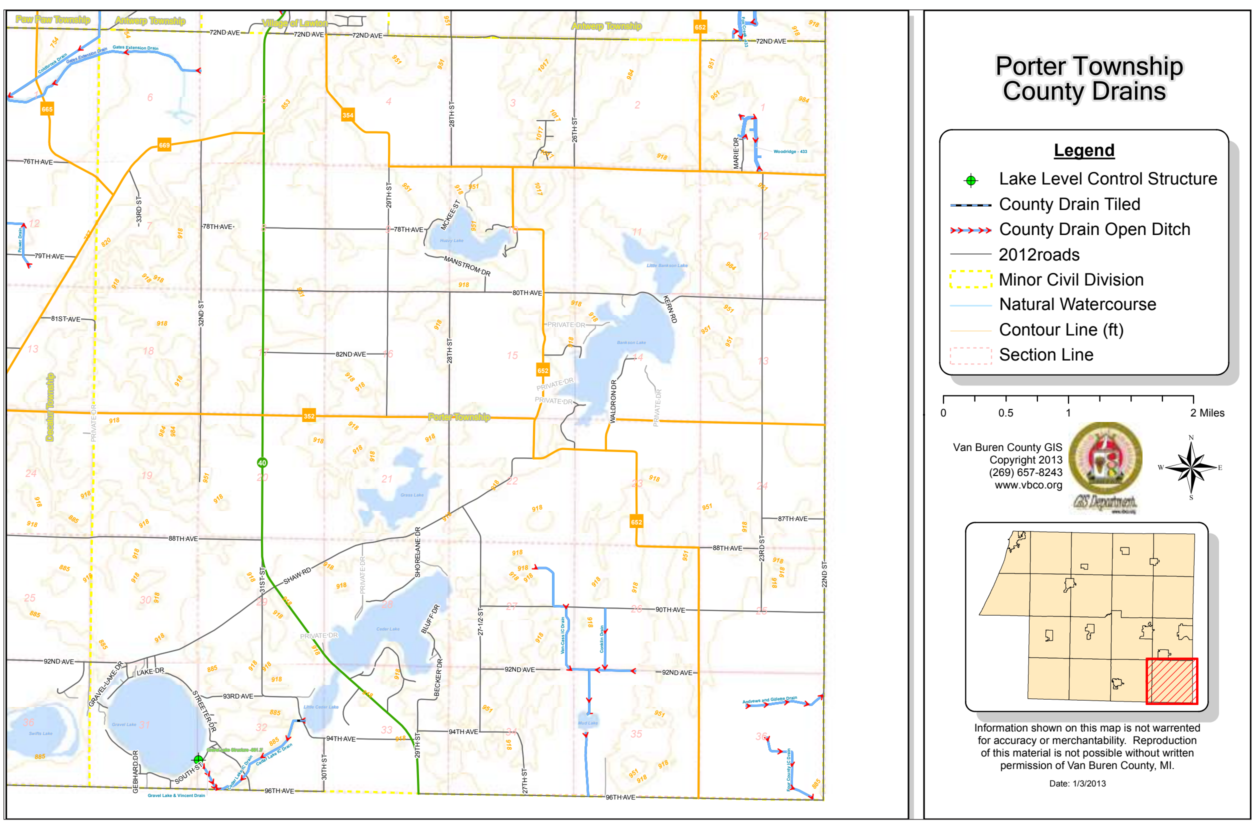

Figure 22. Porter Township County Drains. Source: Van Buren County GIS.

When drainage from Little Cedar and Cedar Lakes is excluded, the Gravel Lake watershed is 1,830 acres, an area approximately 6 times larger than lake itself (Table 2; Figure 23). There are no tributary streams that drain to Gravel Lake; surface water sheet-flows to the lake from overland runoff. There is a wetland on the east side of the lake that drains to the lake via a culvert under Drive D (Idle Ease Drive).

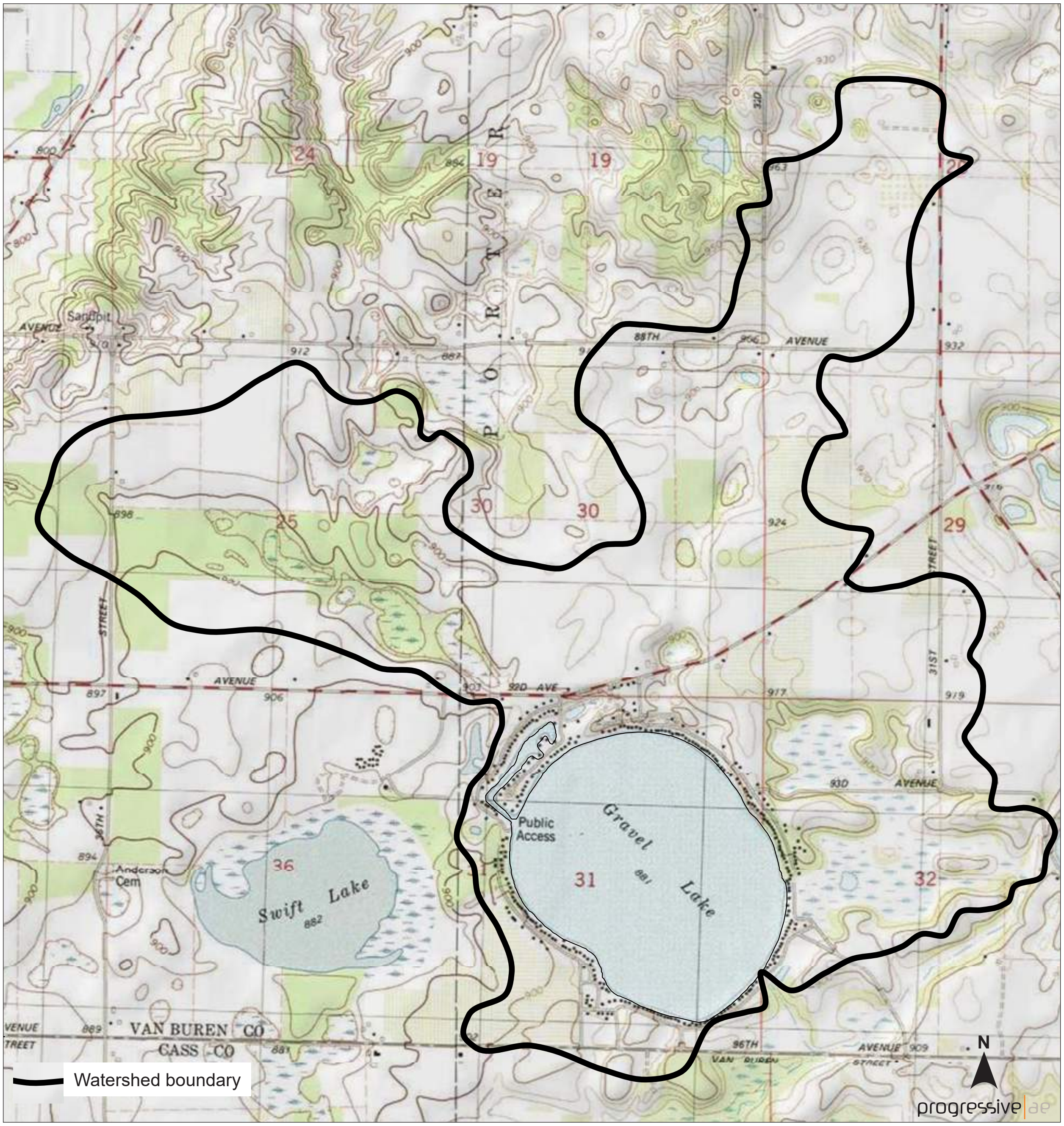

Figure 23. Gravel Lake watershed topography map. Base map: USGS 7.5 minute series topographic maps, Decatur quadrangle (1981) and Marcellus quadrangle (1981). Contour interval: 10 feet.

While a majority of the Gravel Lake watershed is agricultural land, it is generally located several hundred feet from the lake behind residential development that directly borders the lake (Table 3 and Figures 24 and 25).

TABLE 3
GRAVEL LAKE WATERSHED LAND USE[1]

Land Use	Acres	Percent of Total
Agricultural	1,202	66%
Residential	114	6%
Forested	341	19%
Open Space	56	3%
Wetland	117	6%
Total	1,830	100%

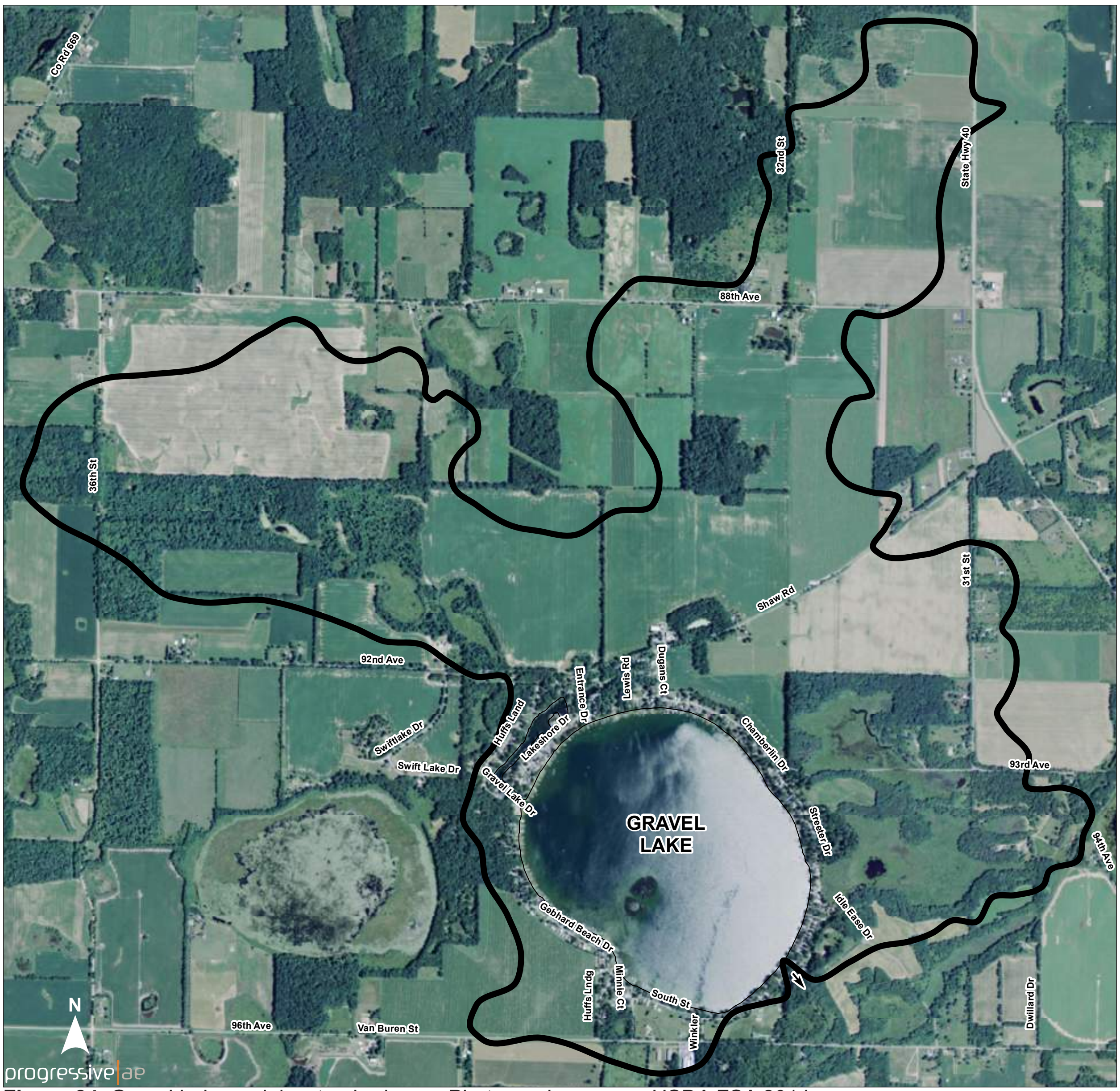

Figure 24. Gravel Lake aerial watershed map. Photography source: USDA FSA 2014.

1 Source: Michigan Geographic Data Library; originator: Michigan Department of Natural Resources; publication date: 1999; based on 1978 aerial photography.

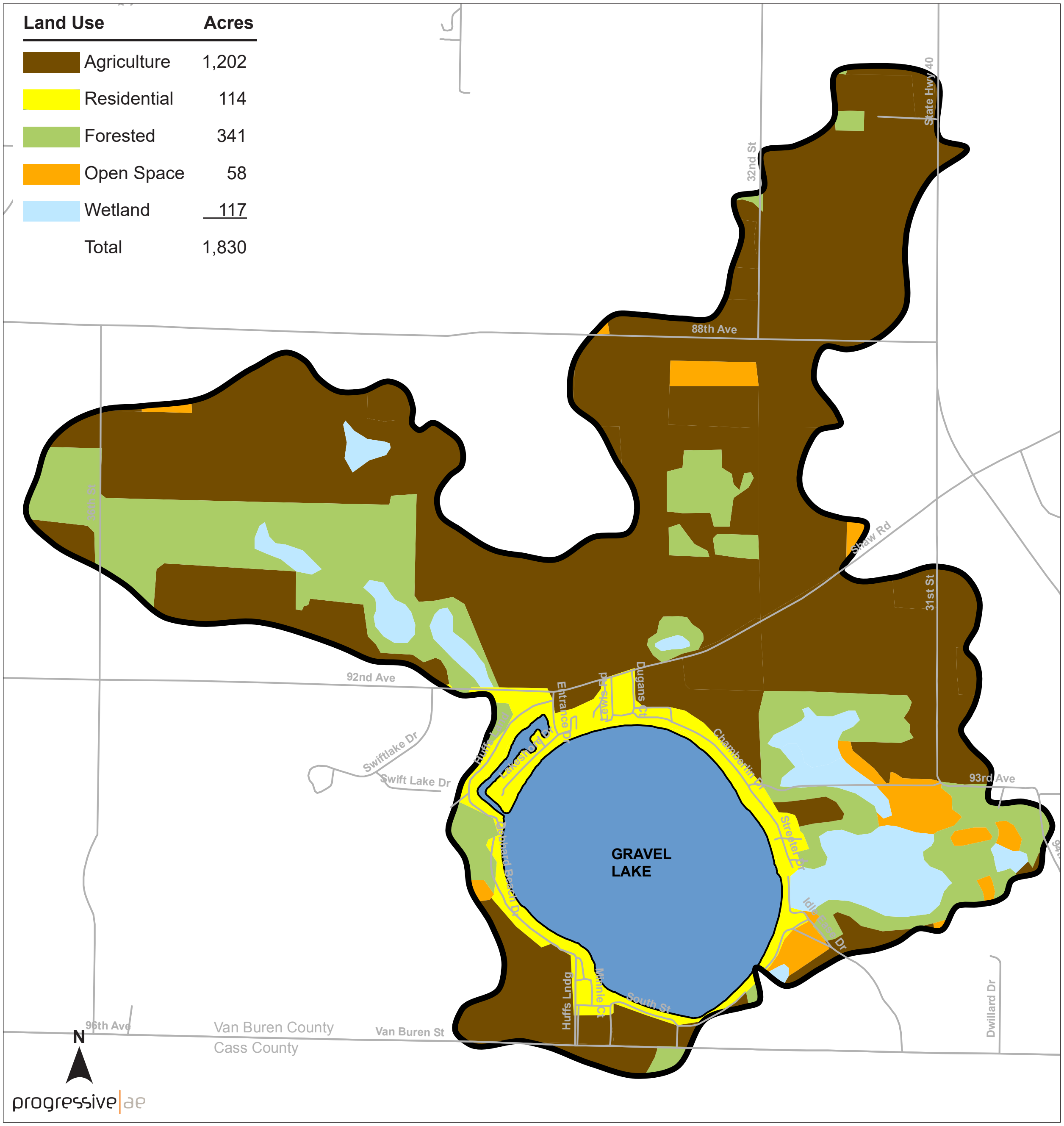

Figure 25. Gravel Lake watershed land use map. Source: Michigan Geographic Data Library; originator: Michigan Department of Natural Resources; publication date: 1999; based on 1978 aerial photography.

While agriculture is the predominant land use in the Gravel Lake watershed, there is little direct drainage from area farmlands to the lake. The impact of farmland runoff appears to be further mitigated by forested areas and wetlands in the watershed that act to trap and prevent nutrient and sediment transport to Gravel Lake. By contrast, residential development in the Gravel Lake watershed is concentrated in close proximity to the lake, and drainage tends to flow directly to the lake. As such, the residential lands in the Gravel Lake watershed have a greater potential to impact water quality. Maintaining and restoring natural areas around the lake may be one of the most important things lake residents can do to protect water quality. Fortunately, pollution from septic systems was eliminated with the construction of the sewer system in 2011.

The majority of soils in the watershed are Oshtemo sandy loam and Kalamazoo loam which are, in general, well-drained soils with low to moderate runoff potential (Figures 26 and 27). As such, it is likely that runoff would tend to infiltrate to the groundwater rather than reaching the lake as surface runoff. Runoff from land abutting the lake, i.e., the residential area, has the greatest potential to impact Gravel Lake water quality for two reasons: close proximity to the lake and the prevalence of impervious surfaces. Rooftops, driveways, and other hard surfaces hasten the delivery of runoff, rather than promoting groundwater infiltration.

Van Buren County

Soil		Slope	Acres
6B	Oshtemo sandy loam	0 to 6	477
6C	Oshtemo sandy loam	6 to 12	251
6D	Oshtemo-Coloma loamy sands	12 to 18	98
6E	Oshtemo-Coloma loamy sands	18 to 25	1
12B	Spinks-Oshtemo complex	0 to 6	17
12C	Spinks-Oshtemo complex	6 to 12	8
18B	Ormas loamy sand	0 to 6	4
22A	Kalamazoo loam	0 to 2	282
22B	Kalamazoo loam	2 to 6	419
22C	Kalamazoo loam	6 to 12	64
24A	Bronson sandy loam	0 to 3	3
26	Gilford sandy loam	0 to 1	25
28	Houghton muck	0 to 1	104
39A	Matherton loam	0 to 2	9
61B	Udipsamments and Udorthents	0 to 4	27
W	Water		28
		Total:	1,815

Cass County

Soil		Slope	Acres
4B	Oshtemo sandy loam	2 to 6	9
9A	Kalamazoo loam	0 to 2	4
9B	Kalamazoo loam	2 to 6	<1
9C	Kalamazoo loam	6 to 12	2
9D	Kalamazoo loam	12 to 18	<1
12A	Brady sandy loam	0 to 2	2
		Total:	17

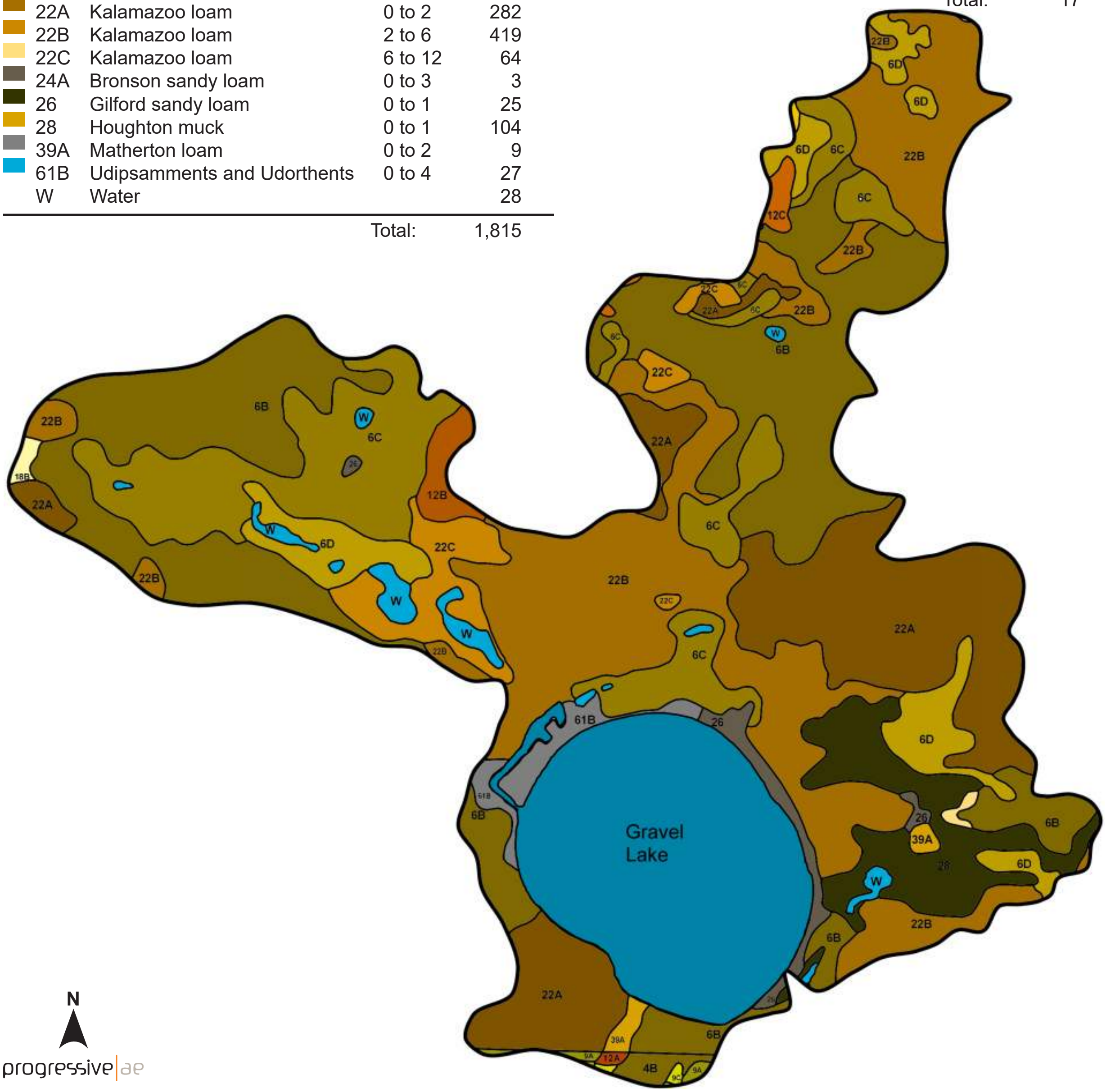

Figure 26. Gravel Lake watershed soils map. Source: Soil Survey staff, Natural Resources Conservation Service, USDA Soil Survey Geographic (SSURGO) database for Van Buren County, Michigan at http://soildatamart.nrcs.usda.gov. Accessed December 2, 2015.

Soil Group			Acres	Percent	Runoff Potential
(color swatch)	A	Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.	442	24	Low
	B	Soils having a moderate rate of infiltration when thoroughly wet.	0	0	
(color swatch)	C	Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.	419	23	
	D	Soils in Group D have a very slow infiltration rate when thoroughly wet.	0	0	High
(color swatch)	A/D	Group A in drained areas and Group D in undrained areas.	46	3	
(color swatch)	B/D	Group B in drained areas and Group D in undrained areas.	896	49	
(color swatch)		Unclassified	27	1	
		Total:	1,830	100	

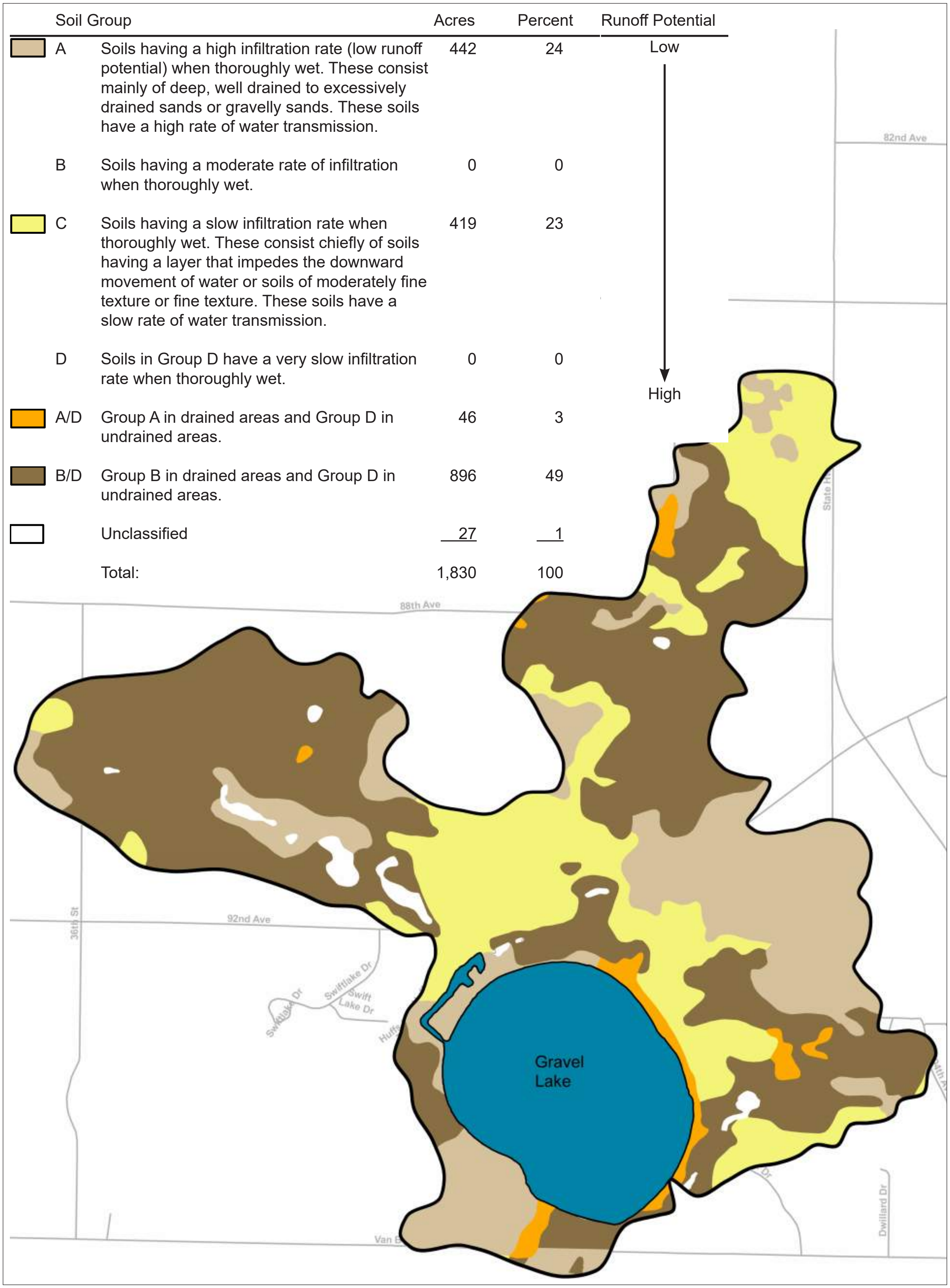

Figure 27. Gravel Lake watershed hydrologic soils group map. Source: Soil Survey staff, Natural Resources Conservation Service, USDA Soil Survey Geographic (SSURGO) database for Van Buren County, Michigan at http://soildatamart.nrcs.usda.gov. Accessed December 2, 2015.

CHEMICAL CHARACTERISTICS

When we refer to a lake's "water quality," what we often mean is "water chemistry." Water samples are collected or probes are lowered into the water to measure various aspects of water chemistry in order to determine the lake's current condition. It is also helpful to characterize the chemistry of water flowing into and out of the lake as well as the lake sediments to understand the effect on current water quality.

Temperature

Temperature is important in determining the type of organisms that may live in a lake. For example, trout prefer temperatures below 68°F. Temperature also determines how water mixes in a lake. As the ice cover breaks up on a lake in the spring, the water temperature becomes uniform from the surface to the bottom. This period is referred to as “spring turnover” because water mixes throughout the entire water column. As the surface waters warm, they are underlain by a colder, more dense layer of water. This process is called “thermal stratification.” Once thermal stratification occurs, there is little mixing of the warm surface waters with the cooler bottom waters. The transition layer that separates these layers is referred to as the “thermocline.” The thermocline is characterized as the zone where temperature drops rapidly with depth. As fall approaches, the warm surface waters begin to cool and become more dense. Eventually, the surface temperature drops to a point that allows the lake to undergo complete mixing. This period is referred to as “fall turnover.” As the season progresses and ice begins to form on the lake, the lake may stratify again. However, during winter stratification, the surface waters (at or near 32°F) are underlain by slightly warmer water (about 39°F). This is sometimes referred to as “inverse stratification” and occurs because water is most dense at a temperature of about 39°F. As the lake ice melts in the spring, these stratification cycles are repeated (Figure 28). Shallow lakes do not stratify. Lakes that are about 15 to 30 feet deep may stratify and destratify with storm events several times during the year.

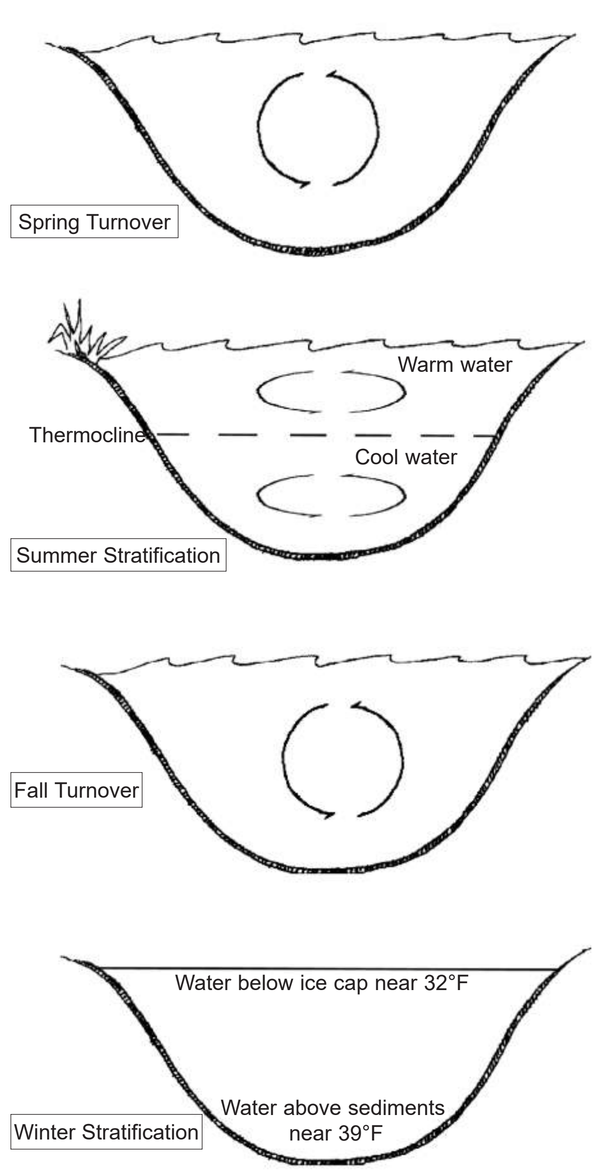

Figure 28. Seasonal thermal stratification cycles.

Gravel Lake Temperatures

During the August sampling period, Gravel Lake was stratified.

Temperatures in Gravel Lake were cool and well-mixed during the April sampling period at all three stations indicating the lake was undergoing spring turnover (Table 4). During the August sampling period, Gravel Lake was stratified. At the deepest location (Site 1, Figure 8), the thermocline formed at approximately 30 feet of depth. The surface was 27 degrees warmer than at 45 feet of depth. The bottom of Site 2, at the south end of the lake, was only 10 degrees cooler than the surface, but is a shallower location with a maximum depth of 25 feet. As such, Site 2 is barely deep enough to stratify. Site 3, located in the canal, is too shallow to stratify.

TABLE 4
GRAVEL LAKE DEEP BASIN WATER QUALITY DATA

Date	Station	Sample Depth (feet)	Temperature (°F)	Dissolved Oxygen (mg/L)[1]	Total Phosphorus (µg/L)[2]	pH (S.U.)[3]	Total Alkalinity (mg/L as $CaCO_3$)[4]
15-Apr-15	1	1	51	11.7	9	8.3	135
15-Apr-15	1	10	51	11.4	5	8.3	140
15-Apr-15	1	20	50	7.8	9	8.3	135
15-Apr-15	1	30	49	10.7	7	8.2	137
15-Apr-15	1	40	49	11.0	6	8.0	135
15-Apr-15	1	48	47	10.3	5	8.1	133
15-Apr-15	2	1	51	11.6	26	8.3	136
15-Apr-15	2	10	50	9.7	<5	8.1	135
15-Apr-15	2	20	50	11.3	<5	8.2	134
15-Apr-15	2	26	49	11.1	7	8.1	135
15-Apr-15	3	1	56	12.0	13	8.0	119
19-Aug-15	1	1	80	9.0	<5	9.0	118
19-Aug-15	1	10	80	9.1	<5	9.0	83
19-Aug-15	1	20	79	8.0	5	8.9	120
19-Aug-15	1	30	66	4.5	<5	8.3	135
19-Aug-15	1	40	54	1.0	21	8.0	157
19-Aug-15	1	45	53	0.4	25	8.1	162
19-Aug-15	2	1	80	8.5	6	9.1	132
19-Aug-15	2	10	79	8.5	<5	9.1	115
19-Aug-15	2	20	78	7.0	<5	8.8	122
19-Aug-15	2	25	70	1.2	24	7.9	143
19-Aug-15	3	1	81	13.3	12		99
19-Aug-15	3	6	80	13.1	41		93

1 mg/L = milligrams per liter = parts per million.
2 µg/L = micrograms per liter = parts per billion.
3 S.U. = standard units
4 mg/L $CaCO_3$ = milligrams per liter as calcium carbonate.

Dissolved Oxygen

An important factor influencing lake water quality is the quantity of dissolved oxygen in the water column. The major inputs of dissolved oxygen to lakes are the atmosphere and photosynthetic activity by aquatic plants. Cool water can hold more oxygen than warm water, thus oxygen levels are usually higher in spring than in summer. Water at 50°F can hold 11 parts per million (ppm) of oxygen while water at 80°F can only hold 8 ppm. An oxygen level of about 5 mg/L (milligrams per liter, or parts per million) is required to support warm-water fish. In lakes deep enough to exhibit thermal stratification, oxygen levels are often reduced or depleted below the thermocline once the lake has stratified. This occurs because deep water is cut off from plant photosynthesis and the atmosphere, and oxygen is consumed by bacteria that use oxygen as they decompose organic matter (plant and animal remains) at the bottom of the lake. Lakes with bottom-water oxygen depletion cannot support cool-water fish because the cool, deep water (that the fish require to live) does not contain sufficient oxygen (Figure 29).

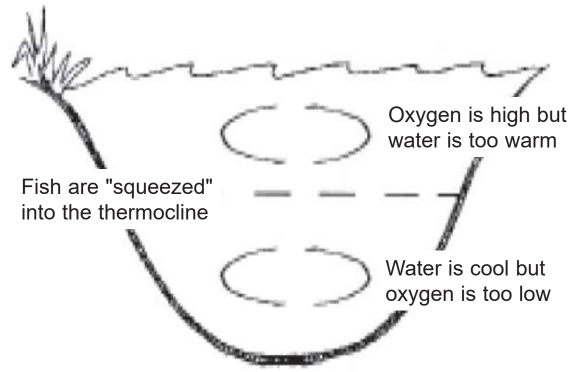

Figure 29. Temperature and oxygen impact fish habitat.

Gravel Lake Dissolved Oxygen

Hypolimnetic oxygen depletion indicates Gravel Lake is biologically productive.

As expected, dissolved oxygen levels in Gravel Lake were high at all sites and depths during spring turnover when temperatures were cool and the lake was well mixed (Table 4). During summer stratification, the upper portions of the lake, i.e., the epilimnion, were well oxygenated, but oxygen declined below the thermocline. Site 1 was essentially oxygen-depleted below 40 feet, and Site 2 was nearly depleted at the bottom (25 feet). Site 3 was well-oxygenated in summer. Hypolimnetic (deep-water) oxygen depletion indicates Gravel Lake is biologically productive. That is, there is enough growth and decomposition of aquatic plants to cause oxygen depletion by bacteria as they decompose organic matter at the lake bottom.

Dissolved oxygen levels measured during the current study were similar to those reported by the Kalamazoo Nature Center (1976), Engemann (1978), Water Quality Investigators (1995), MDEQ (2001), and PLM Lake and Land Management (2004 to 2015; Appendix A).

Phosphorus

The quantity of phosphorus present in the water column is especially important since phosphorus is the nutrient that most often controls aquatic plant and algae growth and the rate at which a lake ages and becomes more nutrient-enriched. By reducing the amount of phosphorus in a lake, it may be possible to control the amount of aquatic plant growth. In general, lakes with a phosphorus concentration above 20 ppb are able to support abundant plant growth. The highest phosphorus levels measured in Michigan inland lakes exceed 2,000 ppb.

In the presence of oxygen, phosphorus settles to the lake bottom and is unavailable for algae growth. However, if bottom-water oxygen is depleted, as often occurs in late summer, phosphorus is released from the sediments and may be available to promote algae growth. In some lakes, the release of phosphorus from the bottom sediments is the primary source of phosphorus loading (or input) to the lake.

Gravel Lake Phosphorus

During spring turnover sampling in 2015, total phosphorus levels in the main body of Gravel Lake (Sites 1 and 2) were less than 10 ppb, with the exception of the surface sample at Site 2 (26 ppb; Table 4). The canal sample (Site 3) was slightly higher (13 ppb) compared to the main body (Table 4). Assuming a conservative concentration of 5 ppb for samples that were below the laboratory detection limit, the average spring turnover total phosphorus concentration in Gravel Lake was quite low at 8.8 ppb. During summer stratification, phosphorus levels were very low in the epilimnion (upper waters) with a modest increase in the oxygen-depleted hypolimnion (bottom waters) in the main body of the lake. Phosphorus levels were high and moderately high at the bottom and top of Site 3, respectively.

The average spring turnover total phosphorus concentration in Gravel Lake was quite low at 8.8 ppb.

Given the modest increase in late-summer phosphorus concentrations in the oxygen-depleted hypolimnion, it appears that, at present, internal phosphorus loading is not significant in Gravel Lake.

Total phosphorus levels measured during the current study were similar to those reported by Water Quality Investigators (1995), MDEQ (2001), and PLM Lake and Land Management (2004 to 2015). The Kalamazoo Nature Center (1976) collected samples from the shoreline, therefore results were not comparable to subsequent monitoring. Engemann (1978) results were also not comparable due to a much higher limit of detection (0.1 ppm, or 100 ppb).

pH and Total Alkalinity

pH is a measure of the amount of acid or base in the water. The pH scale ranges from 0 (acidic) to 14 (alkaline or basic) with neutrality at 7. The pH of most lakes in the Upper Midwest ranges from 6.5 to 9.0 (MDEQ 2012; Table 5).

TABLE 5
pH AND ALKALINITY OF UPPER MIDWEST LAKES

Measurement	Low	Moderate	High
pH (in standard units)	Less than 6.5	6.5 to 9.0	Greater than 9.0
Total Alkalinity or ANC (in mg/L as $CaCO_3$[1])	Less than 23	23 to 148	Greater than 148

In addition, according to MDEQ (2016):

> While there are natural variations in pH, many pH variations are due to human influences. Fossil fuel combustion products, especially automobile and coal-fired power plant emissions, contain nitrogen oxides and sulfur dioxide, which are converted to nitric acid and sulfuric acid in the atmosphere. When these acids combine with moisture in the atmosphere, they fall to earth as acid rain or acid snow. In some parts of the United States, especially the Northeast, acid rain has resulted in lakes and streams becoming acidic, resulting in conditions which are harmful to aquatic life. The problems associated with acid rain are lessened if limestone is present, since it is alkaline and neutralizes the acidity of the water.
>
> Most aquatic plants and animals are adapted to a specific pH range, and natural populations may be harmed by water that is too acidic or alkaline. Immature stages of aquatic insects and young fish are extremely sensitive to pH values below 5. Even microorganisms which live in the bottom sediment and decompose organic debris cannot live in conditions which are too acidic. In very acidic waters, metals which are normally bound to organic matter and sediment are released into the water. Many of these metals can be toxic to fish and humans. Below a pH of about 4.5, all fish die.

1 mg/L $CaCO_3$ = milligrams per liter as calcium carbonate.

The Michigan Water Quality Standard (Part 4 of Act 451) states that pH shall be maintained within the range of 6.5 to 9.0 in all waters of the state.

Alkalinity, also known as acid-neutralizing capacity or ANC, is the measure of the pH-buffering capacity of water in that it is the quantitative capacity of water to neutralize an acid. pH and alkalinity are closely linked and are greatly impacted by the geology and soil types that underlie a lake and its watershed. According to MDEQ (2012):

> Michigan's dominant limestone geology in the Lower Peninsula and the eastern Upper Peninsula contributes to the vast majority of Michigan lakes being carbonate-bicarbonate dominant [which increases alkalinity and moderates pH] and lakes in the western Upper Peninsula having lower alkalinity and thus lesser buffering capacity.

The alkalinity of most lakes in the Upper Midwest is within the range of 23 to 148 milligrams per liter, or parts per million, as calcium carbonate (MDEQ 2012; Table 5).

Gravel Lake pH and Alkalinity

The pH and total alkalinity of Gravel Lake was generally moderate during this study (Table 4), although alkalinity was measured at the upper end of the moderate scale, and was occasionally in the high range. Thus, Gravel Lake's pH is within a range that can readily support aquatic life, and alkalinity levels are such that the lake is well-buffered against pollution inputs that could impact pH.

Chlorophyll-*a*

Chlorophyll-*a* is a pigment that imparts the green color to plants and algae. A rough estimate of the quantity of algae present in lake water can be made by measuring the amount of chlorophyll-*a* in the water column. Chlorophyll-*a* concentrations greater than 6 ppb are high, and lake water can appear green in color from algae growth.

All chlorophyll-a measurements in 2015 were quite low, indicating algae growth was not significant in Gravel Lake at the time of sampling.

Gravel Lake Chlorophyll-*a*

All chlorophyll-*a* measurements in 2015 were quite low, indicating algae growth was not significant in Gravel Lake at the time of sampling (Table 6). MDEQ results were similar in 2001.

TABLE 6
GRAVEL LAKE SURFACE WATER QUALITY DATA

Date	Sample Location	Chlorophyll-*a* (µg/L)[1]	Secchi Transparency (feet)
15-Apr-15	1	<1	21.5
15-Apr-15	2	2	19.0
15-Apr-15	3	<1	Bottom[2]
19-Aug-15	1	<1	12.0
19-Aug-15	2	<1	13.0
19-Aug-15	3	2	Bottom[2]

1 µg/L = micrograms per liter = parts per billion.
2 The Secchi disk was visible on the lake bottom and could not be extended deeper.

Secchi Transparency

A Secchi disk is often used to estimate water clarity. The measurement is made by fastening a round, black and white, 8-inch disk to a calibrated line (Figure 30). The disk is lowered over the deepest point of the lake until it is no longer visible, and the depth is noted. The disk is then raised until it reappears. The average between these two depths is the Secchi transparency. Generally, it has been found that aquatic plants can grow at a depth of approximately twice the Secchi transparency measurement. In nutrient-enriched lakes, water clarity is often reduced by algae growth in the water column, and Secchi disk readings of 7.5 feet or less are common.

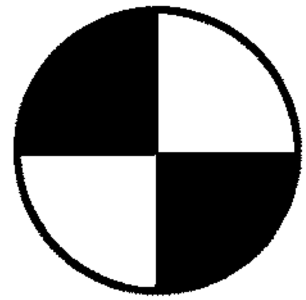

Figure 30. Secchi disk.

Gravel Lake Secchi Transparency

In 2015, Secchi transparency in Gravel Lake was high in spring and moderate in summer at Sites 1 and 2 (Table 6). Secchi transparency exceeded the maximum depth at Site 3 in both spring and summer. The reduced water clarity in late summer was evidently not caused by algae growth since chlorophyll-*a* levels were quite low. Instead, the reduced clarity may have been due to boating activity which can stir sediments into the water column.

Since 1980, Gravel Lake Secchi transparency has generally been good to excellent.

Secchi transparency has been measured by Gravel Lake resident volunteers almost continuously since 1980 (Figure 31). The long-term average Secchi measurement is 12.4 feet, ranging from 4.5 to 26 feet. Since 1980, Gravel Lake Secchi transparency has generally been good to excellent.

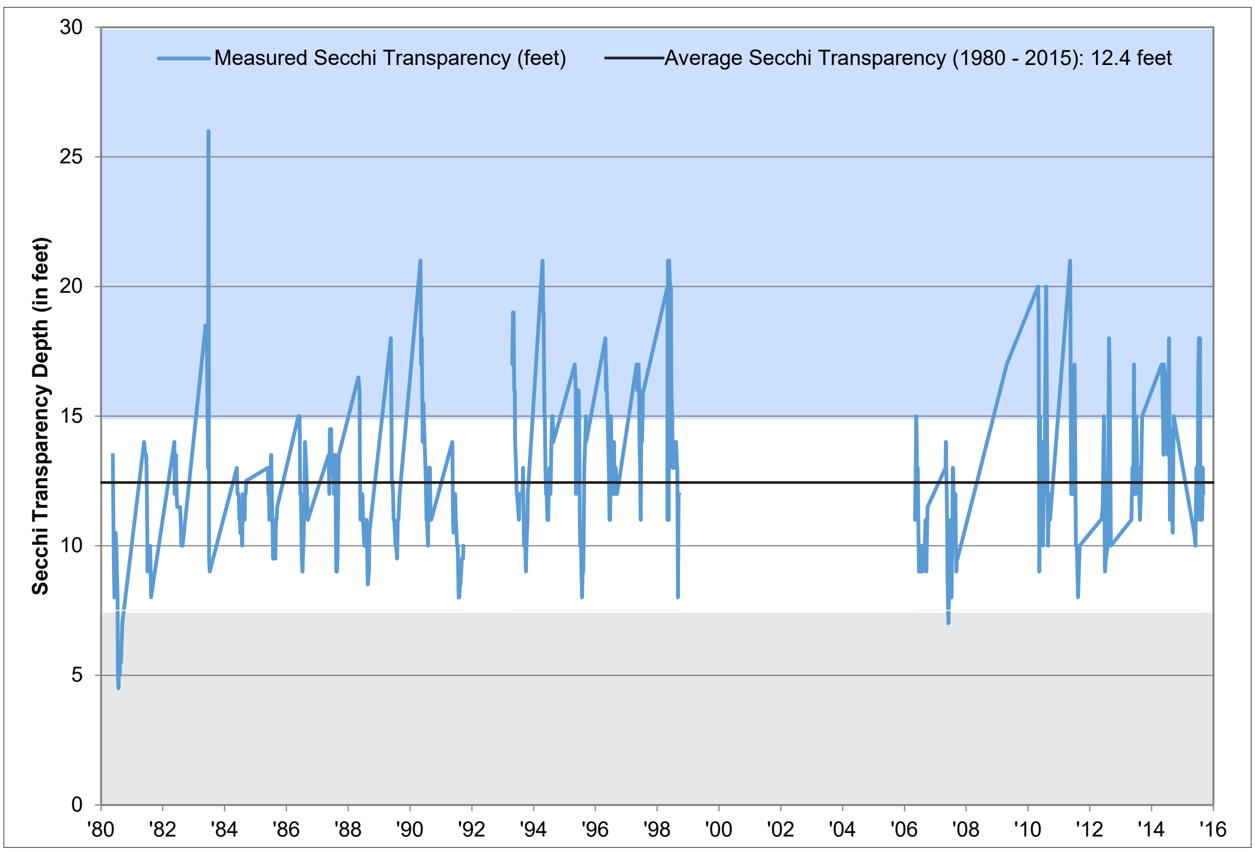

Figure 31. Gravel Lake Cooperative Lakes Monitoring Program Secchi transparency data, 1980-2015. Grey-shaded depths from 0 to 7.5 feet = eutrophic measurements; unshaded depths from 7.5 to 15 feet = mesotrophic measurements; blue-shaded depths from 15 feet and greater = oligotrophic measurements.

Chemical Criteria for Lake Classification

Ordinarily, as phosphorus concentrations in a lake increase, the amount of algae will also increase. Thus, chlorophyll-*a* levels will increase and transparency decreases. Lake scientists often use phosphorus, chlorophyll-*a*, and Secchi transparency to determine a lake's trophic state. A summary of lake classification criteria developed by the Michigan Department of Natural Resources is shown in Table 7.

TABLE 7
LAKE CLASSIFICATION CRITERIA

Lake Classification	Total Phosphorus (μg/L)[1]	Chlorophyll-*a* (μg/L)[1]	Secchi Transparency (feet)
Oligotrophic	Less than 10	Less than 2.2	Greater than 15.0
Mesotrophic	10 to 20	2.2 to 6.0	7.5 to 15.0
Eutrophic	Greater than 20	Greater than 6.0	Less than 7.5

During the course of the current study, Gravel Lake chlorophyll-*a* levels were in the oligotrophic range; phosphorus and Secchi transparency measurements have been in the oligotrophic and mesotrophic ranges.

Gravel Lake Sediments

Samples collected from the two deep basins indicate most of the deep-water sediments in Gravel Lake at the time of sampling contain silt-sized particles with organic content of approximately 45 percent (Table 8). Given that there are no major tributaries to the lake, and given the low abundance of algae in the lake, it is likely that decaying rooted plants are the primary source of organic matter to the Gravel Lake sediments.

TABLE 8
GRAVEL LAKE SEDIMENT CHARACTERISTIC DATA

August 19, 2015

Station	Percent Organic Content	Percent Course Gravel	Percent Fine Gravel	Percent Course Sand	Percent Medium Sand	Percent Fine Sand	Percent Silt	Percent Clay
1	45	0	0	0	2	13	79	7
2	46	0	0	0	2	4	85	10

1 μg/L = micrograms per liter = parts per billion.

Gravel Lake Inlet and Outlet

In addition to in-lake monitoring, water samples were also collected from the wetland that flows into the east side of the lake as well as from the outlet (Table 9).

TABLE 9
GRAVEL LAKE TRIBUTARY WETLAND AND OUTLET WATER QUALITY DATA

Date	Station	Sample Location	Total Phosphorus (µg/L)[1]	Total Solids (mg/L)[2]	Total Suspended Solids (mg/L)[2]
15-Apr-15	4	Inlet	68	147	10
15-Apr-15	5	Outlet	7	268	<4
19-Aug-15	4	Inlet	77	172	6
19-Aug-15	5	Outlet	<5	160	4.4

The water flowing into Gravel Lake contains relatively high phosphorus concentrations, as would be expected from highly productive wetlands. Although inlet phosphorus concentrations are high, the amount of water draining to the lake from the east-shore wetland is quite low, therefore the impact to Gravel lake is not significant. Suspended solids concentrations in the tributary are low. According to MDEQ (2016):

> Total suspended solids (TSS) include all particles suspended in water which will not pass through a filter... Most people consider water with a TSS concentration less than 20 mg/L to be clear. Water with TSS levels between 40 and 80 mg/L tends to appear cloudy, while water with concentrations over 150 mg/L usually appears dirty.

Phosphorus concentrations in water exiting Gravel Lake are similar to those measured in the lake itself. Outflow water also has low levels of suspended solids, which is apparent in the good clarity of the outlet stream.

1 µg/L = micrograms per liter = parts per billion.
2 mg/L = milligrams per liter = parts per million.

BIOLOGICAL CHARACTERISTICS

The current study included an assessment of aquatic plants, zooplankton (microscopic, free-floating animals), and fish. Although there are many other organisms that live in lakes, aquatic plants and fish are often of primary importance to lake residents due to their impact on recreational activities. While most residents are unaware of zooplankton, they are a primary food source for many fish, particularly in their early life stages. In order to understand the dynamics of the fish population, it is important to examine the zooplankton population as well.

Aquatic Plants

Aquatic plants are an important ecological component of lakes. They produce oxygen during photosynthesis, provide food and habitat for fish, and help stabilize shoreline and bottom sediments (Figure 32).

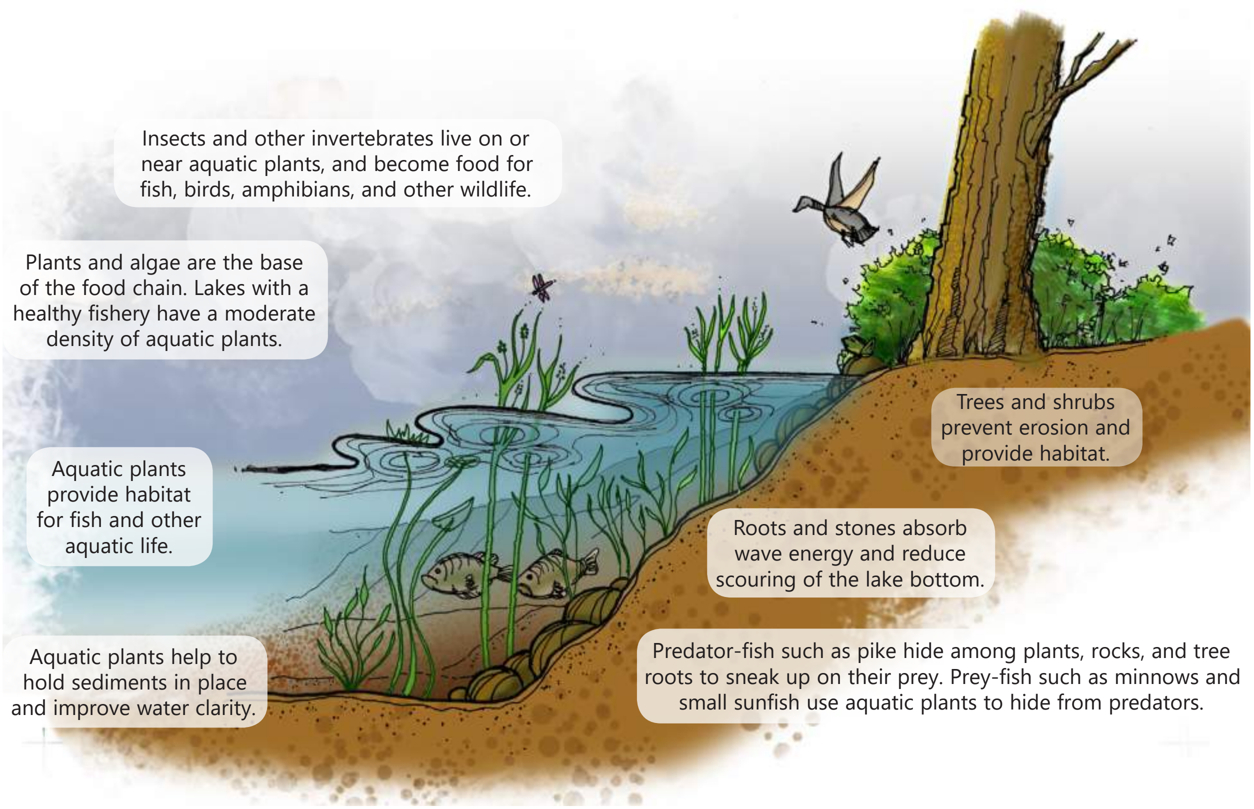

Figure 32. Benefits of aquatic plants.

The distribution and abundance of aquatic plants are dependent on several variables, including light penetration, bottom type, temperature, water levels, and the availability of plant nutrients. The term "aquatic plants" includes both the algae and the larger aquatic plants or macrophytes. The macrophytes can be categorized into four groups: the emergent, the floating-leaved, the submersed, and the free-floating (Figure 33). Each plant group provides unique habitat essential for a healthy fishery.

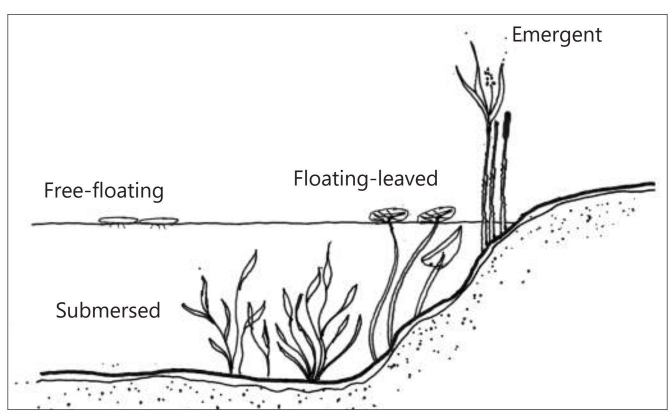

Figure 33. Aquatic plant groups.

Nuisance Aquatic Plants

While aquatic plants are essential for a healthy lake, aquatic plant management may be necessary when exotic, or non-native, species invade a lake, or if native plants grow to nuisance densities.

An exotic species is one that is found outside of its natural range. Exotic aquatic plants often have aggressive and invasive growth tendencies. They can quickly out-compete native plants and gain dominance in a lake. Two examples of exotic plant species that are a threat to Michigan lakes include Eurasian milfoil (*Myriophyllum spicatum*) and starry stonewort (*Nitellopsis obtusa*).

Eurasian milfoil often becomes established early in the growing season and can grow at greater depths than most plants. Eurasian milfoil often forms a thick canopy at the lake surface that can degrade fish habitat and seriously hinder recreational activity (Figure 34). Once introduced into a lake system, Eurasian milfoil may out-compete and displace more desirable plants and become the dominant species.

Starry stonewort looks like a rooted plant but it is actually an algae (Figure 35). It was first found in the Detroit River in the 1980s and has since infested hundreds of inland lakes (Brown 2015, Schloesser et al. 1986). Starry stonewort closely resembles the native aquatic plant Chara. However, unlike Chara, which is generally considered to be a beneficial plant, starry stonewort has a tendency to colonize deeper water and can form dense mats several feet thick. Starry stonewort can impede navigation, and quickly displace native plants. Fisheries biologists have expressed concern that starry stonewort may cover valuable fish habitat and spawning areas.

At times, native plants can grow to densities that interfere with navigation, swimming, and other recreational lake uses (Figure 36).

Figure 34. Eurasian milfoil (*Myriophyllum spicatum*).

Figure 35. Starry stonewort (*Nitellopsis obtusa*).

Figure 36. Nuisance native aquatic plant growth.

In addition to information on depth, the hydro-acoustic survey on July 10, 2015 also yielded information on the location of plant beds and the relative height of plants in the water column, i.e., bio-volume (Figure 37). Plants grow to a depth of about 10 to 15 feet in Gravel Lake and cover roughly 40 percent of the lake area.

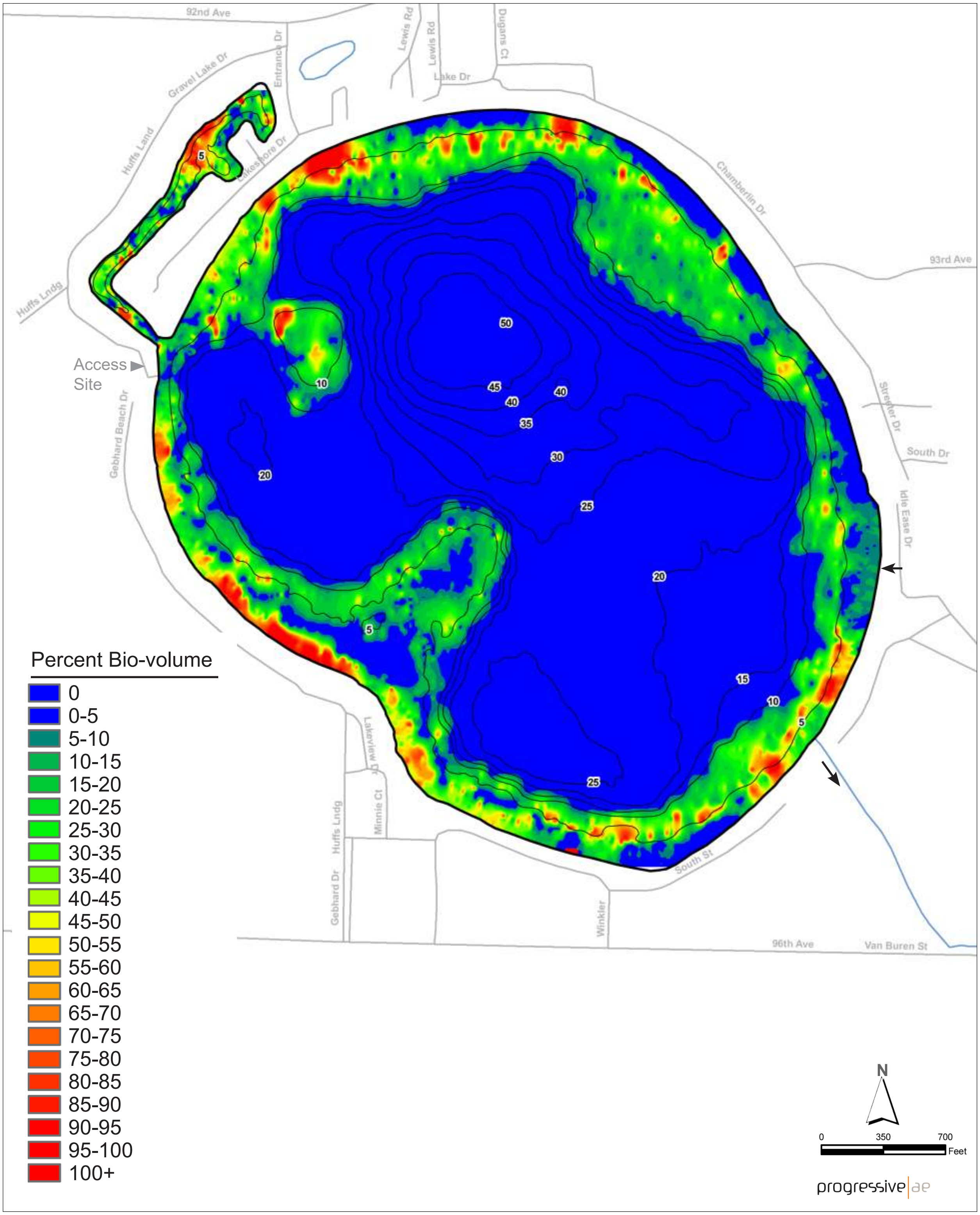

Figure 37. Gravel Lake aquatic vegetation bio-volume map. Bio-volume is a measure of the height of plants in the water column. A bio-volume measurement of 50% indicates plants occupy one-half of the water column. Hydro-acoustic data collected on July 10, 2015 and processed by Navico. Lake shoreline digitized from 2014 aerial orthodigital photography (Source: USDA FSA).

Following the hydro-acoustic survey, plants were identified at 197 survey sites within the vegetated areas of Gravel Lake on July 28, 2015 (Figure 9, Table 10, Appendix D).

TABLE 10
GRAVEL LAKE AQUATIC PLANTS
July 28, 2015

Common Name	Scientific Name	Group	Percent of Sites Where Present
Chara	*Chara* sp.	Submersed	81%
Illinois pondweed	*Potamogeton illinoensis*	Submersed	44%
Wild celery	*Vallisneria americana*	Submersed	30%
Naiad	*Najas flexilis*	Submersed	21%
Richardson's pondweed	*Potamogeton richardsonii*	Submersed	13%
Starry stonewort[1]	*Nitellopsis obtusa*	Submersed	11%
Flat-stem pondweed	*Potamogeton zosteriformis*	Submersed	9%
Large-leaf pondweed	*Potamogeton amplifolius*	Submersed	7%
Small pondweed	*Potamogeton pusillus*	Submersed	7%
Sago pondweed	*Stuckenia pectinata*	Submersed	3%
Eurasian milfoil[1]	*Myriophyllum spicatum*	Submersed	2%
Thin-leaf pondweed	*Potamogeton* sp.	Submersed	2%
Coontail	*Ceratophyllum demersum*	Submersed	1%
Nitella	*Nitella flexilis*	Submersed	1%
Curly-leaf pondweed[1]	*Potamogeton crispus*	Submersed	1%
Variable pondweed	*Potamogeton gramineus*	Submersed	1%
Robbins pondweed	*Potamogeton robbinsii*	Submersed	1%
Yellow waterlily	*Nuphar* sp.	Floating-leaved	4%
White waterlily	*Nymphaea odorata*	Floating-leaved	1%
Bulrush	*Scirpus* sp.	Emergent	3%
Purple loosestrife[1]	*Lythrum salicaria*	Emergent	2%
Cattail	*Typha* sp.	Emergent	1%

Twenty-two species of aquatic plants were recorded during the plant survey, of which four species are not native to Michigan. Plant survey results are similar to those of the Kalamazoo Nature Center (1976), MDEQ (2001), and PLM Lake and Land Management (2013, 2014), with the exception that surveys prior to 2013 did not include starry stonewort. All milfoil plant samples were identified as a hybrid between Eurasian milfoil and northern milfoil (*Myriophyllum spicatum* x *M. sibiricum*; Appendix E).

Prior to the plant survey, two herbicide treatments occurred on July 8 and July 27 (Appendix F). The treatments included the use of diquat dibromide targeting milfoil in a 5-acre treatment on the 8th and a 0.5-acre treatment on the 27th, one day prior to the aquatic plant survey. Diquat dibromide can impact other species besides milfoil, although the applied dose was relatively low at 1 gallon per acre, thus non-target impacts were likely minimized. The other herbicides applied on July 8 were algaecides and would not impact rooted vegetation. Given the type, dose, and timing, treatments likely had only minimal impact on aquatic plant survey results.

1 Non-native species.

Gravel Lake contains a good diversity of native aquatic plant species. At the time of the survey, the non-native submersed plants hybrid milfoil and curly-leaf pondweed were relatively rare, thus it would appear that plant control efforts have been effective in controlling these species. The non-native starry stonewort, however, was abundant in the channel and was found in three locations in the main body of the lake, in the deepest reaches of the off-shore plant beds (Figure 38). Similar colonization patterns have been observed in other Michigan inland lakes with disturbed areas (such as the dredged channel) and deep off-shore locations inhabited first with the plant spreading to other areas later.

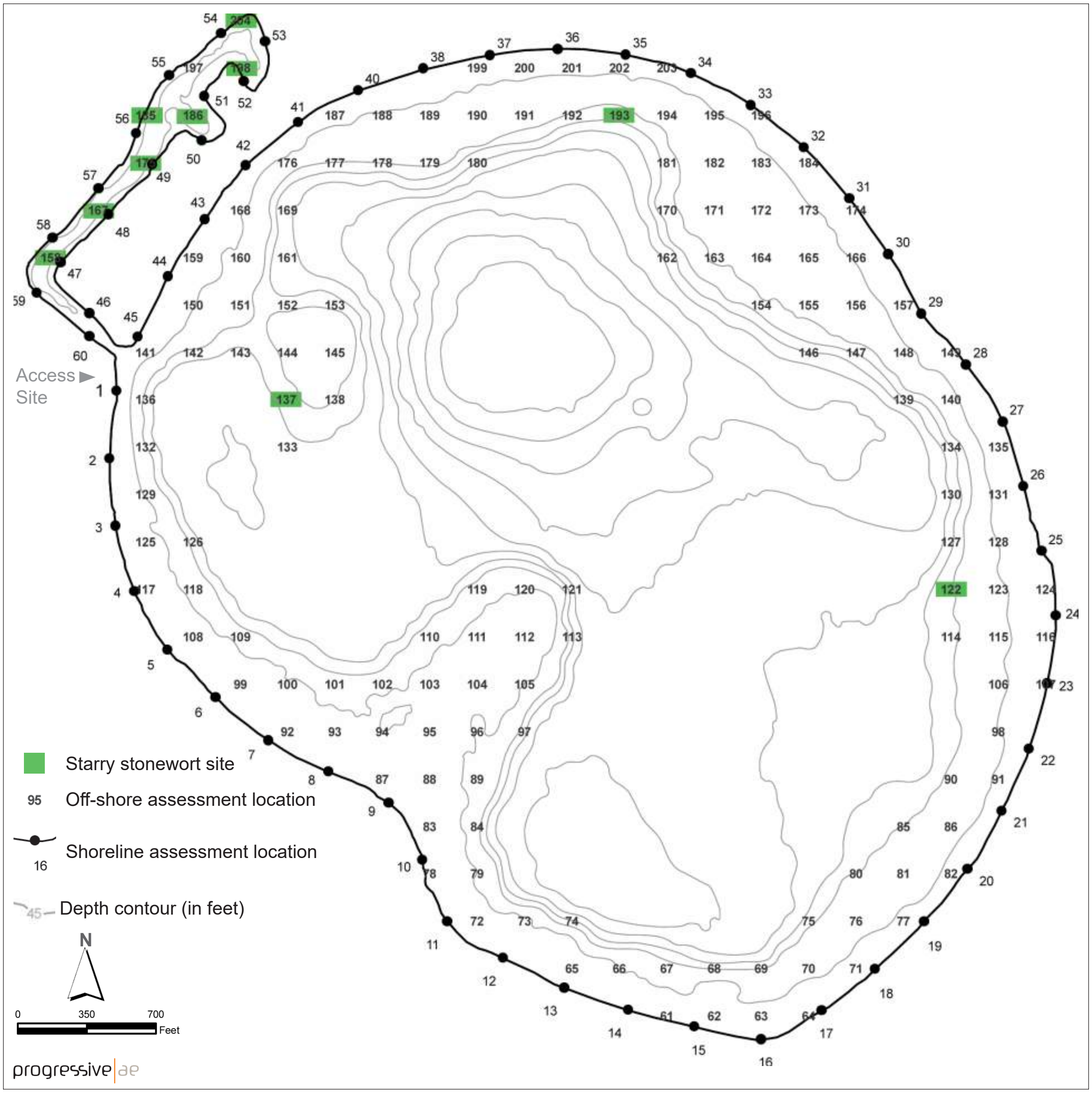

Figure 38. Gravel Lake starry stonewort (*Nitellopsis obtusa*) locations, July 28, 2015.

Review of Plant Control Activities

Gravel Lake herbicide treatments since 2007 are summarized in Table 11. In general, most of the treatments have occurred in the channel at the northwest end, although herbicides have also been applied in the main body of the lake. Most of the treatments target non-native milfoil and, in recent years, starry stonewort.

In addition to the treatments summarized in Table 11, the herbicide fluridone (trade name Sonar®) was applied as a whole-lake treatment in 2004 and 2013 in order to treat non-native milfoil. Unlike other herbicides, fluridone can only be applied once in a three-year period.

TABLE 11
GRAVEL LAKE HERBICIDE TREATMENT SUMMARY
2007-2015

Herbicide Applied	Target Plant	Annual Number Treatments	Acres Per Treatment
Copper sulfate	Free-floating algae	3-5	1-10
Copper sulfate	Starry stonewort	3-5	1-10
Copper herbicide	Wild celery	1	1-5
Diquat dibromide	Non-native milfoil	1-5	1-30

While one of the treatment targets has been non-native milfoil, the herbicide that has usually been applied for its control during the non-fluridone years is diquat dibromide, which can impact beneficial native plants besides non-native milfoil. Diquat dibromide is effective on milfoil for several weeks; because diquat is a contact herbicide, not a systemic one, diquat does not kill the roots, and milfoil can re-grow within a month or so. Systemic herbicides may be a season-long alternative for milfoil control while protecting native plants. Mechanical harvesting should not be used to control milfoil since harvesting can fragment the plant and spread it further in the lake.

Unlike most aquatic herbicides which do not persist in the lake, copper in herbicide has the potential to accumulate and persist in lake sediments. Given that copper-based herbicides are only partially successful at controlling starry stonewort, consideration should be given to using a combination of mechanical harvesting and herbicides for starry stonewort control. This approach could reduce the need for, and frequency of, copper-based herbicide treatments. In addition, harvesting would have the long-term advantage of removing plant biomass from the lake, which could be especially important in the canal. However, in order to prevent the infestation of any new invasive species, harvesting equipment would need to be thoroughly washed and dried before launching into Gravel Lake. Also, since harvesting can fragment and spread non-native milfoil, treatments for milfoil would need to be conducted prior to the harvesting operation.

Zooplankton

Zooplankters are small invertebrates present in most lakes and ponds (Figures 34 and 35). They are critical connectors between plants (they eat algae) and fish, since they are important as food for larval fish and other small fishes in the lake and are indicators of the amount of predation that fish exert on these organisms. Zooplankton we collected at the deep station A (Table 12) was comprised of very few species (four), indicating that there was not a diverse group of these organisms in Gravel Lake. These species included: *Daphnia* (Figure 35), *Cyclops bicuspidatus*, immature *Diaptomus* spp., and male *Tropocyclops prasinus*.

Figure 39. A copepod.

Figure 40. *Daphnia*, a large zooplankter, adept at eating algae.

TABLE 12
GRAVEL LAKE ZOOPLANKTON SPECIES

Group	Abundance[1]
Daphnia spp.	85%
Cyclops bicuspidatus	4%
Diaptomus (Immature)	3%
Tropocylops prasinus (Male)	8%

The dominant group was *Daphnia* (85% by number), which has two implications. First, one of the things we look for is the presence of the large species of zooplankton, *Daphnia* especially. *Daphnia* is slow, energy-rich, large, and an easy target for fishes. Therefore, since we found large quantities of these large zooplankters present in the lake it indicates that at least during summer fish predation is not intense, as is often seen in lakes dominated with planktivores (zooplankton eaters), such as small bluegills, yellow perch, and black crappies. Our fish sampling confirmed that there were moderate numbers of small bluegills present, but they were confined to the near-shore zone in the sparse aquatic plants, and apparently did not go offshore much into the open water during our sampling in July. This may likely be due to the clear water and presence of two predators: walleyes and largemouth bass in the 10- to 15-inch range which were very abundant both near shore and offshore based on our sampling and fishing reports. Our diet data confirm that largemouth bass were eating many fishes. We also noted that yellow perch were also eating bluegill; brown bullheads, which mostly feed at night, were really consuming large numbers of this species. It is well known that bluegills will remain in plant cover and feed more on benthos than zooplankton if predation threats are severe.

Second, *Daphnia* are more efficient than copepods (a smaller, faster group of zooplankton—*Cyclops* and *Diaptomus* are examples) at filtering algae from the water column. Since *Daphnia* were so abundant, they are helping to control algae in the surface waters and are partly responsible for the high water clarity in the lake during summer. Copepods are also not fed on as often by fish since they are faster, unless other large zooplankters are rare. We documented feeding on zooplankton by many bluegills, so some are venturing into deeper water, as well as yellow perch and largemouth bass (Table 14).

1 Percent composition based on counting a random sample of 100 organisms.

Fish

Fish Species Diversity

The lake has a high diversity of fish species, some of which were stocked (walleye, smallmouth bass); most were native. We collected 19 species in our sampling efforts in July (Figure 41 and Table 13). Bowfin and northern pike were reported to us as being in the lake. Our lake guardians report they have not seen or caught any northern pike for years and suggested the one observed in the canal was a bowfin. The MDNR reports northern pike were present during 1949 (Appendix A3 p. 15), 1957 (p. 17), 1959 (p. 21-22), and one was caught during 1979 (p. 25); none were caught during 1965 (p. 23) and comments suggested they were in very low abundance during the late 1970s and sometime prior. Bowfin were collected only once in MDNR sampling: 1965 (p. 23) but a recent YouTube video of Gravel Lake fishers shows one being collected. In addition, past records of MDNR (Appendix A3) showed that in the past, six additional species that we did not observe were collected during their sampling efforts. These included: grass pickerel *Esox americanus*, lake chubsucker *Erimyzon sucetta*, golden shiner *Notemigonus crysoleucas*, redhorse *Moxostoma* spp., green sunfish *Lepomis cyanellus*, and longnose gar *Lepisosteus osseus*. Our resident fisher experts report that no longnose gar has ever been seen by them in recent years, suggesting they may be extant or very rare. Our review of MDNR records (Appendix A2 and A3) shows that longnose gar were observed during 1949 (p. 15). If all species reported and collected by us during 2015 are counted, this results in 27 species present or extant in Gravel Lake, which is outstanding diversity.

Figure 41. Fishes captured in Gravel Lake seine hauls, 29 July 2015. Shown are: largemouth bass, yellow perch, bluegills, pumpkinseeds (note the lack of YOY), and various minnows.

TABLE 13
GRAVEL LAKE FISH COLLECTED OR OBSERVED[1]
July 29-31, 2015

Fish Code	Taxon	Scientific Name	Sample Size	Length Range (in.)
BK	Banded Killifish	*Fundulus diaphanus*	6	1.6-1.9
BH	Blackchin Shiner	*Notropis heterodon*	4	1.7-2
BG	Bluegill	*Lepomis macrochirus*	66	1.3-9
BM	Bluntnose Minnow	*Pimephales notatus*	7	1.7-2.2
BC	Black Crappie	*Pomoxis nigromaculatus*	1	8.4
BF	Bowfin[2]	*Amia calva*	NA	NA
SV	Brook Silversides	*Labidesthes sicculus*	19	0.9-3.3
BN	Brown Bullhead	*Ameiurus nebulosus*	7	11.5-13.9
JD	Johnny Darter	*Etheostoma nigrum*	2	1.4-1.9
LB	Largemouth Bass	*Micropterus salmoides*	52	1.3-21.5
MC	Mimic Shiner	*Notropis volucellus*	3	2.2-2.4
NP	Northern Pike[3]	*Esox lucius*	NA	NA
PS	Pumpkinseed	*Lepomis gibbosus*	10	6.2-8.7
PN	Pugnose Shiner	*Notropis anogenus*	1	1.9
SA	Sand Shiner	*Notropis stramineus*	16	1.9-2.4
SB	Smallmouth Bass	*Micropterus dolomieu*	1	15
SF	Spotfin Shiner	*Cyprinella spiloptera*	12	1.4-2.8
WL	Walleye	*Sander vitreus*	5	10.5-23
WM	Warmouth	*Lepomis gulosus*	5	2.6-4.9
WS	White Sucker	*Catostomus commersonii*	1	18
YP	Yellow Perch	*Perca flavescens*	38	1.5-10.5

There appears to be a huge year class of largemouth bass in the 10- to 15-inch range in the lake, since we collected and were given many fish in this range. These fish seem to be growing adequately, but are probably having a cropping effect on their prey. Of note is that past studies by the IFR (Institute for Fisheries Research) have also noted a similar distribution of largemouth bass, many smaller individuals up to 15 inches and none or very few collected that were bigger fish (Appendix A3). In addition there are two other important top predators in the lake: walleye and brown bullheads. Brown bullheads were commonly caught in our gear and reported from almost all previous IFR studies (Appendix A3), suggesting fair numbers reside in the lake. They are voracious predators, eating large numbers of bluegills and other fish. In addition, black crappies (which appear to be rare) and yellow perch also are predaceous at larger sizes and act as top predators. It appears from what we know about northern pike (and walleyes) and our diet information, that the dearth of northern pike probably has fostered a higher population of yellow perch in your lake, since yellow perch are a preferred prey item, if not enough soft-rayed fishes (minnows) of sufficient size are available. We have already noted that northern pike and walleye are probably stressed during summer because of the lack of dissolved oxygen in the bottom waters of the lake during late summer. Since walleyes are present during the whole year, and because the lake is so productive, the five fish we aged appeared to be growing at or above state averages during the cooler periods of the year.

1 Previous Institute for Fisheries Research studies (Appendix A3) have noted the presence of: grass pickerel *Esox americanus*, lake chubsucker *Erimyzon sucetta*, golden shiner *Notemigonus crysoleucas*, redhorse *Moxostoma* spp., green sunfish *Lepomis cyanellus*, and longnose gar *Lepisosteus osseus* in Gravel Lake.
2 Present based on YouTube video.
3 Fishers noted at least one was present in the lagoon next to launch site.

In addition to a good suite of top predators, the lake also contains a good population of bluegills and some huge pumpkinseeds were also documented. The strange finding about pumpkinseeds is we seined no young of the year (YOY). Either they are not spawning successfully, they were distributed in places where we did not sample, or their young suffered severe mortality. There were many YOY yellow perch indicating good reproduction plus a good distribution of other sizes up to many in the 10-inch range. There were many YOY largemouth bass as well, indicating excellent reproduction. The sandy habitat and macrophyte-covered areas are prime habitat for many minnow species and they were commonly observed in the shoreline areas. We captured six species of minnows: mimic shiner, bluntnose minnow, spotfin shiner, sand shiner, blackchin shiner, and pugnose shiner. The pugnose shiner is considered an endangered species by MDNR; we only caught one individual. Overall this is an excellent diversity of predators and prey. Lastly, we collected Johnny darters, diminutive members of the Perch family, banded killifish (small minnow-like species with vertical stripes), and brook silversides (they are the fish that make small ripples on the surface of the water in calm periods) which add to the diversity and prey fish populations in the lake.

Fish Diets

We collected one black crappie, which testifies to their low abundance in Gravel Lake. This fish was rather large (8.4 inches) but had no food in its stomach. The diet of bluegills was almost exclusively insects (Table 14). Fish caught ranged in size from 1.3 to 9 inches. The smaller 1.3-2.7-inch group ate chironomids (fly larvae), amphipods, phantom midges, ants, and some detritus. Somewhat bigger fish (3-3.8 inches) fed on a similar group of organisms, including caddisflies, dragonflies, amphipods, zebra mussels, and zooplankton. Fish 4-5.4 inches ate many chironomids, which are important fish food and members of the Diptera (fly) order, sometimes called midges; fingernail clams; terrestrial insects; and dragonflies. Those greater than 5.4 inches ate zooplankton, zebra mussels, snails, and dragonflies. In many other lakes I work on, at this time of the year, the bluegills are struggling to find food and often I see these fish eating only algae and aquatic plants, which does not get them much energy. Hence, I expect their populations are doing well in the lake.

We captured a number of banded killifish (small fish with vertical stripes) which ranged in length from 1.6-1.9 inches (Table 14). They are not common in the lake, but can be important prey items for top predators and tend to prey on items in the upper water column improving the conversion of prey to small fish to top predators.

Another minnow we collected in fair abundance was the blackchin shiner. They are common in sandy areas and those we obtained ranged from 1.7 to 2 inches.

Bluntnose minnows are a widespread species and were common in Gravel Lake (Table 14). Those seined ranged from 1.7 to 2.2 inches. Both of these minnow species contribute to a well balanced fish community, they act as prey for top predators, and they consume food that would probably not have been eaten if it were not for these species.

There is another common species that is probably confused with minnows in the lake called the brook silversides. They have a 2-year life cycle, grow up to 2-3 inches, and can be seen feeding at the surface, sometimes jumping out of the water when they are chased by predators. We collected a moderate number of these fish, which ranged from 0.9 to 3.3 inches. Again this is another good member of the fish community adding another prey species to the wide diversity in the lake.

Another species that appears to be common in Gravel Lake is the brown bullhead, which was also notably present in most sampling done by IFR in the past (Appendix A3). Brown bullheads ranged from 11.5 to 13.9 inches and were eating bluegills (many YOY), the large snail or gastropod that inhabits the lake (river snail, Viviparidae), crayfish, and one had a lot of chironomids in its stomach (Table 14).

TABLE 14
DIETS OF GRAVEL LAKE FISH EXAMINED[1]

Station	Sampling Gear	Total Length (in)	Weight (oz)	Sex	Diet
BLACK CRAPPIE					
3	TN	8.4	6	M1	MT
BLUEGILL					
8	S-R1,R2	1.3	0.02		
8	S-R1,R2	1.4	0.02		
8	S-R1,R2	1.5	0.03		
8	S-R1,R2	1.6	0.03		
8	S-R1,R2	1.6	0.03		
8	S-R1,R2	1.7	0.04	II	DETRITUS
8	S-R1,R2	1.7	0.04	II	DETRITUS
8	S-R1,R2	1.7	0.04	II	MT
8	S-R1,R2	1.7	0.04		
8	S-R1,R2	1.7	0.04		
8	S-R1,R2	1.7	0.04	II	PHANTOM MIDGE, AMPHIPODS
8	S-R1,R2	1.7	0.04		
8	S-R1,R2	1.7	0.04		
2	TN	1.8	0.04	II	MT
8	S-R1,R2	1.8	0.05		
8	S-R1,R2	1.8	0.05		
2	TN	1.8	0.05	II	MT
2	TN	1.8	0.05	II	MT
8	S-R1,R2	1.8	0.05		
2	TN	1.9	0.05	II	MT
8	S-R1,R2	1.9	0.05		
2	TN	1.9	0.05	II	MT
8	S-R1,R2	1.9	0.06		
8	S-R1,R2	2.0	0.07		
8	S-R1,R2	2.0	0.07		
8	S-R1,R2	2.0	0.06		
2	TN	2.0	0.08	II	MT
2	TN	2.2	0.08	II	MT
2	TN	2.2	0.06	II	MT
2	TN	2.2	0.08	II	MT
8	S-R1,R2	2.4	0.11		
8	S-R1,R2	2.4	0.12	II	CHIRONOMIDS
8	S-R1,R2	2.5	0.14	II	MT
8	S-R1,R2	2.6	0.15		
8	S-R1,R2	2.6	0.15	II	ZOOPLANKTON
8	S-R1,R2	2.7	0.17	II	ANTS
8	S-R1,R2	3.0	0.23	II	MT
2	TN	3.0	0.23	II	ZEBRA MUSSEL
8	S-R1,R2	3.0	0.25		
8	S-R1,R2	3.1	0.23	II	MT
8	S-R1,R2	3.2	0.28		
8	S-R1,R2	3.2	0.30	II	AMPHIPODS (FAIRY SHRIMP)
8	S-R1,R2	3.2	0.33		

1 NA=not available; M=male, F=female; 1=poorly developed gonads, 2=moderately developed, 3=well developed, 4=ripe running, and 5=spent. I=immature; MT=empty stomach; MT=empty stomach; xx=unknown. F.Pole=fishing pole. TN=trapnet, GN=gill net, S=seine. R1 and R2 are replicates.

TABLE 14 (continued)
DIETS OF GRAVEL LAKE FISH EXAMINED[1]

Station	Sampling Gear	Total Length (in)	Weight (oz)	Sex	Diet
2	TN	3.3	0.35	II	MT
8	S-R1,R2	3.4	0.40	II	ZOOPLANKTON
8	S-R1,R2	3.5	0.44	II	ANTS
8	S-R1,R2	3.6	0.46	II	ANTS
2	TN	3.7	0.45	II	CADDISFLIES
8	S-R1,R2	3.8	0.53	F1	DRAGONFLIES
8	S-R1,R2	4.2	0.73	M1	MT
8	S-R1,R2	4.6	1.03	F1	TERRESTRIAL INSECTS
8	S-R1,R2	4.7	1.05	F1	CHIRONOMIDS
8	S-R1,R2	4.9	1.19		FINGERNAIL CLAMS, OTHER INSECTS
8	S-R1,R2	5.0	1.27	F1	CHIRONOMIDS
8	S-R1,R2	5.0	1.27	F1	CHIRONOMIDS
8	S-R1,R2	5.3	1.47	F1	DRAGONFLIES
14	GN	5.4	NA	F1	MT
8	S-R1,R2	5.4	1.67	F1	DRAGONFLIES
1	GN	6.9	3	F5	ZOOPLANKTON
3	TN	7.0	4	F1	MOTH
1	GN	7.0	3	M1	ZOOPLANKTON
1	GN	7.2	4	F1	ZOOPLANKTON
3	TN	7.4	3	M2	MT
14	GN	7.6	NA	F3	DETRITUS
1	GN	8.1	6	F3	ZEBRA MUSSELS and SNAILS
13	TN	9.0	NA	M3	DRAGONFLIES
BANDED KILLIFISH					
8	S-R1,R2	1.6	0.02		
8	S-R1,R2	1.7	0.03		
8	S-R1,R2	1.7	0.03		
8	S-R1,R2	1.7	0.03		
8	S-R1,R2	1.7	0.03		
8	S-R1,R2	1.9	0.04		
BLACKCHIN SHINER					
8	S-R1,R2	1.7	0.02		
8	S-R1,R2	1.7	0.02		
8	S-R1,R2	1.8	0.03		
8	S-R1,R2	2.0	0.04		
BLUNTNOSE MINNOW					
8	S-R1,R2	1.7	0.02		
6	S1	1.8	0.03		
8	S-R1,R2	2.0	0.04		
6	S1	2.1	0.05		
6	S1	2.2	0.05		
6	S1	2.2	0.06		
8	S-R1,R2	2.2	0.05		
BROOK SILVERSIDES					
6	S1	0.9	0.003		
8	S-R1,R2	1.1	0.005		

1 NA=not available; M=male, F=female; 1=poorly developed gonads, 2=moderately developed, 3=well developed, 4=ripe running, and 5=spent. I=immature; MT=empty stomach; MT=empty stomach; xx=unknown. F.Pole=fishing pole. TN=trapnet, GN=gill net, S=seine. R1 and R2 are replicates.

TABLE 14 (continued)
DIETS OF GRAVEL LAKE FISH EXAMINED[1]

Station	Sampling Gear	Total Length (in)	Weight (oz)	Sex	Diet
8	S-R1,R2	1.2	0.01		
8	S-R1,R2	1.3	0.01		
6	S1	1.3	0.01		
6	S1	1.4	0.01		
8	S-R1,R2	1.4	0.01		
8	S-R1,R2	1.4	0.01		
8	S-R1,R2	1.4	0.01		
6	S1	1.5	0.01		
6	S1	1.5	0.01		
8	S-R1,R2	1.5	0.01		
8	S-R1,R2	1.6	0.01		
8	S-R1,R2	2.7	0.06		
8	S-R1,R2	2.9	0.07		
8	S-R1,R2	3.1	0.08		
8	S-R1,R2	3.1	0.08		
8	S-R1,R2	3.3	0.10		
8	S-R1,R2	3.3	0.11		
BROWN BULLHEAD					
13	TN	11.5	NA	M1	MT
11	TN	11.6	NA	M1	BG:48,45,50,43,35,50,43,45,42;2 VIVIPARIDAE
3	TN	11.9	14	F5	SNAIL- VIVIPARIDAE; CRAYFISH
10	GN	13.2	1	F1	MT
4	TN	13.2	17	F3	BG 130 MM TAIL ONLY; SNAIL VIVIPARIDAE
13	TN	13.4	NA	M1	MT
13	TN	13.9	NA	F1	CHIRONOMIDS
JOHNNY DARTER					
8	S-R1,R2	1.4	0.02		
8	S-R1,R2	1.9	0.03	CC	MT
LARGEMOUTH BASS					
8	S-R1,R2	1.3	0.02		
8	S-R1,R2	1.4	0.02	II	
8	S-R1,R2	1.4	0.02		
8	S-R1,R2	1.4	0.02	II	
8	S-R1,R2	1.4	0.02	II	
8	S-R1,R2	1.4	0.02		
6	S1	1.5	0.03		ZOOPLANKTON
8	S-R1,R2	1.5	0.02	II	
8	S-R1,R2	1.5	0.03	II	
8	S-R1,R2	1.5	0.02		
6	S1	1.5	0.03		
8	S-R1,R2	1.6	0.03	II	
8	S-R1,R2	1.6	0.03	II	
8	S-R1,R2	1.7	0.04	II	
8	S-R1,R2	1.7	0.04	II	
8	S-R1,R2	1.7	0.03		
8	S-R1,R2	1.7	0.04	II	MT

1 NA=not available; M=male, F=female; 1=poorly developed gonads, 2=moderately developed, 3=well developed, 4=ripe running, and 5=spent. I=immature; MT=empty stomach; MT=empty stomach; xx=unknown. F.Pole=fishing pole. TN=trapnet, GN=gill net, S=seine. R1 and R2 are replicates.

TABLE 14 (continued)
DIETS OF GRAVEL LAKE FISH EXAMINED[1]

Station	Sampling Gear	Total Length (in)	Weight (oz)	Sex	Diet
8	S-R1,R2	1.7	0.03		
8	S-R1,R2	1.8	0.04	II	CHIRONOMIDS
8	S-R1,R2	1.8	0.04	II	
8	S-R1,R2	1.8	0.04		
8	S-R1,R2	2.6	0.10		XX FISH
8	S-R1,R2	2.6	0.11	II	MT
8	S-R1,R2	2.7	0.12		
8	S-R1,R2	2.7	0.13		XX FISH
8	S-R1,R2	4.8	0.68		LB 34 mm, 27 mm
8	S-R1,R2	4.9	0.82	F1	XX FISH
8	S-R1,R2	5.0	0.87	F1	XX FISH
6	S1	6.0	2	F1	MT
8	S-R1,R2	6.9	2	F1	XX FISH
8	S-R1,R2	6.9	2	M1	3 XX FISH
6	S1	8.9	5	M1	XX FISH; DAMSELFLY
6	S1	9.0	5	M1	JD, XX FISH
6	S1	9.3	6	F1	YP 44 MM; XX FISH
6	S1	9.6	7	F1	CADDISFLY; 2 DRAGONFLIES
6	S1	9.7	7	M1	XX FISH
8	S-R1,R2	9.7	7	M1	DRAGONFLY; XX FISH
8	S-R1,R2	10.0	7	M1	BG 56 MM
6	S1	10.2	7	F1	CRAYFISH
6	S1	10.3	8	M1	CRAYFISH
8	S-R1,R2	10.4	8	M1	MT
1	GN	11.7	11	F1	?YP 43 MM; XX FISH 35 MM
6	S	12.0	12	F5	CRAYFISH
GL	FPOLE	12.5	NA		COLLECTOR: JAMES OPOKA
1	GN	12.9	11	F5	YP 33 MM
GL	FPOLE	13.0	1#		COLLECTOR: FISHER
GL	FPOLE	13.0	1#1OZ		COLLECTOR: FISHER
GL	FPOLE	14.0	NA		COLLECTOR: JAMES OPOKA-27 JUN
GL	FPOLE	19.0	3.8#		COLLECTOR: JAMES OPOKA-25 JUL
GL	FPOLE	19.0	3.2 #		COLLECTOR: JAMES OPOKA-27 JUN
GL	FPOLE	21.0	3#10 OZ		COLLECTOR: JAMES OPOKA-4 JUL
GL	FPOLE	21.5	5.25 #		COLLECTOR: PETER RUCINSKI-7 AUG
MIMIC SHINER					
8	S-R1,R2	2.2	0.04		
8	S-R1,R2	2.2	0.05		
8	S-R1,R2	2.4	0.07		
PUMPKINSEED					
12	TN	6.2	NA	F2	MT
1	GN	7.0	5	M1	SNAILS
13	TN	7.2	NA	M2	SNAILS, CHARA
4	TN	7.3	5	F3	MT
8	S-R1,R2	8.0	6	M2	CADDISFLY CASE; SNAIL Gyraulus
10	GN	8.3	6	M2	SNAILS

1 NA=not available; M=male, F=female; 1=poorly developed gonads, 2=moderately developed, 3=well developed, 4=ripe running, and 5=spent. I=immature; MT=empty stomach; MT=empty stomach; xx=unknown. F.Pole=fishing pole. TN=trapnet, GN=gill net, S=seine. R1 and R2 are replicates.

TABLE 14 (continued)
DIETS OF GRAVEL LAKE FISH EXAMINED[1]

Station	Sampling Gear	Total Length (in)	Weight (oz)	Sex	Diet
9	GN	8.3	9	F3	SNAILS
8	S-R1,R2	8.3	8	M2	SNAILS Gyraulus, CADDISFLY
8	S-R1,R3	8.6	9	F1	SNAILS
9	GN	8.7	9	F3	SNAILS
PUGNOSE SHINER					
8	S-R1,R2	1.9	0.03		
SAND SHINER					
8	S-R1,R2	1.9	0.04		
8	S-R1,R2	1.9	0.04		
8	S-R1,R2	1.9	0.03		
6	S	2.0	0.02		
6	S	2.0	0.04		
6	S	2.0	0.04		
6	S	2.0	0.04		
8	S-R1,R2	2.1	0.06		
6	S	2.2	0.05		
6	S	2.2	0.05		
8	S-R1,R2	2.2	0.05		
8	S-R1,R2	2.2	0.07		
6	S	2.3	0.06		
6	S	2.4	0.06		
6	S	2.4	0.06		
8	S-R1,R2	2.4	0.07		
SMALLMOUTH BASS					
GL	FPOLE	15.0	NA		COLLECTOR: MATT SMALL-7 AUG
SPOTFIN SHINER					
8	S-R1,R2	1.4	0.01		
8	S-R1,R2	1.6	0.02		
8	S-R1,R2	1.8	0.03		
8	S-R1,R2	2.3	0.06		
8	S-R1,R2	2.3	0.06		
6	S	2.4	0.07		
8	S-R1,R2	2.6	0.08		
6	S1	2.6	0.11		
8	S-R1,R2	2.6	0.08		
8	S-R1,R2	2.6	0.10		
6	S	2.8	0.10		
6	S	2.8	0.15		
WALLEYE					
3	TN	10.5			
9	GN	14.7	13	F2	MT
1	GN	14.7	17	M1	MT
14	GN	17.0			
4	TN	23.0			

1 NA=not available; M=male, F=female; 1=poorly developed gonads, 2=moderately developed, 3=well developed, 4=ripe running, and 5=spent. I=immature; MT=empty stomach; MT=empty stomach; xx=unknown. F.Pole=fishing pole. TN=trapnet, GN=gill net, S=seine. R1 and R2 are replicates.

TABLE 14 (continued)
DIETS OF GRAVEL LAKE FISH EXAMINED[1]

Station	Sampling Gear	Total Length (in)	Weight (oz)	Sex	Diet
WARMOUTH					
2	TN	2.6	0.18	F1	MT
2	TN	2.8	0.25	II	PLANT SPRIG
2	TN	3.1	0.32	II	?INSECT PARTS
2	TN	4.6	1.00	CC	MT
2	TN	4.9	1.28	F1	MT
WHITE SUCKER					
1	GN	18.0	37	M1	DETRITUS
YELLOW PERCH					
6	S	1.5	0.02		
8	S-R1,R2	2.0	0.04		
8	S-R1,R2	2.8	0.11	II	CHIRONOMID LARVAE
8	S-R1,R2	3.1	0.15		
8	S-R1,R2	3.1	0.18	F1	MT
8	S-R1,R2	3.3	0.19		
8	S-R1,R2	3.3	0.20	F1	MT
8	S-R1,R2	3.3	0.20	F1	MT
8	S-R1,R2	3.3	0.20	M1	MT
8	S-R1,R2	3.4	0.20	M1	MT
8	S-R1,R2	3.5	0.23		
8	S-R1,R2	3.5	0.22	F1	MT
8	S-R1,R2	3.7	0.26	F1	MT
8	S-R1,R2	3.7	0.27	F1	MT
8	S-R1,R2	3.7	0.28		
8	S-R1,R2	3.7	0.25	F1	MT
8	S-R1,R2	3.8	0.27	F1	MT
8	S-R1,R2	3.9	0.32	F1	MT
8	S-R1,R2	4.1	0.34	F1	MT
8	S-R1,R2	4.1	0.40	F1	MT
8	S-R1,R2	4.2	0.40	F1	MT
8	S-R1,R2	4.3	0.45	F1	MT
1	GN	4.5	<1	M1	MT
14	GN	4.5	NA	F1	CHIRONOMIDS, SNAIL
8	S-R1,R2	4.8	0.60	F1	MT
14	GN	5.3	NA	F1	CHIRONOMIDS
12	TN	6.5	NA	F1	BG 45 MM
10	GN	6.6	2	F1	CHIRONOMIDS
14	GN	6.9	NA	F1	ZOOPLANKTON
10	GN	7.3	3	F1	CHIRONOMIDS- MANY
1	GN	7.6	3	F5	BG 33 MM
1	GN	8.5	4	F1	CHIRONOMIDS- MANY
GL	F. POLE	8.7	4	F1	ZOOPLANKTON
14	GN	8.7	NA	F1	CHIRONOMIDS
1	GN	9.5	6	F1	XX FISH
1	GN	9.6	6	M1	PHANTOM MIDGES CHAOBORUS
1	GN	10.5	4	F1	MT
1	GN	10.5	7	F5	MT

1 NA=not available; M=male, F=female; 1=poorly developed gonads, 2=moderately developed, 3=well developed, 4=ripe running, and 5=spent. I=immature; MT=empty stomach; MT=empty stomach; xx=unknown. F.Pole=fishing pole. TN=trapnet, GN=gill net, S=seine. R1 and R2 are replicates.

We seined two Johnny darters which are in the Perch family and these fish are indicators of excellent water quality. The fish we collected were 1.4-1.9 inches and were not eating anything. They are usually benthivores (eat aquatic insects).

Largemouth bass appear to be quite common in the lake, are often caught by fishers, and were present in all the previous sampling done by IFR (Appendix A3). We collected fish ranging from 1.3 to 12 inches (Table 14). We always have difficulty catching larger individuals, since they do not appear in trap nets and are not collected by gill nets very well either.

Fortunately we were able to secure larger individuals from our resident lake guardians, which helped with the growth analyses. There seems to be great spawning substrate (gravel and sand) both for bluegills and largemouth bass, which build and guard nests during spring-early summer. There was ample evidence of many young-of-the-year (YOY) largemouth bass, since they were common to abundant in the seine hauls (Table 14). YOY bass from 1.8 to 2.7 inches were eating zooplankton, chironomids, and two had eaten unknown fish; so they were starting to be piscivorous at this early size.

Largemouth bass from 4.8 to 12.9 inches switched from eating zooplankton and insects to being mostly predators on fish as they grew older; some of them were cannibalistic as well, consuming some of the abundant YOY bass present in the environment (Table 14). Others ate unknown fish, bluegills, Johnny darter, yellow perch, and crayfish. In addition, some were feeding on damselflies, dragonflies, obviously obtained from macrophytes. This is excellent information, since it indicates that largemouth bass are consuming many species of fishes and that these prey items are apparently plentiful enough in the lake to sustain the intense predation largemouth bass can exert on prey populations in a lake, which also includes their own young. We have seen situations where largemouth bass introduced into a eutrophic lake decimated all the other species in the lake except bluegills.

We collected a number of mimic shiners (2.2-2.4 inches), most of which were released, showing that there is great diversity and survival of this species and many others in Gravel Lake.

We collected or were given ten pumpkinseeds that ranged in length from 6.2 to 8.7 inches (Table 14). These fish are known mollusk eaters and they were eating snails *Gyraulus* mainly with some caddisflies and Chara an alga, also eaten. Pumpkinseeds are often stocked along with redear sunfish to control snails which are intermediate hosts for swimmers itch syndrome which can affect swimmers. Pumpkinseeds feed on a prey source that is often underutilized in a lake and there is excellent growth as well, providing another panfish for sport fishers. We noted the lack of YOY in our samples and have no explanation for why there was such poor survival and why there were none collected.

Among the minnows we collected during seining was a pugnose shiner (1.9 inches), which is an endangered species in Michigan. They appear to be rare, but obviously reproducing in Gravel Lake.

We also collected a number of sand shiners appropriately since the Gravel Lake near shore zone is sandy all around its perimeter. Fish ranged from 1.9 to 2.4 inches long and were common in our seine hauls. They represent another excellent prey item for a large number of species in the lake.

One smallmouth bass (15 inches) was collected by a fisher. It had an empty stomach. Smallmouth bass have been reported to be present in the lake in small numbers. Since it was not recorded in past IFR studies through 1979, it must have been stocked in the lake since that time. I have seen them become abundant in lakes and sometimes more abundant than largemouth bass. However, it appears from lack of any YOY in our seine hauls and the rarity of this species that it is uncommon in the lake and not reproducing at this time.

Spotfin shiners are pretty minnows with a spot on their dorsal fins and they were moderately common in our seine hauls in the lake (Table 14). They ranged from 1.4 to 2.8 inches and are usually feeders on insects, detritus, and other organic matter. Again they are an important component of the prey fish available to small and large top predators in the lake.

Walleye is another top predator and some have been stocked into Gravel Lake in the recent past. IFR records (Appendix A3, p. 10) document the stocking of 54 individuals in 1943. More recently 1,000 walleyes have been stocked from 2007 through 2014. We collected five walleyes that ranged in length from 10.5 to 23.0 inches (Table 14). None had food in their stomachs; most were released. Walleyes are known predators on bottom-dwelling fishes, especially yellow perch, and with their specialized eyes do most of their feeding at night or under low-light conditions. They would be another predator that would target yellow perch, which could reduce their abundance in the lake. The fact that we caught five fish in the gill nets and trapnets we set (three were released alive) is an indication that there are quite a few residing in the lake. They obviously survived during summer, despite the considerable stresses experienced during summer stratification: low dissolved oxygen in required cool bottom waters, while too warm temperatures in oxygenated surface waters (Figure 29). Walleye are also cool-water species like northern pike and probably grow poorly and suffer stress during the warmer periods of the year. However, they appeared to be growing well (see below).

Warmouth is an unusual sunfish and not very common in Michigan inland lakes. We captured five from 2.6 to almost 5 inches (Table 14). They are usually insectivorous, but can become piscivorous at larger sizes. These fish were eating plants and insect parts.

Yellow perch are fisher's delight because of their unique flavor. It appears there is a well established population in Gravel Lake based on past IFR reports (Appendix A3) and our survey in 2015. We collected fish from 1.5 inches (YOY) to 10.5 inches (Table 14). There were many YOY collected during our seining activities, documenting a good year class of yellow perch during 2015. These fish show the classical pattern of starting out eating small insects and zooplankton, shift to eating mainly insects, then switch to fish at larger sizes. Most of the fish from 1.5 to 4.5 inches had empty stomachs, except for one 2.8-inch fish that had eaten chironomids. Fish from 4.5 to 5.3 inches were eating chironomids and snails, while fish greater than 6.4 inches were mainly eating fish (bluegills, unknown) along with large numbers of chironomids, phantom midges, and some zooplankton as well.

The panfish community in Gravel Lake is comprised of bluegills, pumpkinseeds, warmouth, black crappies, and largemouth bass, all members of the sunfish (Centrarchidae family). This complex is the backbone of any warm-water lake fish community and is usually self-sustaining, since the largemouth bass have adequate spawning substrate (gravel and sandy shores) and can usually control the panfish and prevent stunting. The high diversity of vertebrate and invertebrate prey is being consumed by the bluegills, black crappies, warmouth, and small largemouth bass along with help from bullheads, yellow perch, so it appears that a considerable amount of your prey resources are being efficiently converted into fishable biomass.

We also collected an amazing five species of cyprinids (minnow family) in our nets. These included the following species: Mimic shiner, pugnose shiner, blackchin shiner, spotfin shiner, and the bluntnose minnow. Minnow species are an excellent addition to the fish fauna, since they utilize resources that none of the other fish consume (algae and detritus and probably some insects) and they add an important forage fish for top predators, such as yellow perch, northern pike, and largemouth bass. These species contribute to the high species diversity we noted in the fish community, which is important for maintaining stability under the different stressors of the environment and varying population swings of the predators in the lake. The analogy to a diverse stock portfolio is apt here. The water quality in the near-shore zone is adequate to support them (high dissolved oxygen), despite the low dissolved oxygen in the deep area during summer stratification. We strongly encourage macrophyte populations in the lake. We recognize the desire to have a clear path from ones dock for the boat, but we stress that plants should be spot-treated in affected areas with plants (and algae) removed mechanically where possible to provide paths or clear beaches, so as to leave more habitat for fish, especially small ones that require them for shelter, survival, and food.

Mercury in Fish

Just a note about mercury. It is a problem in most of Michigan's inland lakes. Most mercury comes to the watersheds of lakes through deposition from the air with most coming from power plants burning coal. The elemental mercury is converted to methyl mercury through bacterial action or in the guts of invertebrates and animals that ingest it. It becomes rapidly bioaccumulated in the food chain, especially in top predators. The older fishes, those that are less fatty, or those high on the food chain will carry the highest levels. Studies we have done in Michigan lakes and studies by the MDNR have shown that large bluegills, largemouth bass, black crappies, northern pike, and walleyes all contain high levels of mercury. This suggests that fishers should consult the Michigan fishing guide for recommendations on consumption, limit their consumption of large individuals, and try to eat the smaller ones. It also suggests that a trophy fishery (catch and release) be established for largemouth bass (which is probably generally followed anyway—this is more incentive), and some of the larger individual bluegills, pumpkinseed, and yellow perch in the lake.

Fish Growth

Growth of the fishes we collected was determined by ageing a sample of fish of various sizes using multiple scales under a microscope and comparing the age of fish from Gravel Lake with Michigan DNR standards (Latta 1958, Laarman 1963). Bluegills are common in Gravel Lake and those we aged (n=19) were growing at state mean lengths up to about 3 years old, then those older grew above state averages (Table 15, Figure 42). The fish we aged ranged from 1.1 to 8.5 inches, so there is a good size range of fish present, suggesting a well balanced population in control by the large numbers of predators in the lake. The scattered aquatic plant beds present in the lake, the good diversity and abundance of benthos, and abundance of large zooplankton are apparently providing food and good habitat for bluegill shelter and sufficient food for adequate growth.

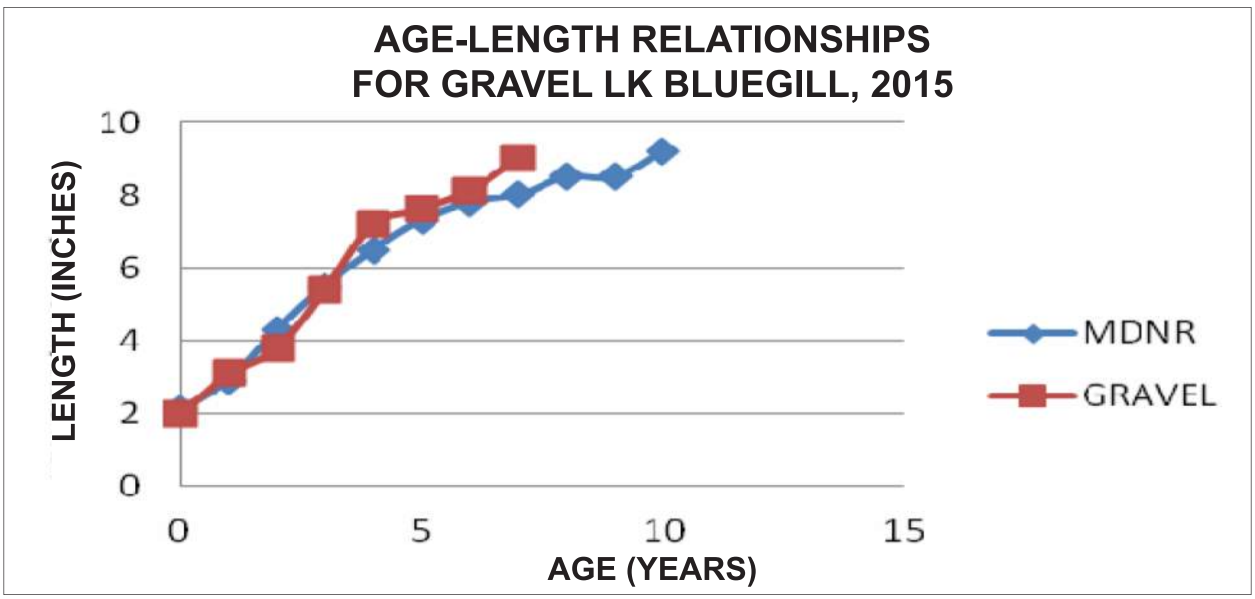

Figure 42. Growth of bluegill in Gravel Lake (red squares) compared with the Michigan state averages (blue diamonds) (see Latta 1958, Laarman 1963), 29 July 2015. See Table 15 for raw data. N=19.

TABLE 15
GRAVEL LAKE FISH AGE DATA[1]
July 29-31, 2015

MDNR Age (year)	MDNR Length (in.)	Gravel Lake Length (in.)
BLUEGILL		n=19
0	2.1	2(1)
1	2.9	3.1(1)
2	4.3	3.8(4)
3	5.5	5.4(6)
4	6.5	7.2(4)
5	7.3	7.6(1)
6	7.8	8.1(1)
7	8	9(1)
8	8.5	
9	8.5	
10	9.2	
LARGEMOUTH BASS		n=28
0	3.3	2.7(3)
1	6.1	5.8(6)
2	8.7	9(1)
3	10	9.8(7)
4	12.1	12.5(6)
5	13.7	14(1)
6	15.1	
7	16.1	
8	17.7	
9	18.8	19(2)
10	19.8	21.3(2)
11	20.8	
PUMPKINSEED		n=9
0	2	
1	2.9	
2	4.1	
3	4.9	
4	5.7	
5	6.2	6.6(2)
6	6.8	8(6)
7	7.3	8.7(1)
8	7.8	
YELLOW PERCH		n=19
0	3.3	
1	4	3.6(4)
2	5.7	4.6(4)
3	6.8	6.9(4)
4	7.8	
5	8.7	8.6(3)
6	9.7	9.5(2)

1 Fishes were collected in seines, gill nets, and trap nets, scales removed, aged, and total lengths at various ages compared with Michigan state mean lengths for various fishes at those same ages (see Latta 1958; Laarman 1963). Shown is the age (years) of the fish, its total length (inches) based on MDNR state of Michigan mean lengths, and the mean length-at-age of Gravel Lake fishes along with sample size in parentheses. Total no. fish aged given at top as n. See Figs. 7-13 for graphical display of these same data. Some fishes from later in the year provided by fishers.

TABLE 15 (continued)
GRAVEL LAKE FISH AGE DATA[1]
July 29-31, 2015

MDNR Age (year)	MDNR Length (in.)	Gravel Lake Length (in.)
7	10.5	10.5(2)
8	11.3	
9	11.7	
BLACK CRAPPIE		n=1
0	3.6	
1	5.1	
2	5.9	
3	8	8.4(1)
4	9	
5	9.9	
6	10.7	
7	11.3	
8	11.6	
WALLEYE		n=5
0	6.6	
1	9.1	10.5(1)
2	12	
3	15.9	15.5(3)
4	17.8	
5	18.9	
6	18.8	
7	18.8	
8	21.4	23(1)
9	19.7	
10	22.6	
SMALLMOUTH BASS		n=1
0	3.3	
1	5.9	
2	9	
3	11.2	
4	13.3	15(1)
5	15	
6	15.3	
7	16.4	
8	16.8	

1 Fishes were collected in seines, gill nets, and trap nets, scales removed, aged, and total lengths at various ages compared with Michigan state mean lengths for various fishes at those same ages (see Latta 1958; Laarman 1963). Shown is the age (years) of the fish, its total length (inches) based on MDNR state of Michigan mean lengths, and the mean length-at-age of Gravel Lake fishes along with sample size in parentheses. Total no. fish aged given at top as n. See Figs. 7-13 for graphical display of these same data. Some fishes from later in the year provided by fishers.

Largemouth bass were also common in Gravel Lake, especially YOY, but we never saw very many very large fish (all large fish came from fishers). Fish collected ranged from 1.3 to 21.5 inches (Table 13). The age-length relationship for Gravel Lake bass (Figure 43) based on ageing 28 fish was mostly similar to the growth rates of Michigan DNR's fish with the large fish growing faster than state averages. There do not appear to be any growth issues with your fish. This species is one of the keystone predators in your lake and responsible for keeping the bluegills in check, so the big fish should be left in the lake to the degree possible (catch and release unless hooking leads to death). The other reason, as noted elsewhere, is that large individuals are probably contaminated with mercury and should not be eaten anyway. We concluded the following: first, they are generally growing at or above state averages, and second, based on our findings of large numbers of young-of-the-year fish caught (personal observations in seine hauls; Table 14), we think that largemouth bass are reproducing adequately in the lake. We explored the near shore zone in the lake, and there definitely was considerable gravel/sand bottom along shore that is good spawning substrate for sunfish family members, including largemouth bass. This finding also has implications for fish management recommendations. There obviously are large numbers of fish in the 10- to 15-inch class and fishers complained that most of the largemouth bass that are caught were this size. This suggests some type of slot limit to reduce the numbers of this size group so they can grow faster and produce larger largemouth bass. However, since this size group is growing at or above state means the incentive for reducing their numbers is weak.

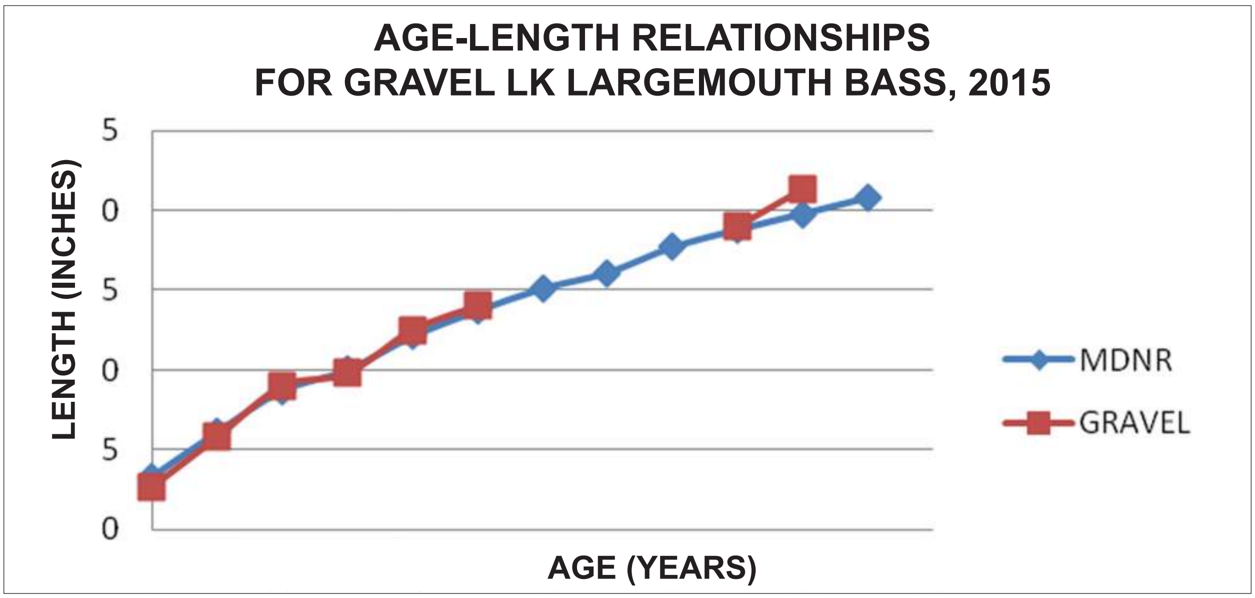

Figure 43. Growth of largemouth bass in Gravel Lake (red squares) compared with Michigan state averages (blue diamonds) (see Latta 1958, Laarman 1963), 29 July 2015. See Table 15 for raw data. N=28.

Yellow perch populations seem to also be well balanced in the lake based on our collections and fishers' reports. Those we caught ranged from 1.5 to 10.5 inches (N=19). They were growing below state means for 2-year-old fish, but at state averages for all the other age groups (Table 15, Figure 44). Yellow perch are important prey fish that are usually not too susceptible to bass predation (however some were eaten), and are outstanding table fare for people. Hence, we would like to have seen more of them in the lake. The dearth or lack of northern pike probably has enhanced their survival rates.

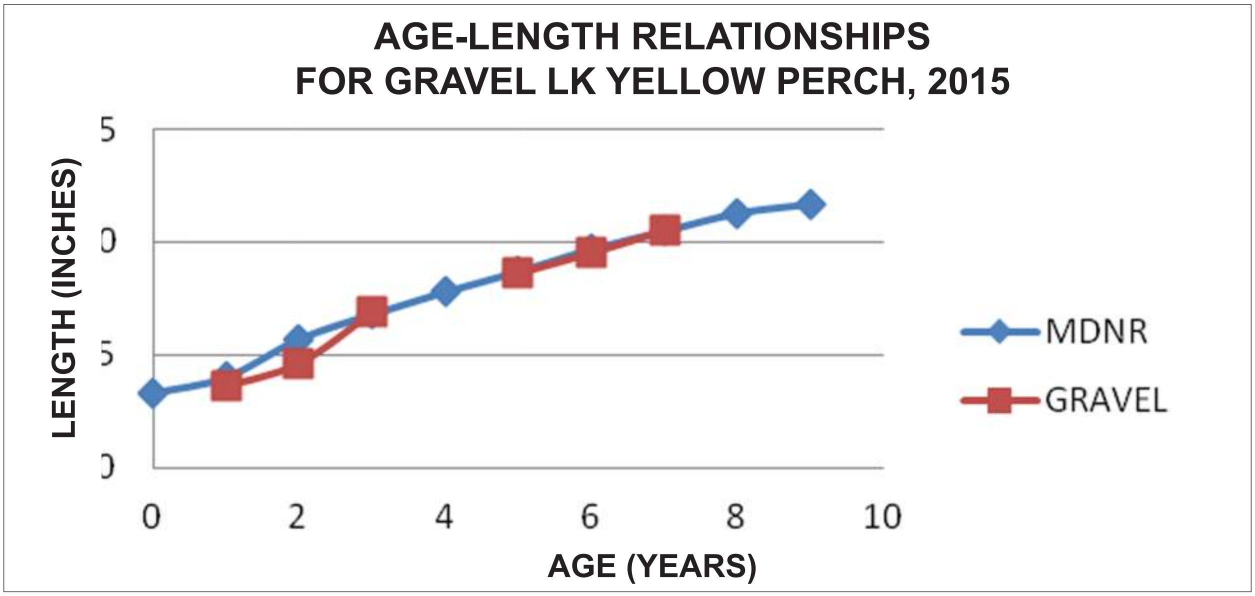

Figure 44. Growth of yellow perch in Gravel Lake (red squares) compared with the Michigan state averages (blue diamonds) (see Latta 1958, Laarman 1963), 29 July 2015. See Table 15 for raw data. N=19.

The one black crappie we collected was growing slightly above state averages. This fish was an 8.4-inch adult (Table 15, Figure 45). They appear to be rare in the lake, but we could have missed them with our sampling design.

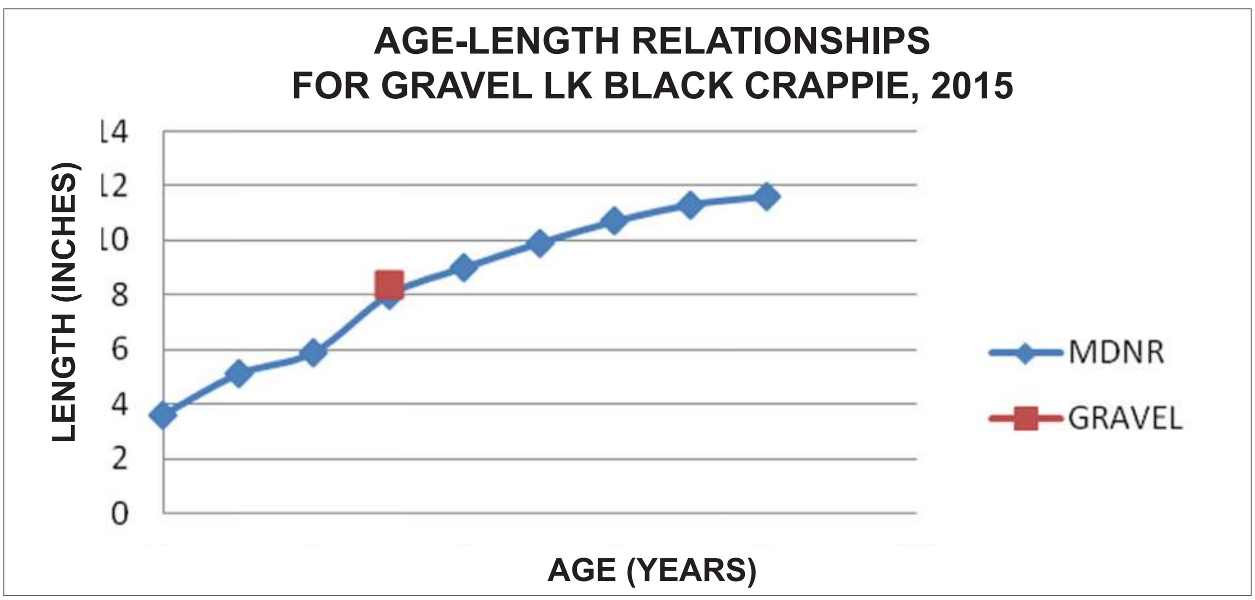

Figure 45. Growth of black crappies in Gravel Lake (red squares) compared with the Michigan state averages (blue diamonds) (see Latta 1958, Laarman 1963), 29 July 2015. See Table 15 for raw data. n=1.

Pumpkinseeds presented an interesting case, since we only were able to collect large specimens (range: 6.2-8.7 inches, n=9); some fish came from fishers. Growth of this species for the 5- to 7-year old age group was higher than state averages (Figure 46). As noted this species is a known molluskivore and therefore feeds on a food supply that is not usually consumed by other sunfish species. The lack of smaller fish collected is an intriguing unanswered question.

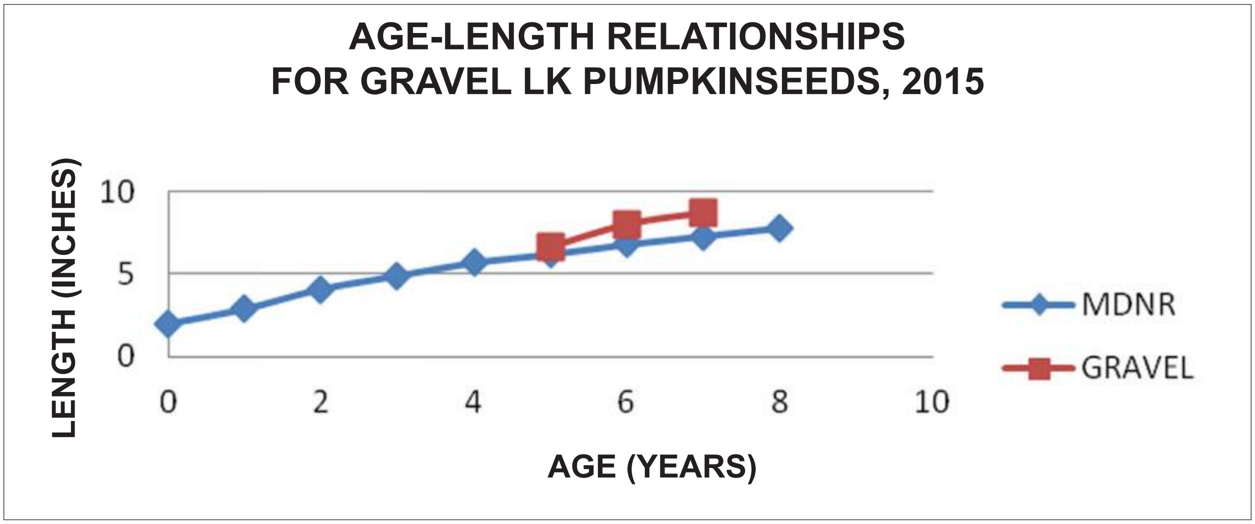

Figure 46. Growth of pumpkinseeds in Gravel Lake (red squares) compared with Michigan state averages (blue diamonds) (see Latta 1958), 29 July 2015. See Table 15 for raw data. N=9.

At least 1,000 walleyes have been stocked into Gravel Lake over the period 2007 to 2014. Some (54) were stocked in 1947 (Appendix A3). Stocking walleyes into an established fish community that has evolved as a warm water fish ecosystem is controversial we believe. They do provide another top predator and are a popular fish with fishers, even though they are notoriously difficult to catch. We believe stocking walleyes is an activity that runs contrary to fish management principles for three reasons: first, walleyes are not native to this population and are not expected to reproduce, and will consume prey that other native species would eat. Second, stocking is only acceptable under a number of conditions that must be clearly documented. This includes a situation where the species is native and some catastrophe reduces numbers to very low levels and stocking can assist recovery of the species. In some cases we have seen stunted bluegill populations reduce the number of largemouth bass surviving by eating eggs and larvae from nests, justifying stocking more predators. Winterkill can also eliminate susceptible species and re stocking may be the only alternative to restore populations. Third, Gravel Lake is a classic example of a lake which puts the squeeze (see Figure 29) on cool water species, such as walleye and also northern pike. These species require cool water with high dissolved oxygen. These conditions are met in Gravel Lake during fall, winter, and early spring. However, during summer stratification, water warms in surface waters to unacceptable levels, while the cool water required for survival is devoid of or has low dissolved oxygen concentrations. During this time, cool water species are stressed, some probably die, and growth is restricted until other times of the year. Interestingly, growth of the walleyes we aged (range: 10.5-23 inches; n=5) was at or above state averages (Table 15, Figure 47). Hence, the argument that they are stressed is weak. Never-the-less, we recommend against stocking walleyes, but recognize that they do survive and provide a small fishery for Gravel Lake fishers. Therefore we could accept some low numbers of stocked fish provided decision makers realize these fish are not well adapted to conditions in mesotrophic lakes and there is a strong desire on the part of sport fishers to have some in the lake.

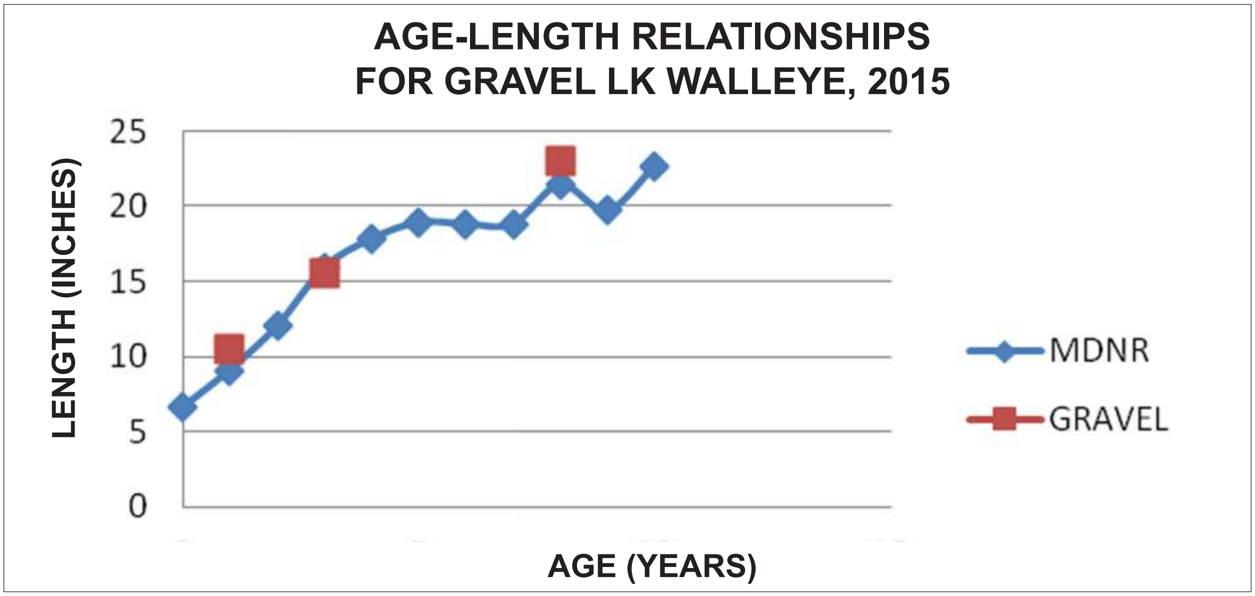

Figure 47. Growth of walleyes in Gravel Lake (red squares) compared with Michigan state averages (blue diamonds) (see Latta 1958, Laarman 1963), 29 July 2015. See Table 15 for raw data. N=5.

Smallmouth bass were also stocked into Gravel Lake, since they were not reported in any of the previous studies by IFR (Appendix A3). They appear to be rare in Gravel Lake. We were given one specimen by a sport fisherman. The smallmouth bass was 15 inches long, 4 years old, and growing above the state average for this year class (Table 15, Figure 48).

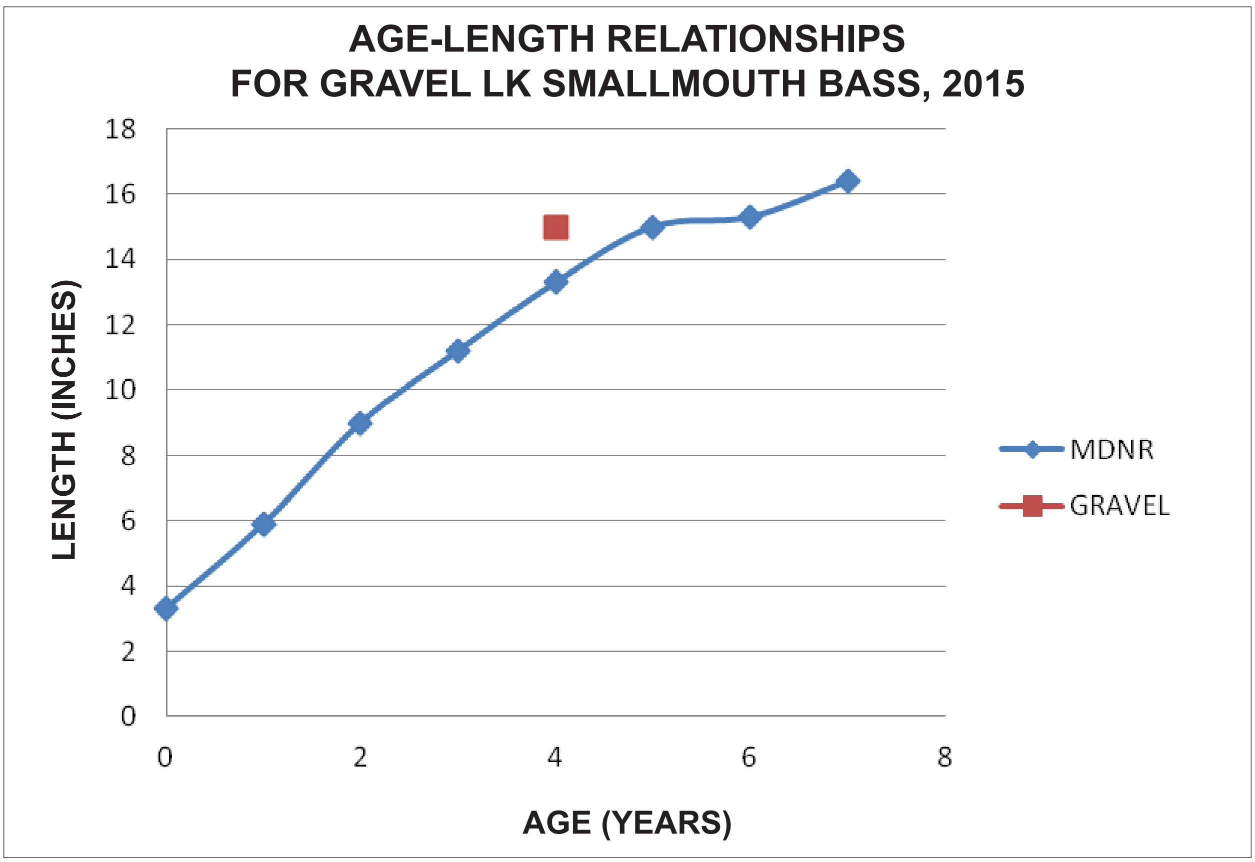

Figure 48. Growth of smallmouth bass in Gravel Lake (red squares) compared with the Michigan state averages (blue diamonds) (see Latta 1958, Laarman 1963), 29 July 2015. See Table 15 for raw data. N=1.

Fish Management Recommendations

There are two overarching concerns we have for Gravel Lake that bear directly on fish management recommendations. All water bodies have an innate carrying capacity and increasing that carrying capacity involves activities such as fertilization, increasing valuable macrophyte fish habitat (and hence fish-food organisms), or perhaps stocking a native species that could utilize more fully an underutilized food resource such as mollusks (pumpkinseed currently fulfill this niche in Gravel Lake). Our other possibilities usually involve shifting of resources and fish species within this food web complex, for example by stocking walleyes, which will consume prey items that native species, like largemouth bass would eat. There are other techniques, such as creation of artificial structure (brush piles) that do nothing to increase productivity, but are just fish attractors that concentrate fish so they are easier to catch. There may be some algal growth on these structures that would foster aquatic insect production and hence lead to some increases in fish production.

Considering this background, our first concern is the overall productivity of Gravel Lake. Based on our 2015 water clarity, the dissolved oxygen profile, and nutrient data, Gravel Lake is a mesotrophic lake which develops hypoxia (low dissolved oxygen) on the bottom during summer stratification. Mesotrophic lakes are generally productive as is Gravel Lake; however, we believe part of the big picture for Gravel Lake is the extensive marl deposits from about 5 to 20 feet along the lake shore. This marl (calcium carbonate) environment may be causing effects similar to a lake improvement technique called an "alum treatment," which is a chemical (aluminum sulfate) applied to lakes to precipitate phosphorus and, once on the bottom, it forms a chemical floc that continues to tie up phosphorus for many years after the application. Hence, Gravel Lake may be limited in productivity by the marl environment which sets basic productivity for the lake leading to lower fish communities compared to lakes without marl. Second, we wish to foster as many native macrophytes as possible to supplement fish habitat, which would benefit the entire Gravel Lake ecosystem, especially the fish. This is not to ignore the needs of boaters and those with beaches nor the primary goal of controlling invasive plants like Eurasian milfoil and starry stonewort. We suggest that algae accumulations on beaches (not including starry stonewort) need not be controlled with copper sulfate; mechanical means (a rake) can take care of most problem beach accumulations and are more healthy alternatives to copper which can also kill lots of snails and other mollusks, important food for fish such as pumpkinseeds. Simply put, try to balance the needs of the recreationalists with those of the fish resource.

Fish management strategies emanating from these data include the following. First, regarding largemouth bass, the most abundant top predator in the lake: As we argued above, there is a surfeit of fish in the 10- to 15-inch range and few greater than 15 inches, which suggests some type of slot limit or the reduction of members in this group, so that more food is available for the greater-than-15-inch group, presumably increasing survival and growth. Had we seen poor growth of the 10- to 15-inch fish, this would support such an action. However, the fish we aged were growing at state levels and the larger largemouth bass exceeded state mean growth. This good growth scenario seemed to be supported by the abundance and diversity of the prey fish we collected from the lake with the caveats noted above (higher productivity and more aquatic plants should increase prey fish growth and survival in the lake).

Second, we recommend catch and release of the bigger largemouth bass and other top predators, say those greater than 15 inches, so they can control prey fish populations, especially bluegills. Note that one of the other prey items we collected was zooplankton and we showed that 85% of the zooplankton in the deep area was *Daphnia*, the large, slow zooplankter which eats algae efficiently. This is very interesting and suggests two conclusions: first, predation by planktivores, especially YOY bluegills, appears to be low in this high water clarity lake, which suggests that either the YOY bluegill population is already being controlled well by predators or that most predation by planktivores on zooplankton occurs in shallower water. A catch-and-release policy is also supported by the fact that larger individuals of many sport fishes in many Michigan inland lakes are contaminated with mercury, limiting their consumption to small fish or long intervals between meals (see *Mercury in Fish* for a discussion).

Third, as we pointed out, stocked walleyes are stressed in Gravel Lake during summer stratification by too warm water at the surface and no dissolved oxygen on the bottom where cooler waters reside (Figure 29). This usually results in poor growth during summer and probably some fish die as a result. In addition, as pointed out, stocking walleyes into Gravel Lake violates at least four principles of fishery science: 1. The fish is not native and most likely will not spawn, 2. The existing fish community is a co-evolved, warm-water fish community and should not be de-stabilized by introduction of another keystone predator, 3. Water quality conditions, warm surface water and no dissolved oxygen in cool bottom waters, are not conducive nor optimal for a cool water fish, 4. You are playing ecological roulette with stocking, since you could introduce diseases (VHS see below), parasites, or non-indigenous species through stocking of fish, especially if done by non-professionals. We therefore recommend against stocking any more walleyes into Gravel Lake and suggest if fishers want walleyes (they are difficult to catch anyway) they go to Saginaw Bay or Lake Erie where a world-class fishery exists. Despite these concerns, it is obvious that some stocked walleyes did survive and actually grew at or above Michigan state averages in Gravel Lake. We know how many were stocked (1,000) over the last 8 years or an average of about 125/year about a half a fish per acre. Not knowing how many survived, we have no indication of what the morality rate was. If a majority of fishers still want to stock walleyes, despite all these warnings, they should be obtained from a reputable source, few and large individuals should be stocked, and obviously they should be stocked during the cooler periods of the year, spring or fall. The cautionary tale I experienced in another lake was the elimination of a cool-water species called lake herring or cisco which co-occurred in the lake with northern pike. A large number of walleyes were stocked and because of the “squeeze” noted above, the northern pike, walleyes, and ciscos all co-occurred in a narrow band of water during summer, apparently resulting in the complete elimination of this prey species, the cisco, which only occurs in some 153 lakes in Michigan.

Fourth, there was good spawning by sunfish family members (especially largemouth bass, but apparently not pumpkinseeds) and yellow perch. Hence, because of the favorable substrate (sand and gravel) for sunfish/bass spawning, there is no need for stocking any of these species.

Fifth, live bait use (minnows, crayfish) should be discouraged or banned because of the threat of introduction of exotic species (e.g., goldfish) and VHS (viral hemorrhagic septicemia) which killed many muskies and other species in many lakes, including Lake St. Clair. As noted above, any stocking should be done with a guarantee from the stocker that the fish are VHS-free. Any stocking by individuals should be banned for this very reason: introduction of fish from other water bodies or launching of contaminated boats may bring in parasites and diseases or non-indigenous species (e.g., quagga mussels), including VHS, that could have a devastating effect on the fish community of Gravel Lake.

Conclusion

Gravel Lake is the 387th largest inland lake in Michigan with an average depth of just over 17 feet. The lake is "mesotrophic," or moderately productive, with generally low phosphorus concentrations, good to excellent water clarity, deep-water oxygen depletion, sparse algae growth, a good diversity of rooted plants that, overall, grow in a moderate abundance, and excellent fish species diversity.

Although Gravel Lake generally has low phosphorus and chlorophyll-*a* concentrations, and excellent Secchi transparency, all of which is indicative of oligotrophic conditions, Gravel Lake is more properly classified as mesotrophic. Hypolimnetic oxygen depletion indicates a significant amount of biological activity in Gravel Lake; phosphorus levels are somewhat elevated in the hypolimnion during oxygen depletion; and rooted plant growth is moderate.

Gravel Lake is mesotrophic

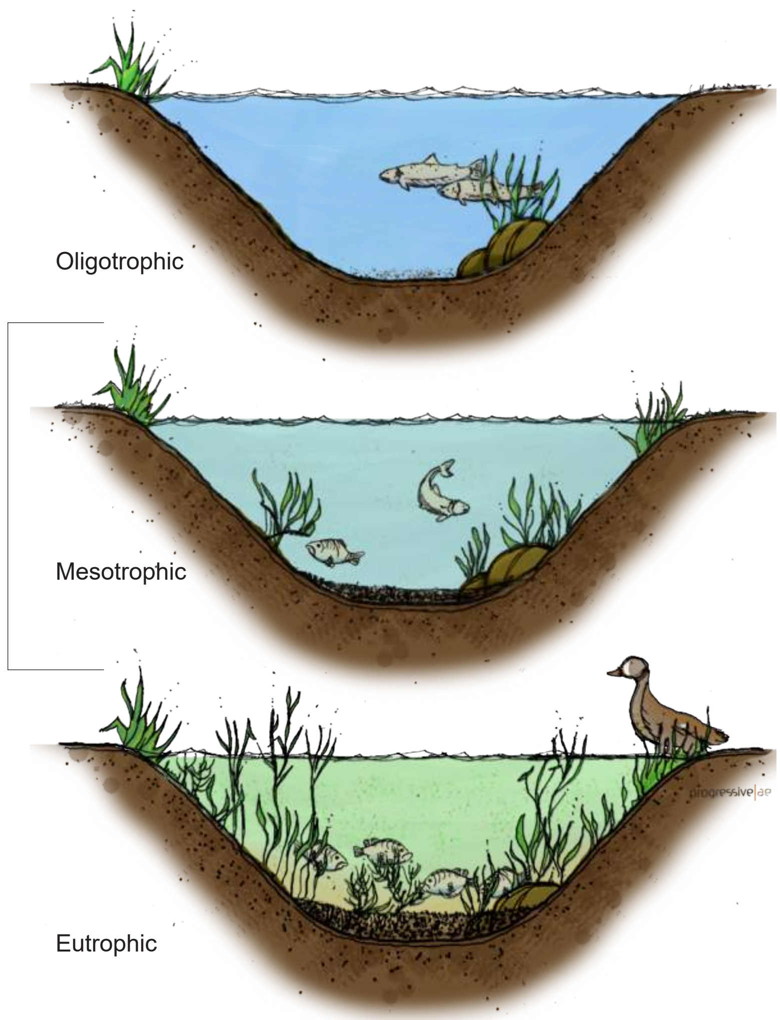

Figure 34. Gravel Lake trophic status.

Phosphorus levels are likely low for a few reasons. First, rooted aquatic plants are fairly abundant and algae growth is minimal. Any phosphorus that enters the lake water is quickly taken up by the rooted plants, which are effectively out-competing algae for the phosphorus. Second, naturally-occurring carbonates in the water may combine with phosphorus and cause it to precipitate to the lake bottom. The presence of the marl lake bottom, as shown in the 1949 Michigan Conservation Department mapping, indicates carbonate precipitation is occurring. Once precipitated, the phosphorus is largely unavailable for algae, but can still be extracted by the roots of aquatic plants allowing them to continue to flourish.

Given the low phosphorus levels, algae growth is minimized, and is likely further reduced by zebra mussel grazing. Consequently, Secchi transparency is increased.

Gravel Lake has a very deep area in the center of the lake. The remainder of the lake has variable depths, while the littoral zone is shallow with extensive plant beds, including milfoil, bulrushes, and 21 submerged aquatic plants. The bottom has extensive areas of sand and gravel in the 0- to 5-foot ring around the lake, which presumably acts as good spawning substrate for sunfish, especially largemouth bass. In addition, since the marl sediments co-precipitate phosphorus, Gravel Lake's trophic level is lower than it might otherwise be, possibly leading to reduced fish biomass. Our zooplankton (small invertebrates in the water column) sample showed that a large species, *Daphnia*, composed 85% of the zooplankton present in the sample. This indicates that there is probably reduced predation on the zooplankton over the deep hole, since lakes with an abundance of planktivores, such as small, stunted bluegills, usually consume most of the *Daphnia* present, leaving only smaller species. This effect would probably not be seen in the near-shore zone because of the abundance of planktivores there.

We collected 19 species of fishes and another two, bowfin and northern pike, are reported present in the lake. Another six species have been collected in the past by IFR, but are no longer present or in low abundance in the lake (e.g., longnose gar). In all that would be 27 different fish species recorded in the lake. This is excellent biodiversity. Members of the sunfish family (Centrachidae) dominated the species collected; the top predator is largemouth bass along with contributions from walleyes, which were stocked into the lake during 2007-2014. Other species that preyed on forage fish included brown bullheads (common), yellow perch, and probably black crappies and bowfin which appeared to be rare in the lake. In addition, there were five species of minnows also found in the lake, including a pugnose shiner, which is an endangered species in Michigan. Gravel Lake also had brook silversides, banded killifish, and Johnny darters present, completing a diverse fish fauna. We believe the high diversity is due to the high diversity of habitats: varying depths, near shore zone with abundant vegetation, but also some areas of gravel and sand, and the prey food supply, zooplankton and undoubtedly benthos, appears to be sufficient to feed the diversity of small fishes present, without eliminating the *Daphnia* from the zooplankton community. Diets of fishes reflected the species, life stage, and feeding strategy of the fish. Small fishes were feeding on zooplankton and benthos, while the large specimens of predaceous fishes were feeding on fishes and sometimes crayfishes. They ate a wide variety of forage, including the young of yellow perch, largemouth bass, sunfish, and probably minnows (many consumed fish could not be identified and were probably minnows). We believe that the dearth of northern pike has had a favorable effect on yellow perch survival, since they are preferred prey of this predator after minnows. Growth of the fishes we examined generally was at MDNR state averages for a given age; some were growing faster than state averages.

Herbicides have been applied to Gravel Lake to control primarily non-native milfoil and starry stonewort. The systemic herbicide fluridone (trade name Sonar®) was applied as a whole-lake treatment in 2004 and 2013 to control non-native milfoil when the growth was widespread. Outside of 2004 and 2013, non-native milfoil growth has been addressed in small spot-treatments with diquat dibromide, a contact herbicide that can impact beneficial native plants and usually provides only short-term control.

Gravel Lake's watershed is moderately large at about six times the size of the lake itself. The majority of the watershed is in agricultural land, but runoff from the farmland is mitigated by its distance from the lake, moderate permeability of watershed soils, and the presence of wetlands which act to filter runoff. The high-density residential land bordering the lake has the greatest potential to impact the lake because of its close proximity and reduced shoreline vegetation.

Recommendations

Following are recommendations regarding nuisance aquatic plant control, fish management, and watershed management for Gravel Lake:

The primary goal of the nuisance aquatic plant control program for Gravel Lake should remain as the protection of native plant species while targeting non-native plants. Non-native plants that currently infest Gravel Lake include non-native milfoil and starry stonewort. Systemic herbicides, such as triclopyr for near-shore areas or 2,4-D for off-shore areas, may be effective alternatives for milfoil control in years when fluridone is not applied. Large-scale triclopyr treatments have the disadvantage of imposing watering restrictions of up to 120 days, and 2,4-D can't be used within 75 feet of any drinking water well or 250 feet of wells less than 30 feet deep. It would be useful to inventory and document the location and depth of drinking water wells around Gravel Lake in order to maximize the flexibility of 2,4-D use for non-native milfoil control.

Mechanical harvesting can be used as an alternative approach to the current copper herbicide treatments in areas where starry stonewort growth interferes with navigation. Areas with non-native milfoil should not be harvested since harvesting can spread milfoil. Instead, systemic herbicides should first be applied to remove the milfoil, then harvesters can begin removing starry stonewort.

The largest group of predators in the lake is 10- to 15-inch largemouth bass. Some larger bass were submitted by sport fishers, indicating larger fish exist in the lake. If these smaller bass were growing slowly we would recommend some type of slot limit to reduce their numbers, however they were growing at Michigan state averages. This is not unexpected due to the high diversity of prey in the lake. The upshot is that some fish from this size group could be removed from the lake, but we do not expect much of an effect.

We recommend catch-and-release for top predators to maintain fish community balance and because these larger individuals probably contain high concentrations of mercury anyway.

Apparently around 1,000 walleyes have been stocked into Gravel Lake from 2003 to 2014. We caught five of these fish and all were growing at or above state averages. Although they provide another top predator for fishers, they are not recommended for more stocking because the fish is not native, will not spawn, and the existing fish community is a co-evolved, warm-water fish community and should not be de-stabilized by introduction of another keystone predator. In addition, water quality conditions are not conducive for a cool-water fish, and you could introduce diseases, parasites, or non-indigenous species through stocking fish. Recognizing the importance of this fish to fishers and if managers are aware of these caveats, we could support some stocking of walleyes, despite the difficulty in catching them.

We observed excellent spawning substrate (gravel and sand) and abundant YOY of yellow perch, largemouth bass, and bluegills (but not pumpkinseeds) indicating these species are doing well in your lake. No stocking of these species should occur.

Residents should consider banning bait from outside the lake (live fish, crayfish) from being used by fishers to avoid getting bait infected with viral hemorrhagic septicemia (VHS) and/or introduction of other non-indigenous species, such as quagga mussels. Riparians and visitors to the lake need to be reminded to clean and treat ballast water with chlorine to prevent introduction of other invasive species or diseases.

The lack of native vegetation along the shoreline is a significant threat to Gravel Lake's water quality and habitat for fish and wildlife. Lakefront residents should consider preserving and restoring natural shoreline where and when possible. In recent years, considerable research in the Upper Midwest and around the country has shown the importance of natural shoreline for water quality and habitat protection. In addition, many agencies and organizations have developed educational materials to provide riparians with informational resources. The Michigan Natural Shoreline Partnership (MNSP) is a collaboration of state agencies, academia, nonprofit organizations and private industry. Their mission is to promote natural shorelines through the use of green landscaping technologies and bioengineered erosion control for the protection of Michigan inland lakes. Gravel Lake residents should consider engaging with the MNSP to become educated about natural shorelines, and to find consultants and contractors who can assist with natural shoreline design and installation.

References

Brown S. 2015. Starry stonewort: Essential information for lakefront property owners. Michigan Riparian Summer 2015.

Fuller, L.M. and C.K. Taricska. 2012. Water-quality characteristics of Michigan's inland lakes, 2001-10: U.S. Geological Survey Scientific Investigations Report 2011-5233, 53 p., plus CD-ROM.

Grafé SF, C. Boutin and F.R. Pick. 2015. A PCR-RFLP method to detect hybridization between the invasive Eurasian watermilfoil (Myriophyllum spicatum) and the native northern watermilfoil (*Myriophyllum sibiricum*), and its application in Ontario lakes. Botany. 93(2):117-121.

Laarman, P. W. 1963. Average growth rates of fishes in Michigan. Michigan Department of Natural Resources, Fish Division Pamphlet no. 1675. Lansing, MI.

Latta, William C. 1958. Age and growth of fish in Michigan. Michigan Department of Natural Resources, Fish Division Pamphlet no. 26. Lansing, MI.

Michigan Department of Environmental Quality. 2016. Water Quality Parameters: pH, accessed February 16, 2016, http://www.michigan.gov/documents/deq/wb-npdes-pH_247233_7.pdf.

Michigan Department of Environmental Quality. 2016. Water Quality Parameters: Total Suspended Solids, accessed February 16, 2016, http://www.michigan.gov/documents/deq/wb-npdes-TotalSuspendedSolids_247238_7.pdf.

Michigan Department of Environmental Quality. 2016. Procedures for Aquatic Vegetation Surveys, accessed February 16, 2016, http://www.michigan.gov/documents/deq/wrd-illm-surveyprocedure_445615_7.pdf.

Michigan Department of Environmental Quality. 2012. Michigan National Lakes Assessment Project 2007. MI/DEQ/WRD-12/006.

Moody M.L. and D.H. Les. 2002. Evidence of hybridity in invasive watermilfoil (*Myriophyllum*) populations. Proceedings of the National Academy of Sciences of the United States of America. 19(23):14867-14871.

Moody, M.L. and D.H. Les. 2007. Geographic distribution and genotypic composition of invasive hybrid watermilfoil (*Myriophyllum spicatum* x *M. sibiricum*) populations in North America. Biological Invasions 9:559–570.

Schloesser. D.W., P.L. Hudson, and J. Nichols. 1986. Distribution and habitat of *Nitellopsis obtusa* (Characeae) in the Laurentian Great Lakes. Hydrobiologia 133: 91-96.

Thum, R. A., J.T. Lennon, J. Connor, and A.P. Smagula. 2006. A DNA fingerprinting approach for distinguishing among native and non-native milfoils. Lake and Reservoir Management 22:1-6.

U.S. Environmental Protection Agency (USEPA). 2009. National Lakes Assessment: A Collaborative Survey of the Nation's Lakes. EPA 841-R-09-001. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, D.C.

Wagner, K.J. 1991. Assessing impacts of motorized watercraft on lakes: Issues and perceptions. Pages 77-93 in: Proceedings of a National Conference on Enhancing the States' Lake Management Programs. Northeastern Illinois Planning Commission.

Wetzel, R.G. and G.E. Likens. 2010. Limnological Analyses. Third edition. Springer Science+Business Media, New York.

Zuellig M.P. and R.A. Thum. 2012. Multiple introductions of invasive Eurasian watermilfoil and recurrent hybridization with native northern watermilfoil in North America. J Aquat Plant Manage. 50:1-19.