Oconto County Lakes Project

STATE OF THE OCONTO COUNTY LAKES

GROUP 1 LAKES

2016-2017

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Center for Watershed Science and Education
College of Natural Resources
University of Wisconsin-Stevens Point

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BACKGROUND

This report is intended to provide a comparison of the conditions in Oconto County lakes. Its content is based on lake studies conducted by Oconto County, Oconto County Land Conservation Department, University of Wisconsin – Stevens Point, and the Wisconsin Department of Natural Resources. In the coming years, the lake studies will be conducted in groups of 5-9 lakes with the first nine included here. Data were collected in 2016 and 2017. This document will be updated with data from new lake study groups as it becomes available. Individual lake management plans developed as part of this project are appended to this report. A total of 59 Oconto County lakes have been identified for this study and planning process (Figure 1).

Oconto County is located in northeastern Wisconsin. It is bordered by Marinette and Forest counties to the north, Langlade, Menomonee and Shawano counties to the west, Brown County to the south, and the Green Bay of Lake Michigan to the east. It has a land area of 1,016 square miles, or 650,766 acres. Oconto County consists of ten watersheds which are part of the larger Lake Michigan Basin. All these watersheds drain indirectly to Lake Michigan through Green Bay or one of the county's major rivers.

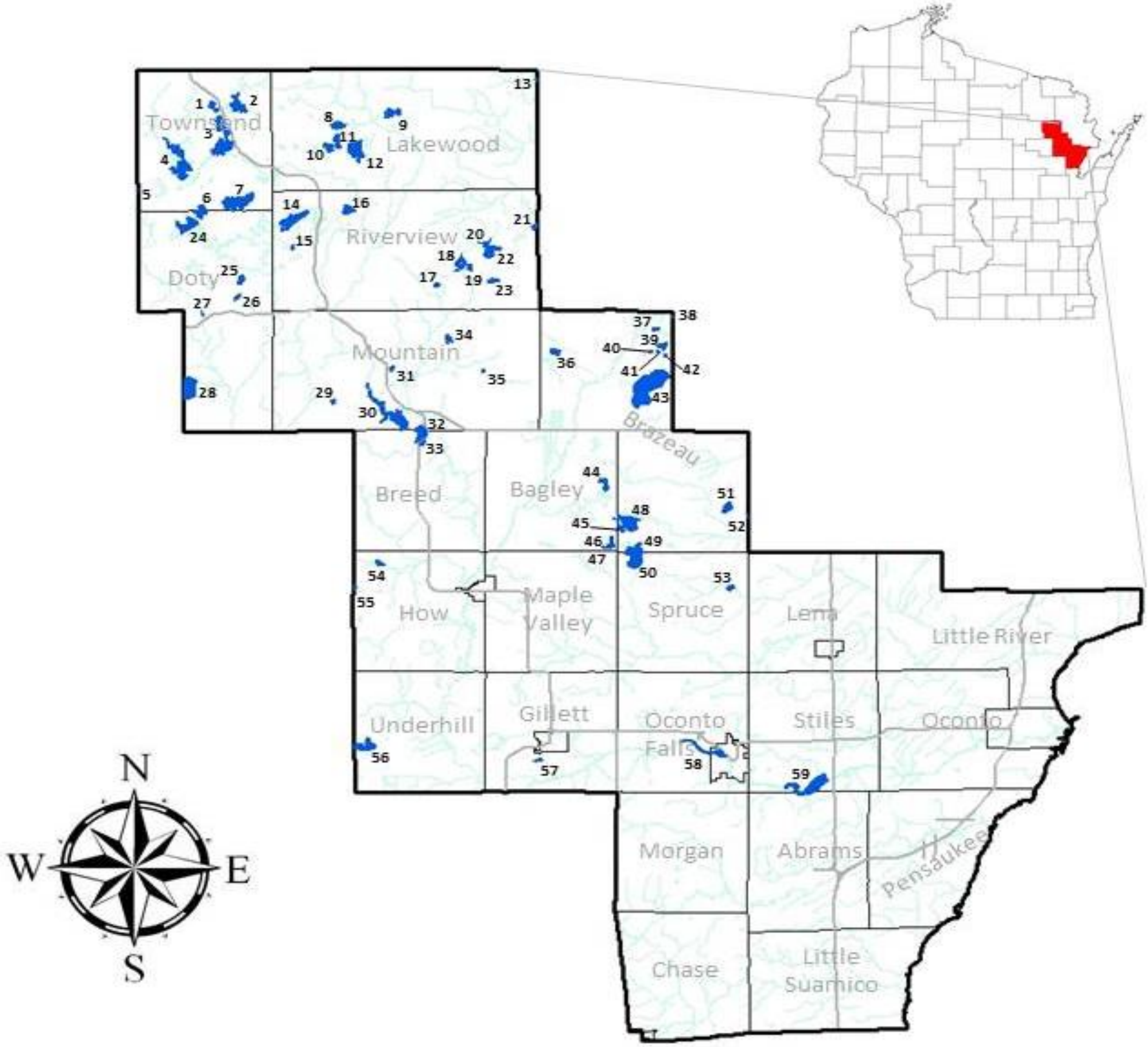
GEOLOGY AND SOIL HELP TO SHAPE LAKE CHARACTERISTICS AND WATER QUALITY

Geology and soil type play significant roles in the chemistry within these lakes, as do the quantity and quality of surface runoff and groundwater feeding the lakes. The subsurface where groundwater occurs in Oconto County is primarily glacial drift comprised of a mix of clay, sand, gravel and boulders (Figure 2) that commonly results in hard water. The glacial drift throughout most of the county is 0 to 300 feet thick. The nature of these glacial features, along with the type of bedrock, creates the natural character.

Oconto County can be divided into three distinct regions. The northern region, including Armstrong, Doty, Lakewood, Riverview, and Townsend Townships, was once a mountainous area of folded and faulted crystalline rock. This area was smoothed by a long period of erosion and glaciation. Some of the highest elevations in Wisconsin are in the part of the county. The major landforms in this region are end moraines and pitted outwash plains.

The central region is a hilly and undulating glacial deposits east of the Oconto River and Peshtigo Brook. Parts of Brazeau, Gillett, Maple Valley, Spruce and Underhill Townships are included in this area. The glacial material is interspersed outwash plains, which merge with the ridge and lowland region in the southeastern part of the county.

The southeastern region is a broad, undulating ground moraine, which slopes to the east and is overlain by lake deposits along Green Bay. A series of low ridges generally oriented northeast to southwest characterizes most of this region. The area encloses numerous depressions and basins and is interspersed with lake plains and outwash plains.



Oconto County Lakes Study

1 Surprise Lake
2 Pickerel Lake
3 Townsend Flowage
4 Reservoir Pond
5 Mary Lake
6 Bass Lake
7 Archibald Lake
8 Lake John
9 Waubee Lake
10 Bear Lake
11 Munger Lake
12 Wheeler Lake
13 Caldron Falls Reservoir
14 Maiden Lake
15 Little Gillett Lake
16 Paya Lake
17 Sunrise Lake
18 Wauppe Flowage
19 Grindle Lake
20 Crooked Lake
21 Boundary Lake
22 Gilkey Lake
23 Nelligan Lake
24 Boot Lake
25 Star Lake
26 Shadow Lake
27 Hills Pond
28 Boulder Lake
29 McComb Lake
30 Chute Pond
31 Green Lake
32 Anderson Lake
33 Moody Lake
34 Bear Paw Lake
35 Farr Lake
36 Shay Lake
37 Halfmoon Lake
38 Yankee Lake
39 Ranch Lake
40 Holt Lake
41 Reader Lake
42 Perch Lake
43 White Potato Lake
44 Ucil Lake
45 Underwood Lake
46 Pecor Lake
47 White Lake
48 Leigh Flowage
49 Round Lake
50 Kelly Lake
51 Rost Lake
52 Montana Lake
53 Porcupine Lake
54 Wiscobee Lake
55 Grignon Lake
56 Berry Lake
57 Finnegan Lake
58 Oconto Falls Pond
59 Machickanee Flowage

FIGURE 1. OCONTO COUNTY LAKES IN THE LAKE STUDY.

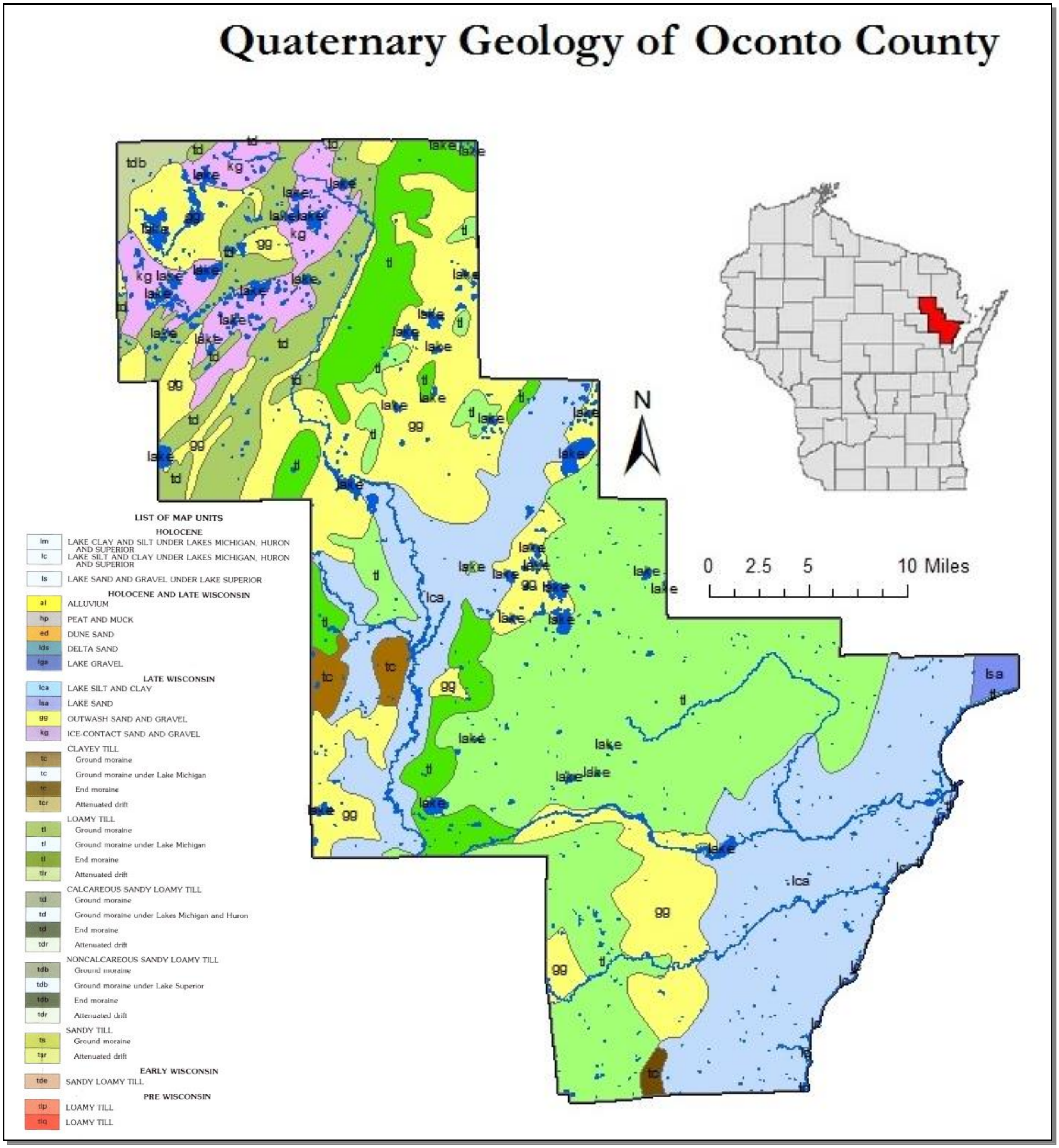


FIGURE 2. PHYSIOGRAPHY, GEOLOGY AND WATER IN OCONTO COUNTY, USDA, 1988

SUSEPTIBILITY TO GROUNDWATER CONTAMINATION

Surface water and groundwater are closely linked in Oconto County. When fluctuations in precipitation, recharge, evapotranspiration, discharge, drainage and storage occur, changes in both groundwater levels and lake levels are observed. These fluctuations may be due to seasonal changes, long-term drought and flood cycles, and groundwater withdrawal. Groundwater and surface water cannot be considered separate sources of water supply in this region (Holt, 1965).

The northwestern part of the county is underlain by crystalline rock. Not much water moves through this bedrock, so the 0-300 feet of glacial drift above it is the primary source of water. Many community water systems, private residences and farms in Oconto County extract water with wells placed into the glacial deposits. These wells are commonly less than 100 feet deep, as these geologic formations have water close to the surface, high hydraulic conductivity, and relatively high groundwater recharge through permeable surface soils. Water in this area tends to be hard as the dolomitic drift contains ions of calcium, magnesium and bicarbonates. The southeastern part of the county sources most of its groundwater from sedimentary bedrock and the water is softer.

Changes to groundwater quality occur from the time water infiltrates the ground until it is discharged to the lakes and streams or extracted through pumping. Many of these changes occur naturally. For example, water dissolves minerals as it enters the aquifer and increases the total dissolved solids content. If those minerals include calcium and magnesium, the water's hardness increases. If the water passes through areas where its oxygen becomes sufficiently depleted, the water may acquire dissolved iron and manganese.

Other changes are reflections of land uses along the groundwater's flow path. Fertilizers and pesticides may leach into the groundwater, and water percolating from septic drainfields can also impact the groundwater. The geologic materials that overlie the groundwater are what protect it from contaminants such as these that originate at the surface, thus, the amount of protection varies from one place to the next.

Groundwater in the county is generally very good quality. Local differences in the quality result from the composition, solubility and surface area of soil and rock particles through which the water moves and the length of time that the water is in contact with these materials (Figure 3).

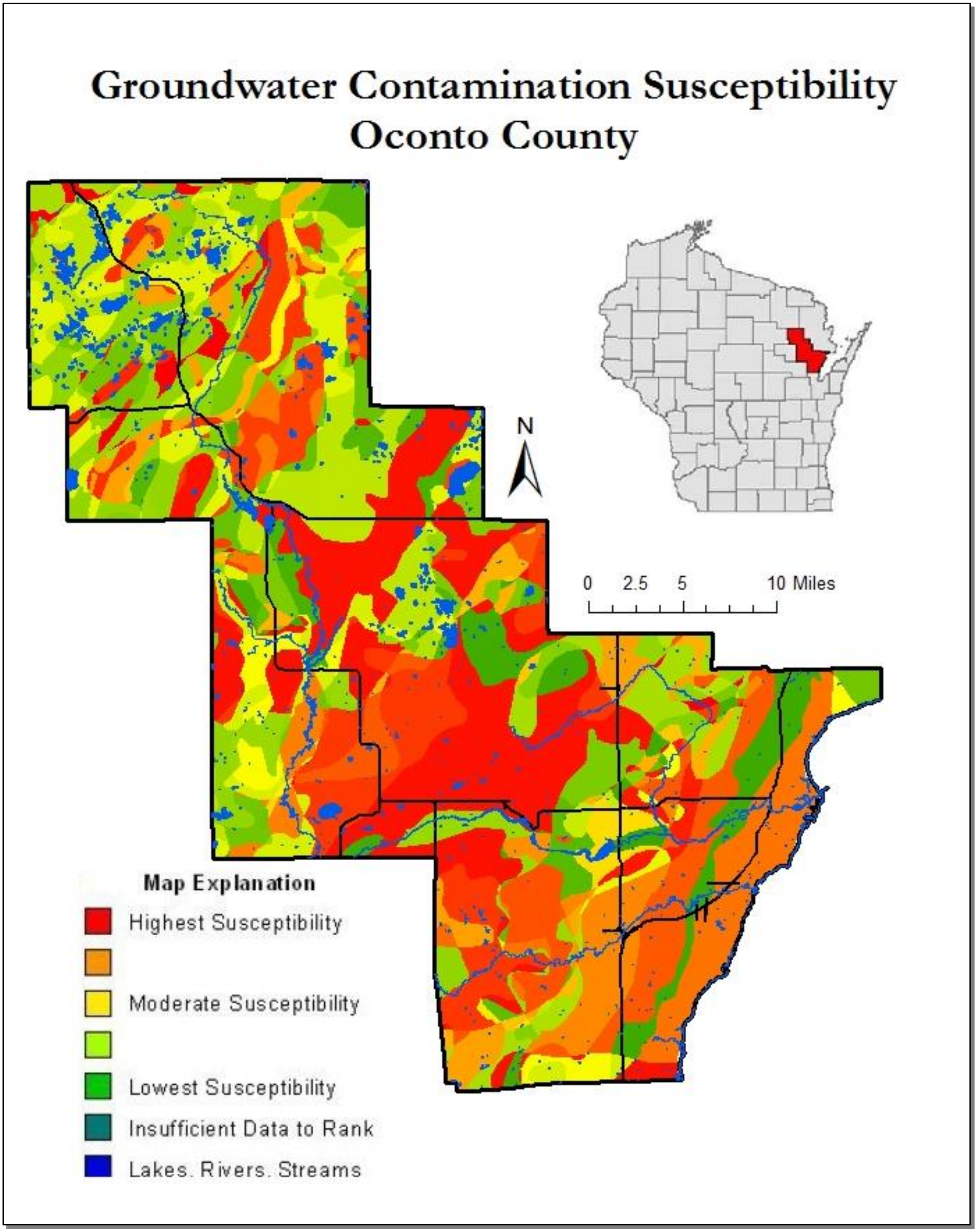


FIGURE 3 IS A MAP OF GROUNDWATER CONTAMINATION SUSCEPTIBILITY IN WISCONSIN (WGNHS, 1989).

LAKE AND WATER CHARACTERISTICS

Much of the following information was adapted from *Understanding Lake Data,* Shaw et al., 2001.

LAKE TYPES

Oconto County lakes are the products of thousands of years of rain falling on the landscape after the last glacier receded approximately 10,000 years ago. These inland lakes have surface elevations ranging from 623 feet to 1337 feet above sea level, so they continuously lose water to lower elevations and gain water from higher elevations via groundwater inflow, runoff, direct precipitation, and inflow from streams and rivers. Different processes influence the water quality of these sources. For example, air quality most affects precipitation and dry deposition, so water from these sources may contain beneficial natural gases and contaminants from air pollution. During the growing season, precipitation can contain phosphorus and nitrogen from agricultural applications, which aquatic plants and algae may use for growth (Anderson and Downing, 2006).

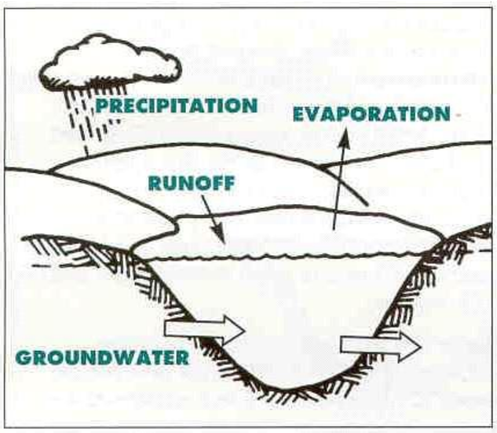
Preventing contamination is critical for maintaining the quality of our lakes and groundwater. Land use practices often influence groundwater lake water quality for many years. In sandy soils, the flow rate of groundwater ranges from 1 to 3 feet/day. Therefore, it can take years or decades to flush contaminants out of the lake. Some of the contaminants in the lakes can be loosely held in lake sediments and released over time, thereby influencing water quality for years. The contaminants are very slowly flushed out of the lake via groundwater or stream flow or are gradually buried deeper in lake sediments.

Differing types of lakes present differing conditions to consider when managing a lake. Water sources provide a way to classify lakes and provide important insight about how a lake functions, including susceptibility to contamination, likely response to invasive species, and the types of fish that can be managed sustainably. Oconto County lakes can be divided into four general categories based on water sources: 1) seepage lakes, 2) groundwater drainage lakes, 3) drainage lakes, and, 4) impoundments. Figure illustrates the differences between the four lake types.

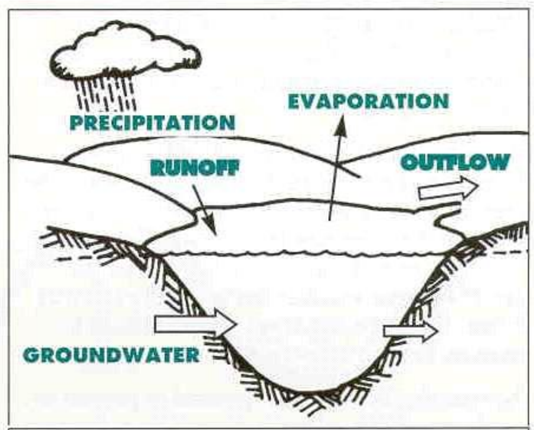
Many of the lakes in Oconto County are **seepage lakes** mostly fed by groundwater and have no stream inlets or outlets (). Melting ice blocks left behind by the last glacier formed these lakes. Water still flows though these lakes, but it does so as groundwater. Most groundwater usually enters at one end of the lake and leaves at the other end; however, areas of groundwater inflow can also occur sporadically around the lake. Water quality in seepage lakes is influenced by land use in the groundwater watershed (land area where the groundwater originates) and by runoff from the surface watershed (all land that slopes toward the lake, usually a small land area for seepage lakes). Land use practices on the end of the lake where groundwater enters are particularly important to water quality, as they can influence both the groundwater quality and runoff water quality. Use of fertilizers in these areas can be particularly damaging, as can septic systems that result in nutrient leaching and movement to the lake via groundwater. Natural vegetation in the entire near shore area helps to minimize the amounts of runoff, sediment and nutrients reaching the lake.

Groundwater drainage and drainage lakes have stream outlets that allow water to leave the lake. The stream outlet may include a dam that controls the water level in the lake, but in contrast to impoundments, these lakes existed prior to dam installation. The majority of water entering a groundwater drainage lake enters as groundwater, whereas a drainage lake receives much of its water from an inlet stream. Surface watersheds for drainage lakes are larger than for groundwater drainage lakes and are the most important areas impacting water quality, including near shore activities. Inlet streams may be impacted by both surface runoff and groundwater inflow. Because of the greater amount of groundwater moving into groundwater drainage lakes, land use in the groundwater watershed is of even more importance than for seepage lakes.

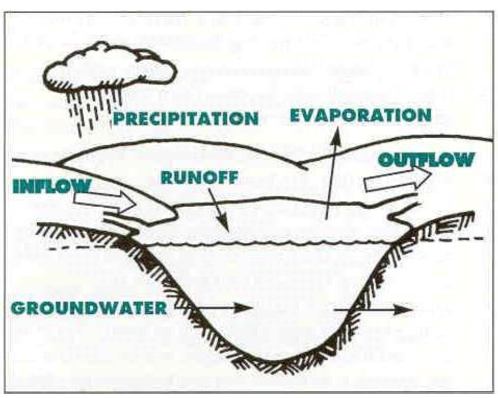
Impoundments are the ponds/lakes created when stream flow is restricted. Impoundments are often created by dams that were installed for other purposes. The primary water source for these lakes is a river, which typically drains a large area of land. Organic material and nutrients are carried into impoundments and often settle out, building up sediment over time. Characteristics of impoundments include relatively large rates of water entry compared to lake size and a correspondingly short water residence time in the lake. Summer water temperatures for the surface layer of impoundments are generally cooler than those of seepage lakes because of the high rate of inflow; however, the increased surface area often results in warmer water temperatures in the impoundment than in its upstream river.



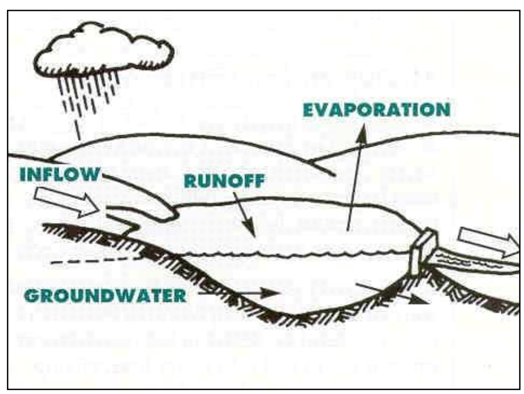
1. SEEPAGE LAKE – a natural lake fed by precipitation, limited runoff and groundwater. It does not have a stream outlet.



2. GROUNDWATER DRAINAGE LAKE – a natural lake fed by groundwater, precipitation and limited runoff. It has a stream outlet.



3. DRAINAGE LAKE – a lake fed by streams, groundwater, precipitation and runoff and drained by a stream.



4. IMPOUNDMENT – a manmade lake created by damming a stream. An impoundment is drained by a stream.

FIGURE 4. MAJOR WATER INPUTS AND OUTFLOWS OF DIFFERENT LAKE TYPES (LARGE ARROWS INDICATE HEAVY WATER FLOW). SHAW, ET. AL. 2001.

RETENTION TIME

The average length of time water remains in a lake is called the **retention time** or **flushing rate**. The lake's size, water source, and watershed size primarily determine the retention time.

Rapid water exchange rates allow nutrients to be flushed out of the lake quickly. Such lakes respond best to management practices that decrease nutrient input. Impoundments, small drainage lakes, and lakes with large volumes of groundwater inflow and stream outlets (groundwater drainage lakes) fit this category. Longer retention times occur in seepage lakes with no surface outlets. Average retention times range from several days for some small impoundments to many years for large seepage lakes. Lake Superior has the longest retention time of Wisconsin lakes: 500 years.

Nutrients that accumulate over a number of years in lakes with long retention times can be recirculated annually with spring and fall mixing. Even after the source of nutrients in the watershed has been controlled, reserve nutrients in lake sediments can continue to recirculate. The effects of watershed protection may not be apparent for years.

Lakes with long retention times tend to have the best water quality, as shown by lower levels of the plant nutrient phosphorus in the table below. Their greater depth and relatively small watersheds result in better water quality (Table 1).

TABLE 1. CHARACTERISTICS OF LAKES WITH DIFFERENT RETENTION TIMES (SHADED IN GRAY - ADAPTED FROM LILLIE AND MASON, 1983).

	Retention time in days					
	0-14	**15-60**	**61-180**	**181-365**	**366-730**	**>730**
Mean depth (ft.)	6	8	11	11	13	23
Max. depth (ft.)	16	21	25	27	35	57
Mean total phosphorus (µg/l)*	94	85	56	48	33	25
Mean DB:LA ratio**	1166	142	42	15	8	6

GROUNDWATER FLOW

Groundwater flow direction in Oconto County was developed using a GFLOW model. Figure 5, below, illustrates the result with groundwater flow across the county trending in a northwest to southeast direction, toward the Green Bay.

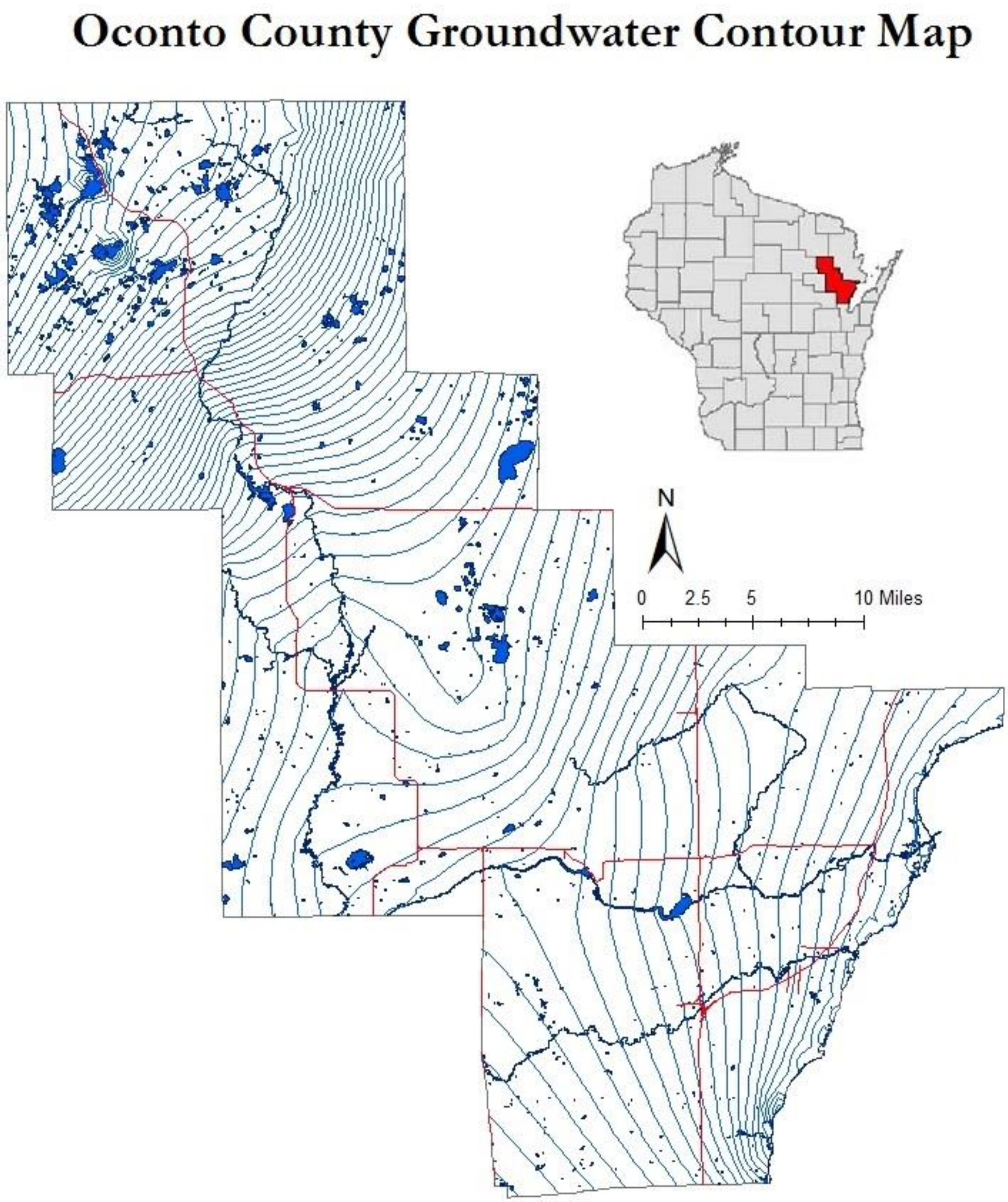


FIGURE 5. OCONTO COUNTY GROUNDWATER CONTOUR MAP. THE GROUNDWATER FLOW DIRECTION IS PERPENDICULAR TO CONTOUR LINES.

MIXING AND LAYERING

Another important characteristic of a lake is the degree of water mixing that occurs (Figure 6). Lakes with water that mixes regularly from top to bottom generally have more uniform temperature and oxygen from top to bottom. Bottom water in lakes that stratify for long periods lacks dissolved oxygen and therefore is inhospitable to many aquatic organisms. Many factors determine if a lake's water mixes, including the season, amount and direction of wind, height of land and vegetation around the lake, and the lake's shape and depth. Many shallow impoundments stay mixed throughout the year; however, most lakes in Wisconsin tend to mix in the spring and fall and stratify in the summer and winter. In some lakes, the extent of mixing can be difficult to determine because lake mixing can vary over time as temperature changes between surface layers and deeper water. Lake mixing will also vary at different areas in a lake with depth and wind/water interaction. Shallow lakes that stratify and mix multiple times during the year often experience more algal blooms than lakes of similar type, depth and size that only mix in spring and fall.

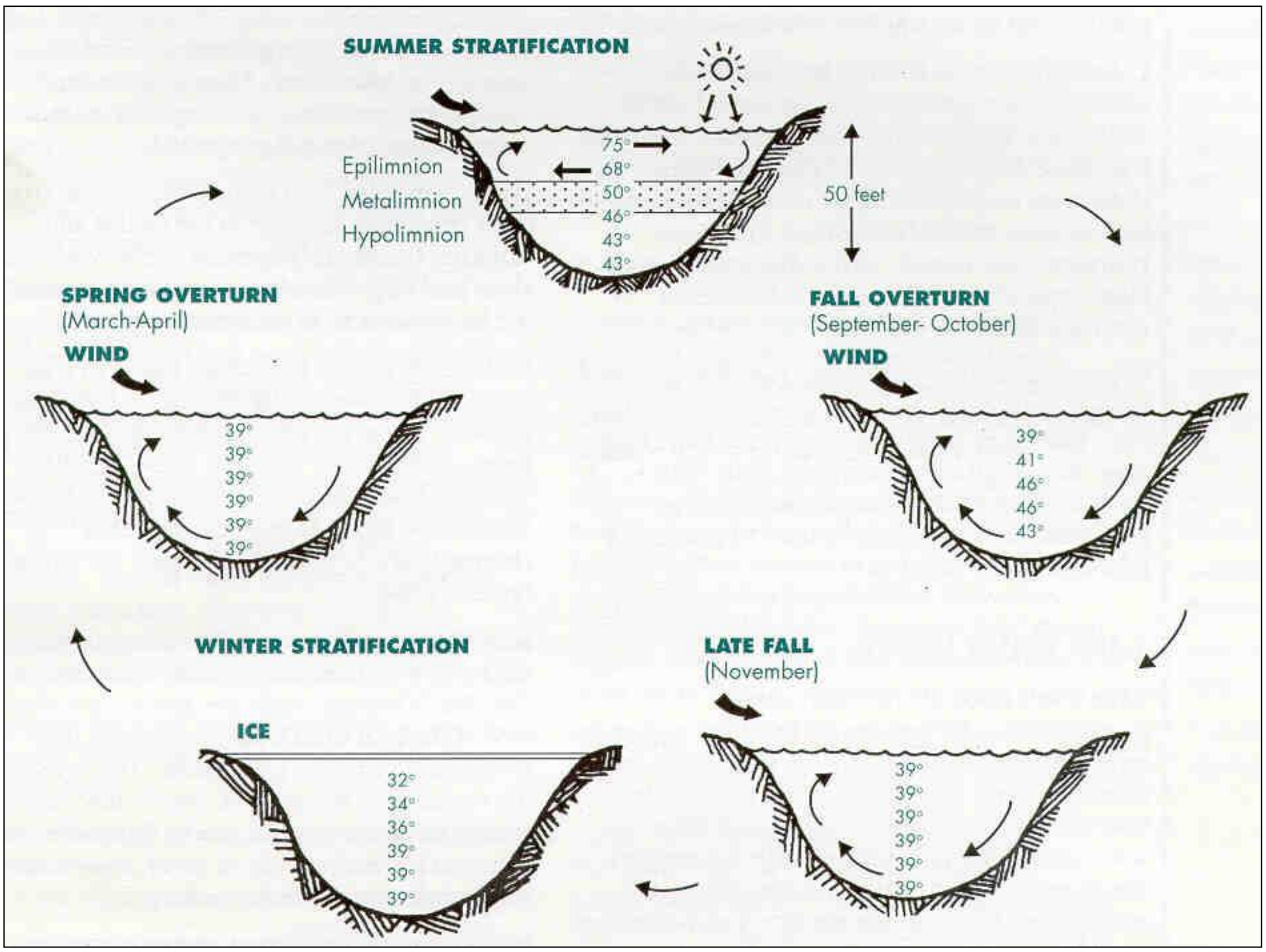


FIGURE 6. SCHEMATIC SHOWING LAKE MIXING AND LAYERING BY SEASON IN A TYPICAL WISCONSIN YEAR (SHAW ET. AL. 2000).

To evaluate how mixing varies within Waushara County lakes, temperature variations between the top and bottom of each lake were calculated. Lakes that are frequently and thoroughly mixed would not be expected to exhibit strong temperature differences between top and bottom. Lakes that are stratified during the summer have cooler, denser water on the bottom of the lake and warmer, less dense water on the surface.

Error! Reference source not found. **7 compares the ratio of top and bottom summer temperatures in the lakes with their maximum depth. When the temperature ratio is close to 1, the lake is mixed with little temperature variation between top and bottom.**

The temperature ratios show mixing differences among the lakes (Figure 7). Some of the lakes exhibited little difference between top and bottom water during the summer. In general, as the maximum depth increases, so does the temperature ratio. In lakes that remain stratified throughout the summer, nutrients in the bottom waters are not available for algae near the surface. Using the temperature ratio and water movement, the lakes can be divided into four different categories (Table). These categories relate to the state phosphorus standards.

Table 2. Oconto County lakes listed by lake type and mixed or stratified.

Shallow Seepage (Mixed)	Deep Seepage (Stratified)	Shallow Drainage (Mixed)	Deep Drainage (Stratified)
	Paya Lake Rost Lake Waubee Lake	Bear Lake Machickanee Flowage Munger Lake	Leigh Flowage Maiden Lake Oconto Falls Pond

WATER QUALITY

DISSOLVED OXYGEN

Dissolved oxygen is essential to most aquatic organisms. Oxygen enters lake water by contact with the atmosphere and production by algae and aquatic plants. The decomposition of microorganisms uses oxygen. During periods when oxygen is not replenished, dissolved oxygen concentrations in the lake water drop. Winter ice cover is one such period, particularly in lakes without inflowing streams. When lakes are stratified, water at the bottom of the lake cannot be replenished with dissolved oxygen from the atmosphere or plants growing in shallow depths. This anoxic (low oxygen) water releases nutrients from bottom sediments that eventually blend into upper waters during mixing episodes. Lakes with minimal volumes of dissolved oxygen greater than 5 mg/L may be prone to winter fish kills during long winters with snow cover. The minimum water depth with dissolved oxygen concentrations of 5 mg/L or less during the lake study are displayed in Table .

Table 3. Minimum depth of lake water with dissolved oxygen concentrations less than 5 mg/L during the Oconto County lake study (2016-17).

Lake Name	Minimum Depth (feet) of water with dissolved oxygen <5 mg/L
Bear Lake	5
Munger Lake	5
Machickanee Flowage	9
Oconto Falls Pond	12
Paya Lake	14

Waubee Lake	14
Rost Lake	18
Leigh Flowage	24
Maiden Lake	30

WATER CLARITY

Water clarity is a measurement of the depth that a black and white disc can be observed in a water column. It is an indication of the depth that rooted plants can grow. Clarity is a measure of water quality related to biological, chemical and physical properties. Water clarity has two main components: true color (materials *dissolved* in the water) and turbidity (materials *suspended* in the water such as algae and sediment/silt). The algal population is usually the largest and most variable component. Water clarity changes throughout the year and can even change by the day or hour, depending upon season, weather, and motorized boating.

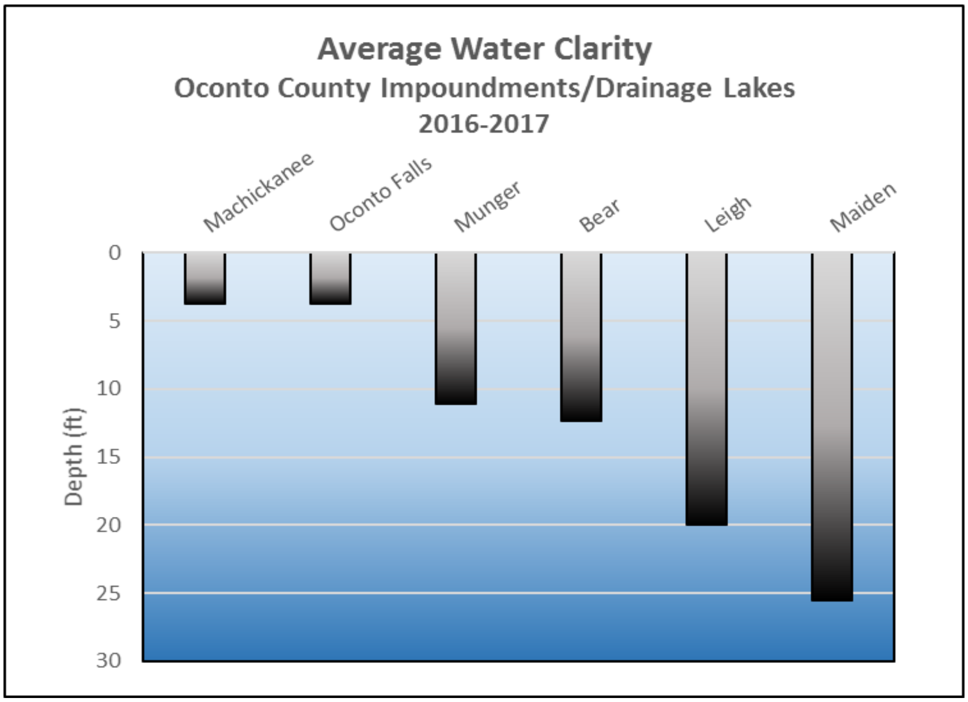


FIGURE 8. AVERAGE WATER CLARITY IN OCONTO COUNTY IMPOUNDMENTS AND DRAINAGE LAKE TYPES, 2016-2017.

Average water clarity data for lakes in the Oconto County Lakes Study are summarized in Figure 8 and Figure 9. It should be noted that these graphs are a gross summary that only provides a snapshot of available information. For consistency and comparison, the water clarity information in this document was solely from the Oconto County Lakes Study. Water clarity data for each lake are summarized by month in the individual lake study reports and are available through the WDNR SWIMS database. Additional water clarity information dating back to the 1990s is available for some lakes in Oconto County; the data were collected by citizens, consultants, and WDNR staff.

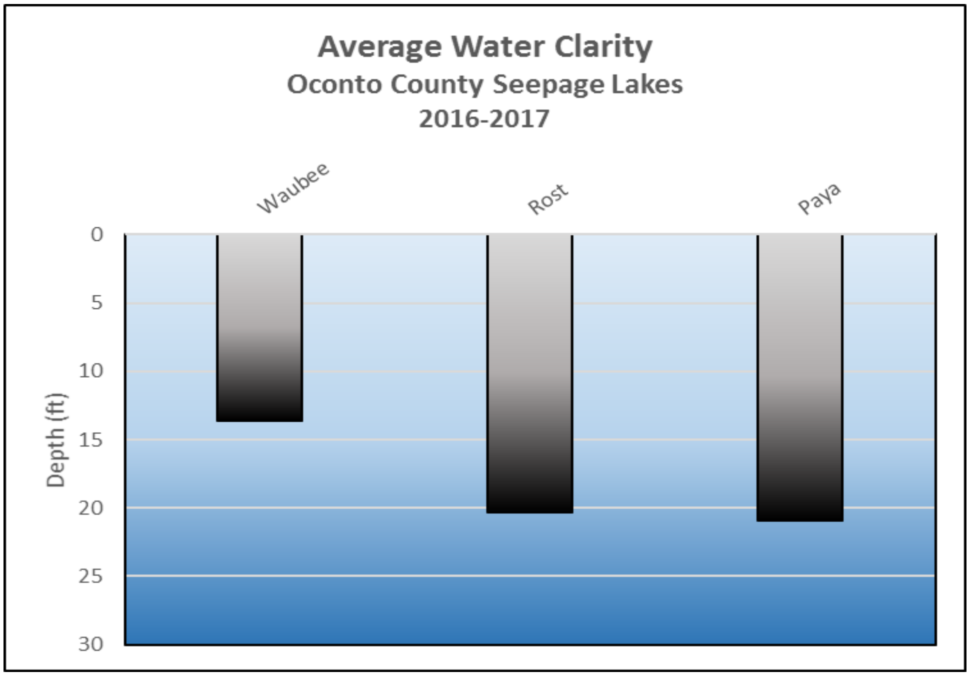


FIGURE 9. AVERAGE WATER CLARITY IN OCONTO COUNTY SEEPAGE AND SPRING-FED LAKE TYPES, 2016-2017.

COLOR

The color of lake water reflects the types and amounts of dissolved organic chemicals it contains; greater color results in a reduction in water clarity. Many lakes possess natural, tan-colored compounds (mainly humic and tannic acids) from decomposing plant material in the watershed. Brown water can result from bogs draining into a lake. Before or during decomposition, algae may impart a green, brown or reddish color to the water. Brown-stained water (high CU) may reduce light penetration, slowing aquatic plant and algae growth. Darker color can also absorb heat and increase the temperature of the lake water. The common categories associated with color are displayed in Table . Color is measured and reported as standard color units (CU). The average color unit measured in spring and fall overturn samples during the Oconto County lake study are shown in Figure 10.

TABLE 4. WATER COLOR (ADAPTED FROM LILLIE AND MASON, 1983).

Low	0-40 units
Medium	40-100 units
High	>100 units

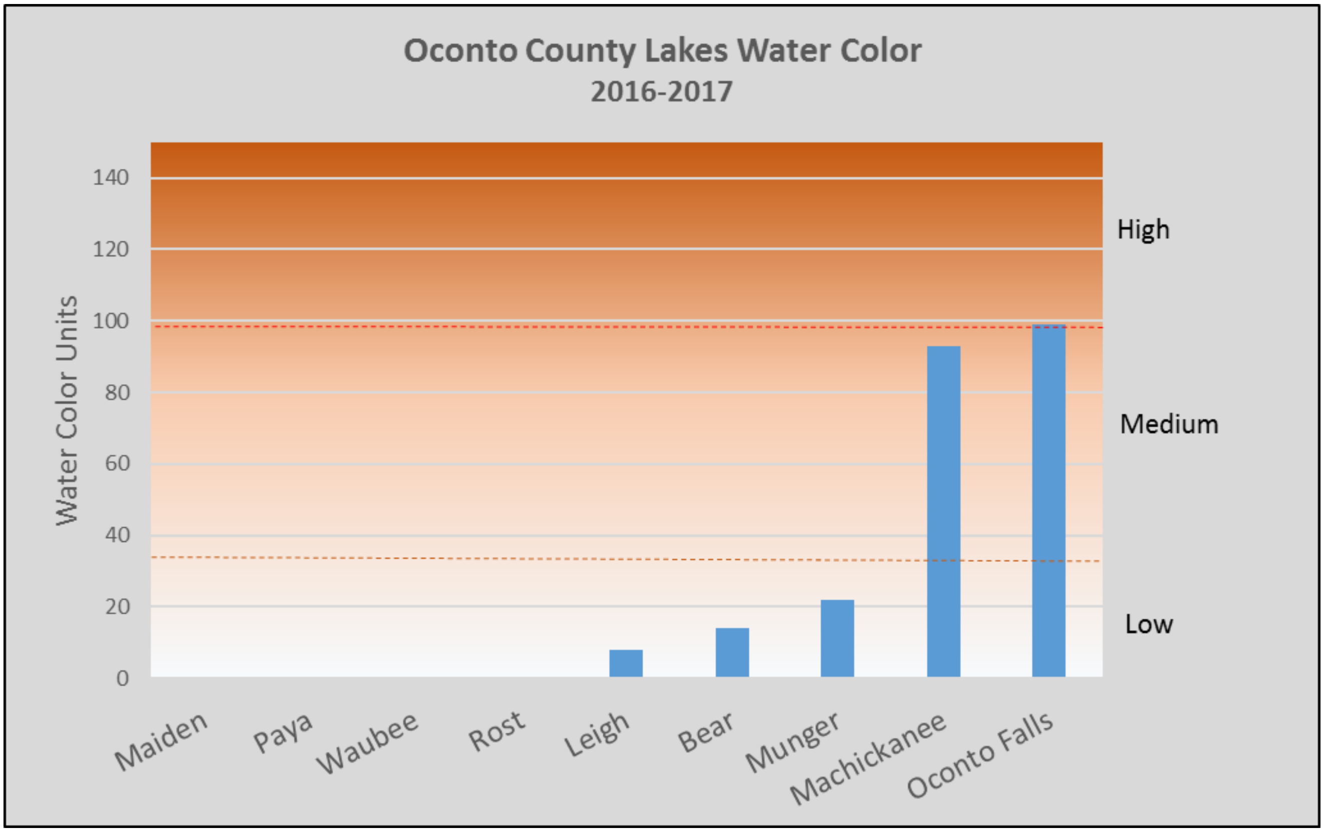


FIGURE 10. AVERAGE COLOR (CU) OF THE LAKE WATER IN THE OCONTO COUNTY LAKES STUDY DURING OVERTURN, 2016-2017.

ALGAE

Many types of algae live in Wisconsin lakes. Some species live in open water, while other species are attached to objects such as aquatic plants, sticks, rocks and docks. Each species shifts in abundance throughout the year, responding to changes in temperature, daylight, nutrients, clarity, and the abundance of predators (e.g. zooplankton, macro invertebrates, and small fish). High concentrations of calcium or iron in lake water can reduce the use of phosphorus for algae growth. Algae form the base of a lake's food web but given the right conditions may also grow to nuisance conditions. Some forms of blue-green algae can be toxic.

Water clarity measurements include measures of algae living in open water. Algal abundance can also be quantified through laboratory analysis of chlorophyll *a*. Sample collection protocol recommended by the WDNR involves an integrated sample representing the upper six feet of the water column. These protocols were followed during the Oconto County Lakes Study.

Median concentrations of chlorophyll *a* in samples collected from the study lakes ranged from 1.04 – 6.4 µg/L (Figure 11). Unfortunately, dissolved oxygen profiles suggest algal blooms were occurring in some of the lakes at depths well below six feet, meaning the average concentrations of chlorophyll *a* may have been higher than what was measured in the sample that was collected.

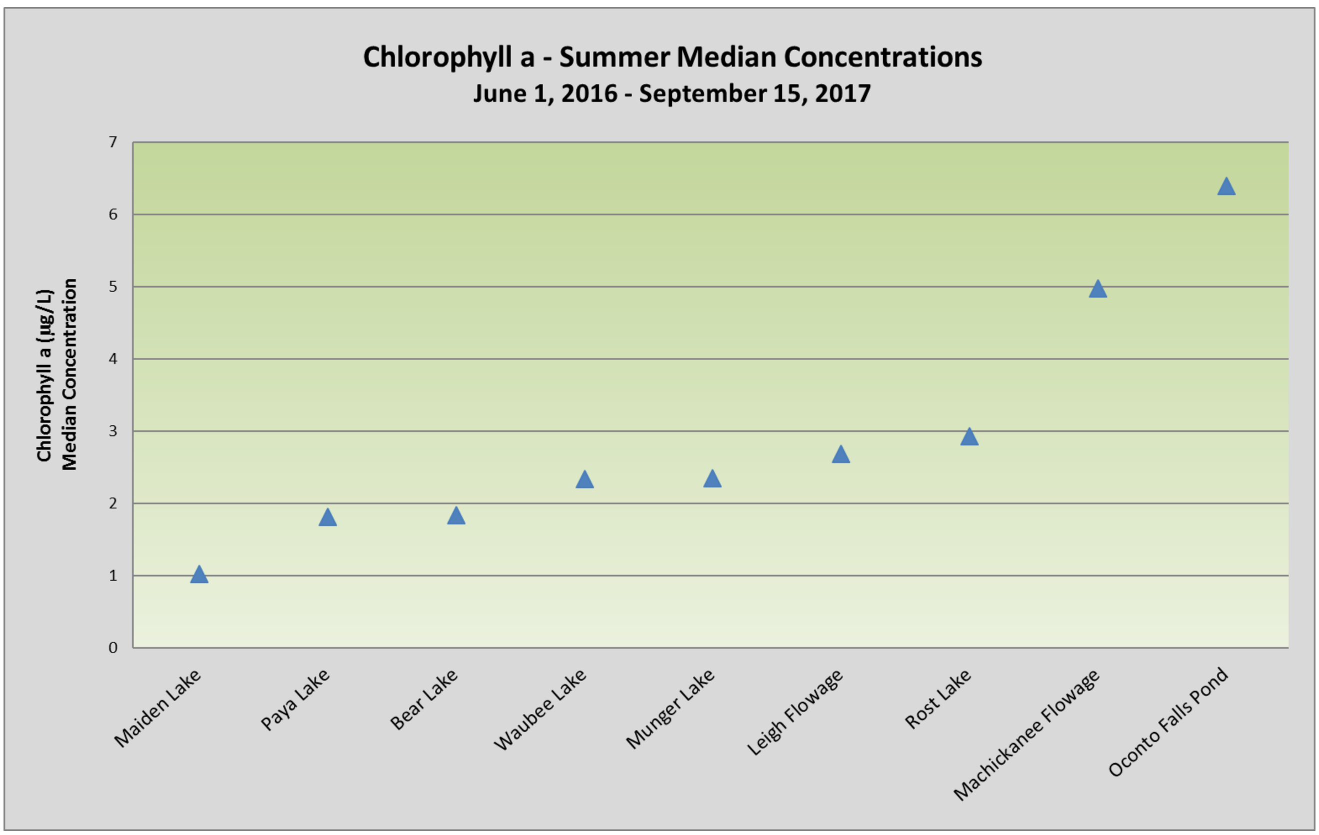


FIGURE 11. MEDIAN SUMMER CONCENTRATIONS OF CHLOROPHYLL *A* (µG/L) IN OCONTO COUNTY LAKES (2016-2017).

PHOSPHORUS AND NITROGEN

In Wisconsin, phosphorus is the most significant limiting nutrient for most lakes. Phosphorus is the primary element that leads to the development of nuisance algae (Wetzel, 2001; Shaw et al., 2000). Direct and indirect results of high phosphorus levels include excessive aquatic plant growth, decreased oxygen levels and subsequent fish kills.

Phosphorus is present naturally in the soil and plants of the lakeshore and the watershed. Sources on the land that move to the lake include soil erosion, animal waste, septic systems/wastewater treatment facilities, fertilizers, wetlands, and to a lesser extent, atmospheric deposition. One study of urban lakes determined that streets and lawns contributed 80% of the dissolved phosphorus to the lakes, with lawns contributing more than streets (Waschbusch et al., 2000). In general, the amount of phosphorus delivered from the land varies with the type of land use. Phosphorus loads for developed and cropped land is typically greater than forested land (Figure). The extent of phosphorus loading also varies within a land use category, depending on soil type, slope, and land management practices. Due to additions of fertilizer and/or animal waste, Wisconsin soil tests show a given amount of soil will now deliver almost double the phosphorus it did in the 1960s (Figure 2).

Phosphorus is primarily transported to lakes in surface runoff. Phosphorus adheres to soil particles, so phosphorus will be transferred from land to water if soil particles are disturbed or if water containing phosphorus is conveyed directly to the lake. Soil has a high capacity to hold phosphorus, but concentrated sources of phosphorus inputs (barnyards, septic drain fields, over-application of fertilizer) may exceed the soil's capacity to retain phosphorus. When heavily loaded (septic drainfields, barnyards), phosphorus may leach to groundwater, and the phosphorus-laden groundwater can discharge to local lakes and streams. The land closest to the lake often has the greatest impact. A wetland submerged in a lake as a result of a dam can also be a significant phosphorus source within a lake.

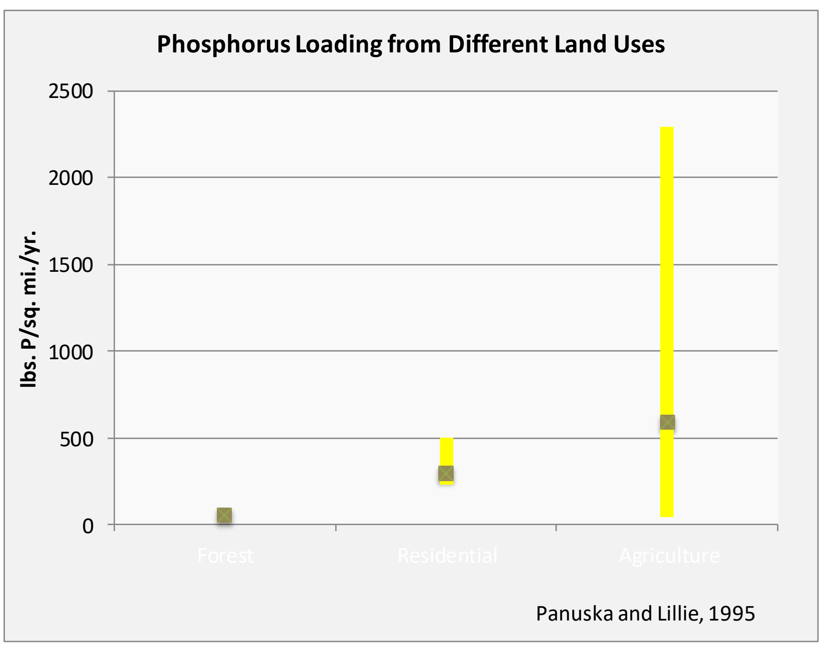


FIGURE 12. RANGE OF MEASURED PHOSPHORUS LOADING FROM DIFFERENT LAND USES IN WISCONSIN. MEDIAN LOADS ARE REPRESENTED BY THE BROWN MARKERS (PANUSKA AND LILLIE, 1995).

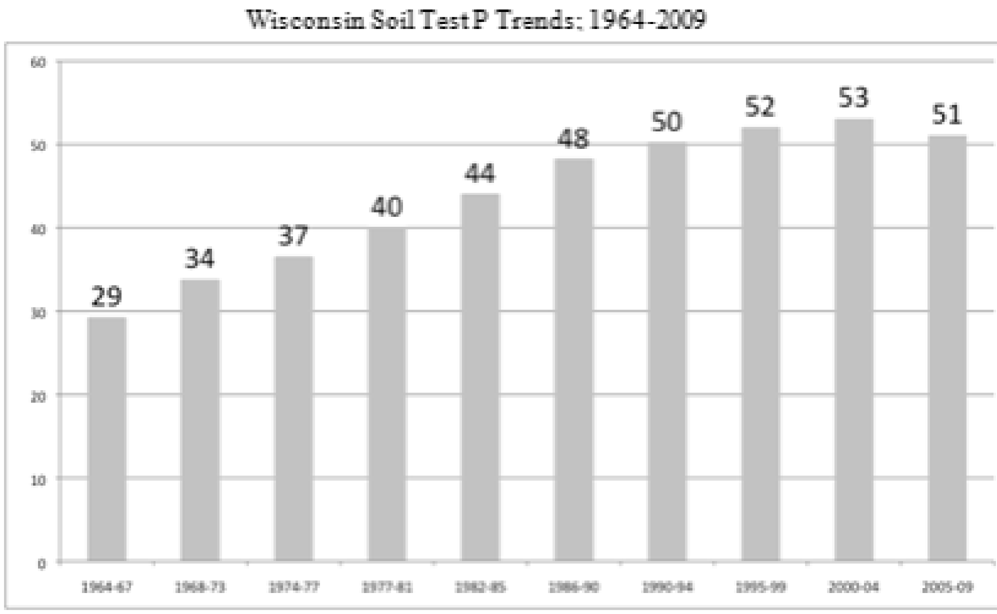


FIGURE 2. SOIL TEST PHOSPHORUS RESULTS (PPM) FROM WISCONSIN SOILS 1964-2009 (PETERS, 2011).

Once phosphorus enters a lake, it becomes part of the aquatic system in the form of plant and animal tissue, sediments, or in solution. Some of the phosphorus can exit a lake with water leaving the lake via a stream or groundwater. A portion of the phosphorus can sink to the lakebed and may be buried by other sediment over time; however, changes in lake chemistry (pH, oxygen) or agitation from wind and boating may liberate phosphorus from the sediment, potentially making it available for use by plants and other aquatic biota. Phosphorus can continue to cycle within the lake for many years (Figure 3).

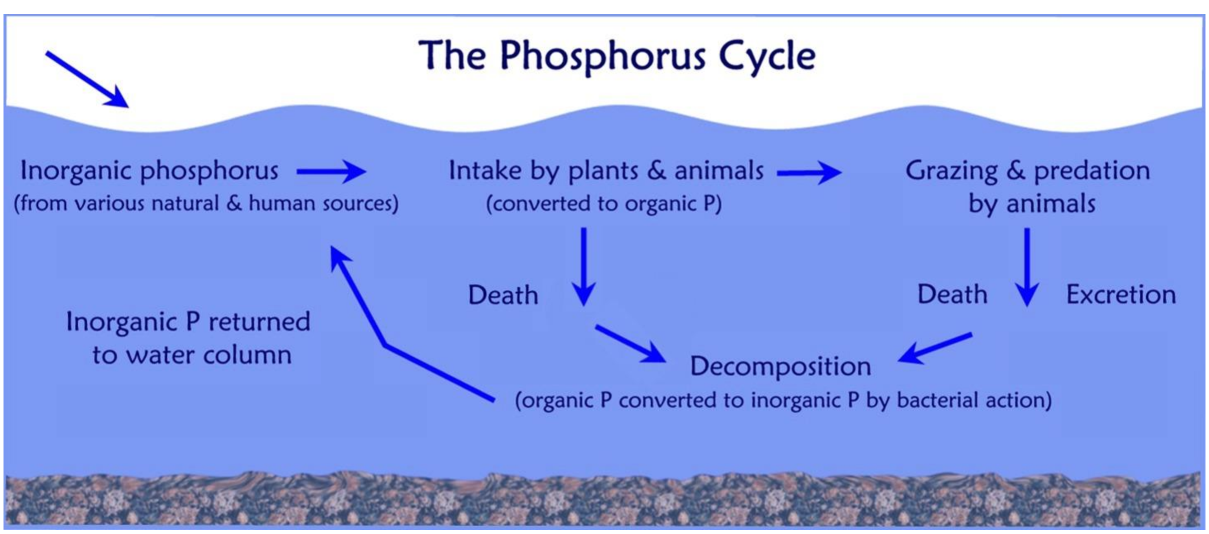


FIGURE 3. SCHEMATIC DEMONSTRATING PHOSPHORUS CYCLING WITHIN A LAKE.

One approach that can be taken to understand the significance of concentrations of phosphorus in a lake is comparison with Wisconsin's phosphorus criteria. The threshold phosphorus concentrations vary by lake type, which is associated with the ability of a lake to retain and respond to increases in phosphorous. Thresholds were identified at concentrations where notable changes in the lake ecosystem (fishery, frequency and type/frequency of algal blooms, etc.) occur. The Wisconsin phosphorus standards are displayed by lake type in Table 5. At the time the criteria were identified, scientists also identified "flag values". The flag values were assigned to concentrations above which changes in the lake ecosystem markers began to occur. While the flag values are not a part of Wisconsin's administrative code, they provide guidance for management decisions. The median concentrations of lake samples collected between June 1 and Sept 15 are the values that are used to determine if a lake exceeds Wisconsin's phosphorus standards (WDNR 2013).

TABLE 5. WISCONSIN PHOSPHORUS CRITERIA AND FLAG VALUES FOR LAKES.

Lake Type	Total Phosphorus (parts per billion)	
	"Flag" Value	**Criteria Value**
Shallow – Drainage	**28**	**40**
Deep – Drainage	**20**	**30**
Shallow – Seepage	**15**	**40**
Deep – Seepage	**15**	**20**
Shallow – Impoundment	**No flag value**	**40**

During the lake study, total phosphorus was analyzed in the Oconto County lakes eight times/year between fall 2016 and fall 2018; five samples were collected each summer, and one sample during winter and spring and fall overturn. The summer phosphorus concentrations for each lake are presented in boxplots in Figure 15 - Figure 67.

While individual samples had concentrations above the phosphorus criteria, based on median concentrations for each year, only Machickanee Flowage and Oconto Falls Pond **exceeded the phosphorus criteria**. Continued monitoring over time is important because concentrations of phosphorus can vary from year-to-year, increases in phosphorus usually occur slowly over time and it is preferable to identify increases in phosphorus prior to biological responses (increases in algal blooms and/or aquatic plant biomass) are observable.

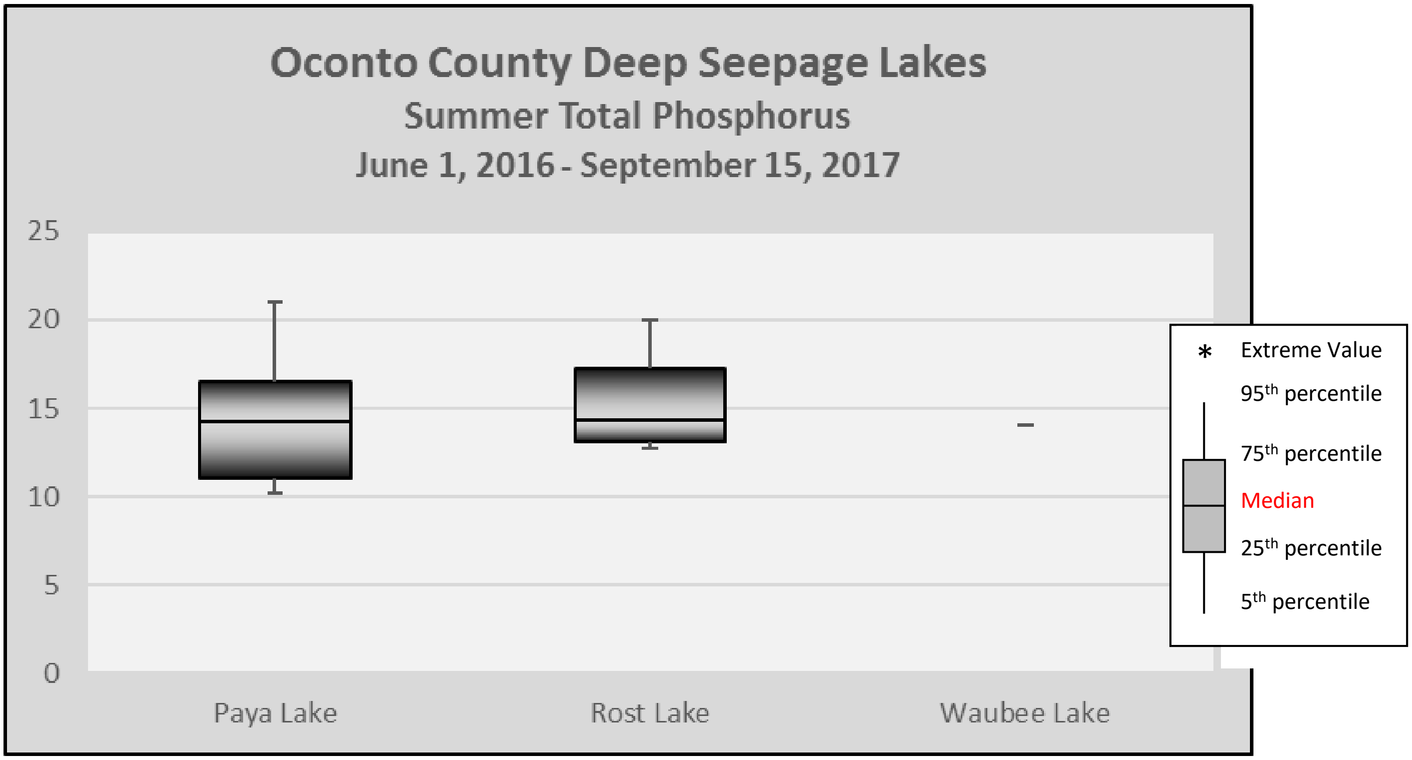


FIGURE 4. SUMMER TOTAL PHOSPHORUS CONCENTRATIONS IN DEEP SEEPAGE LAKES IN OCONTO COUNTY LAKES STUDY, 2016-2017.

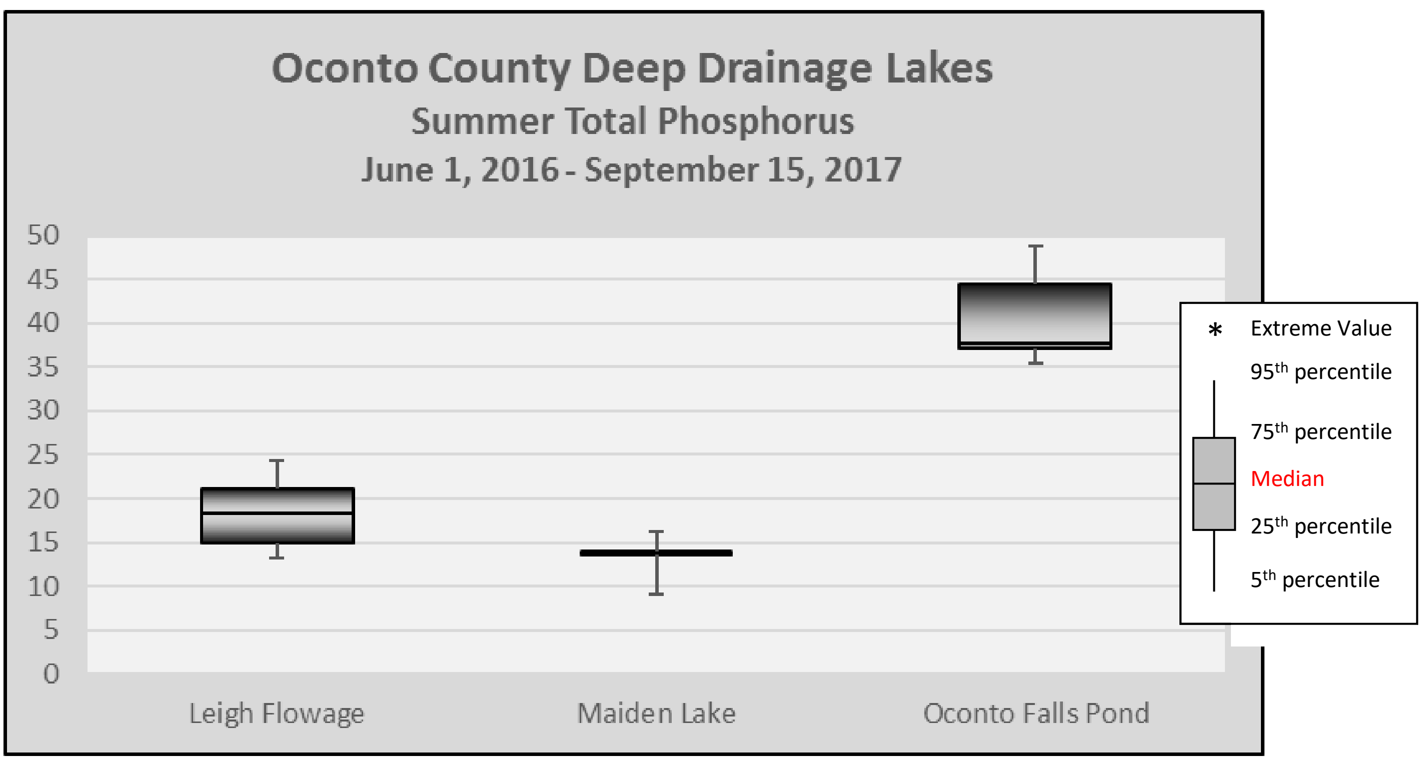


FIGURE 5. SUMMER TOTAL PHOSPHORUS CONCENTRATIONS IN DEEP DRAINAGE LAKES IN THE OCONTO COUNTY LAKES STUDY, 2016-2017.

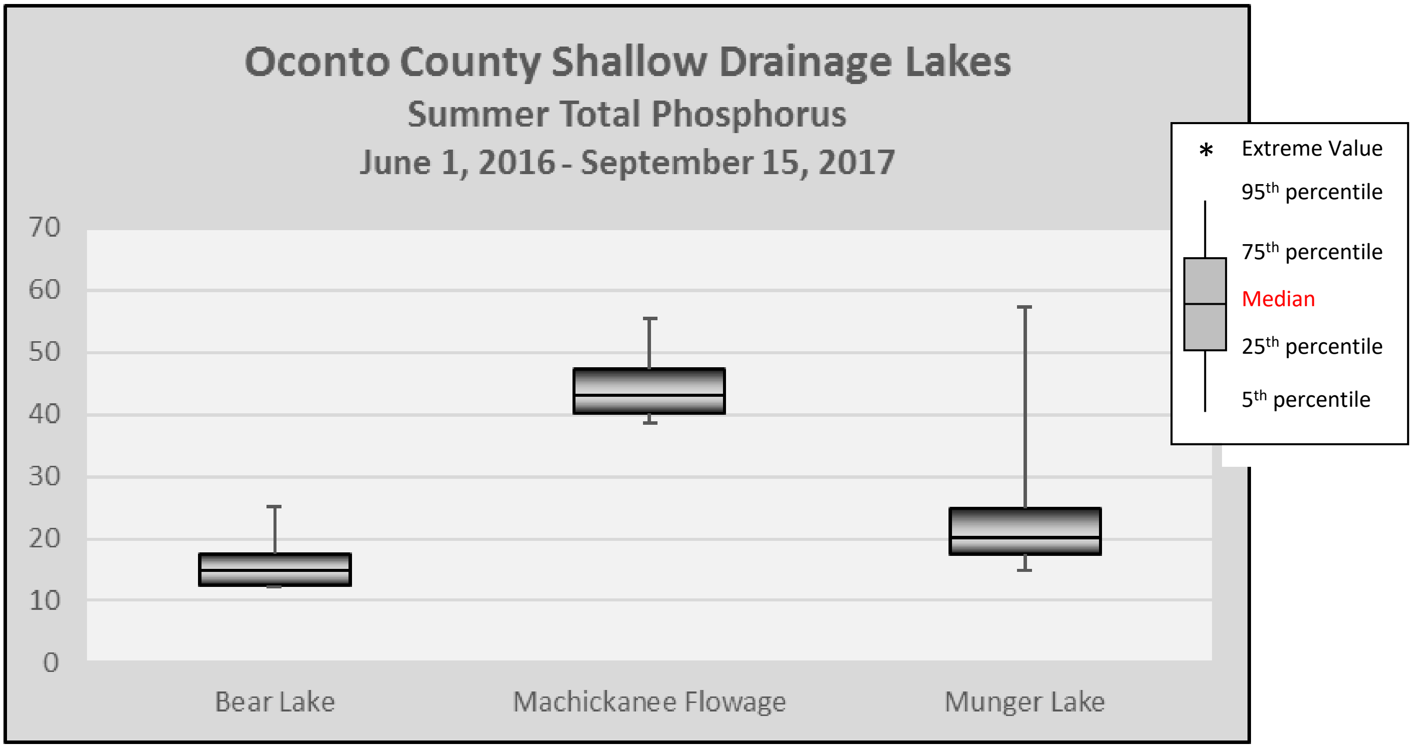


FIGURE 6. SUMMER TOTAL PHOSPHORUS CONCENTRATIONS IN SHALLOW DRAINAGE LAKES AND IMPOUNDMENTS IN THE OCONTO COUNTY LAKES STUDY, 2016-2017.

Nitrogen is an important biological element. It is second only to phosphorus as a key nutrient that influences aquatic plant and algal growth in lakes. Nitrogen sources include groundwater, runoff and rainfall. Because of the variety of sources, nitrogen enters the lakes both as soluble and particulate forms. Sources of nitrogen are often directly related to local land management practices, including septic systems, sewage treatment plants, animal waste, eroding soil, and lawn, garden, and agricultural fertilizers.

Nitrogen enters and exits lakes in a variety of forms. The most common forms include ammonium (NH_4^+), nitrate (NO_3^-), and organic nitrogen bound up in plant and animal tissues. Aquatic plants and algae can readily use inorganic forms of nitrogen (NH_4^+, NO_2^-, NO_3^-). If these inorganic forms of nitrogen exceed 0.3 mg/L in the lake water during the spring, there is sufficient nitrogen to support summer algal blooms (Shaw et al., 2000). Average concentrations of inorganic nitrogen in spring samples from the study lakes are shown in Figure 7.

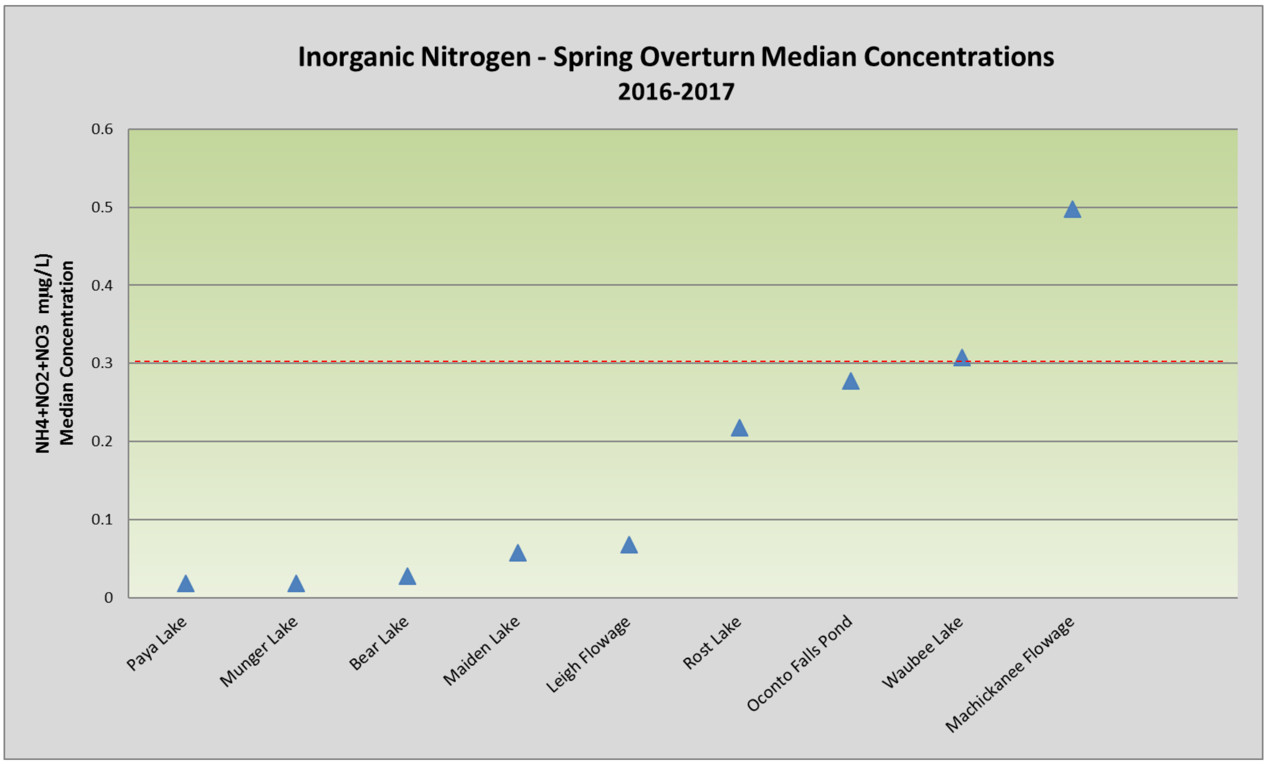


FIGURE 7. AVERAGE CONCENTRATIONS OF INORGANIC NITROGEN (MG/L) DURING THE SPRING. OCONTO COUNTY LAKES STUDY, 2016-2017.

PHOSPHORUS AND CHOROPHYLL *A* (ALGAE)

Chlorophyll-*a* is a measure of algae in water samples. Overall, the chlorophyll- *a* measured in the Oconto County lakes had a positive relationship to phosphorus concentrations; as phosphorus concentrations increase, chlorophyll *a* concentrations also increase. Results from the lake samples for phosphorus and chlorophyll *a* by lake type are shown in

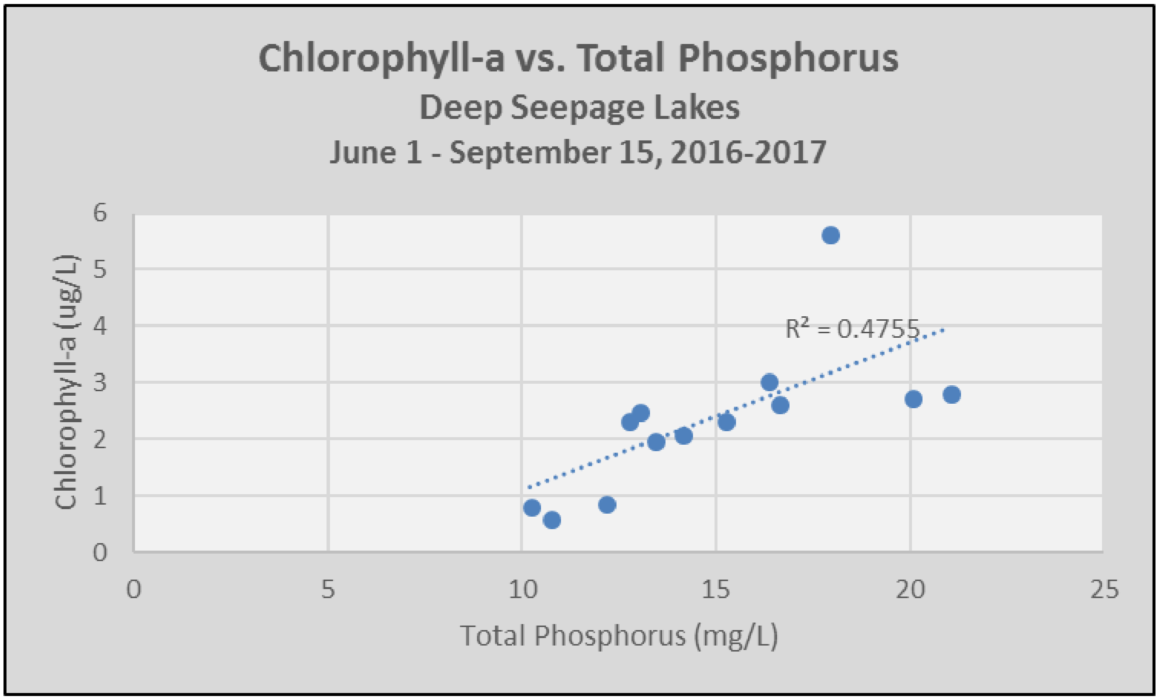


Figure 8 - Figure . Note: WDNR sampling protocol for summer water samples were followed. This protocol uses a sampler that integrates the upper 6 feet of the water column.

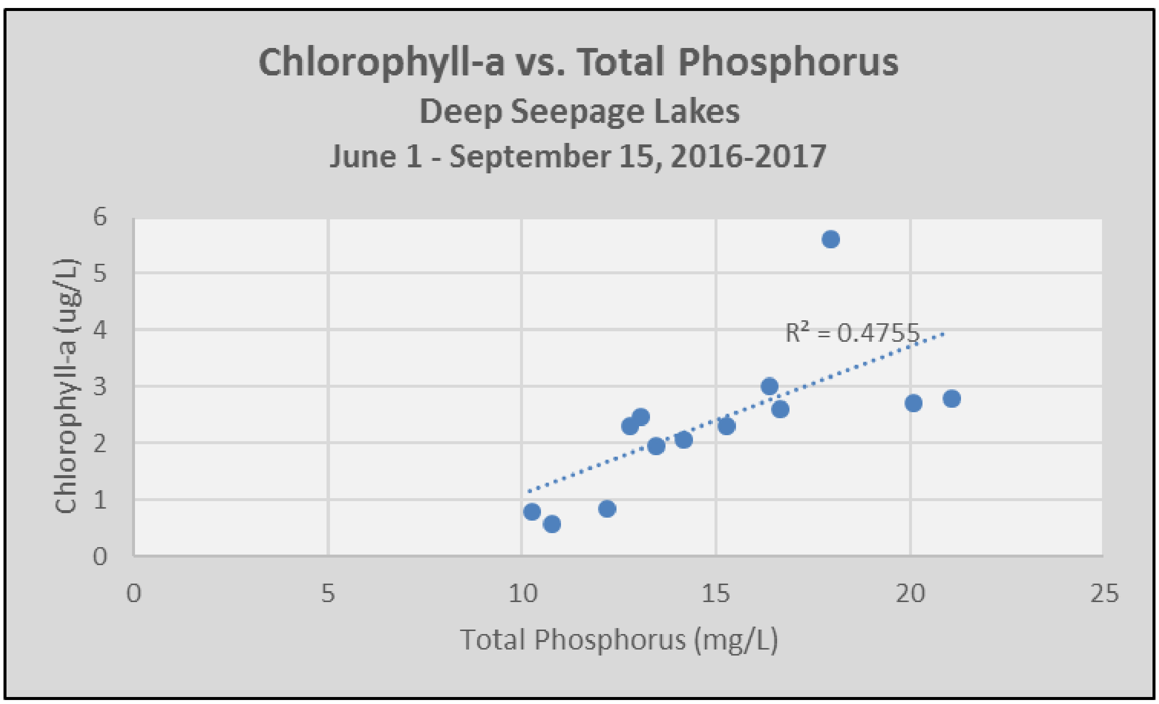


FIGURE 8. CHLOROPHYLL-A AND PHOSPHORUS CONCENTRATIONS (MG/L) IN SAMPLES COLLECTED FROM DEEP SEEPAGE AND SPRING LAKE TYPES IN OCONTO COUNTY. SUMMER 2016 AND 2017.

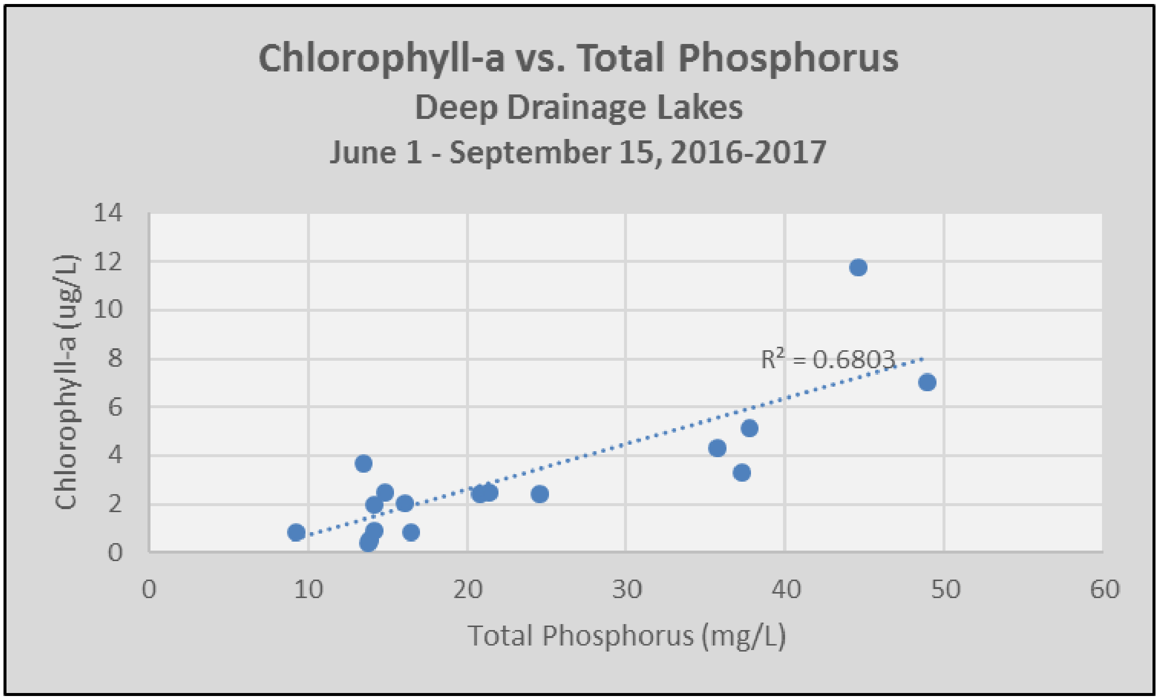


FIGURE 20. CHLOROPHYLL-*A* AND PHOSPHORUS CONCENTRATIONS (MG/L) IN SAMPLES COLLECTED FROM DEEP DRAINAGE LAKE TYPES IN OCONTO COUNTY. SUMMER 2016 AND 2017.

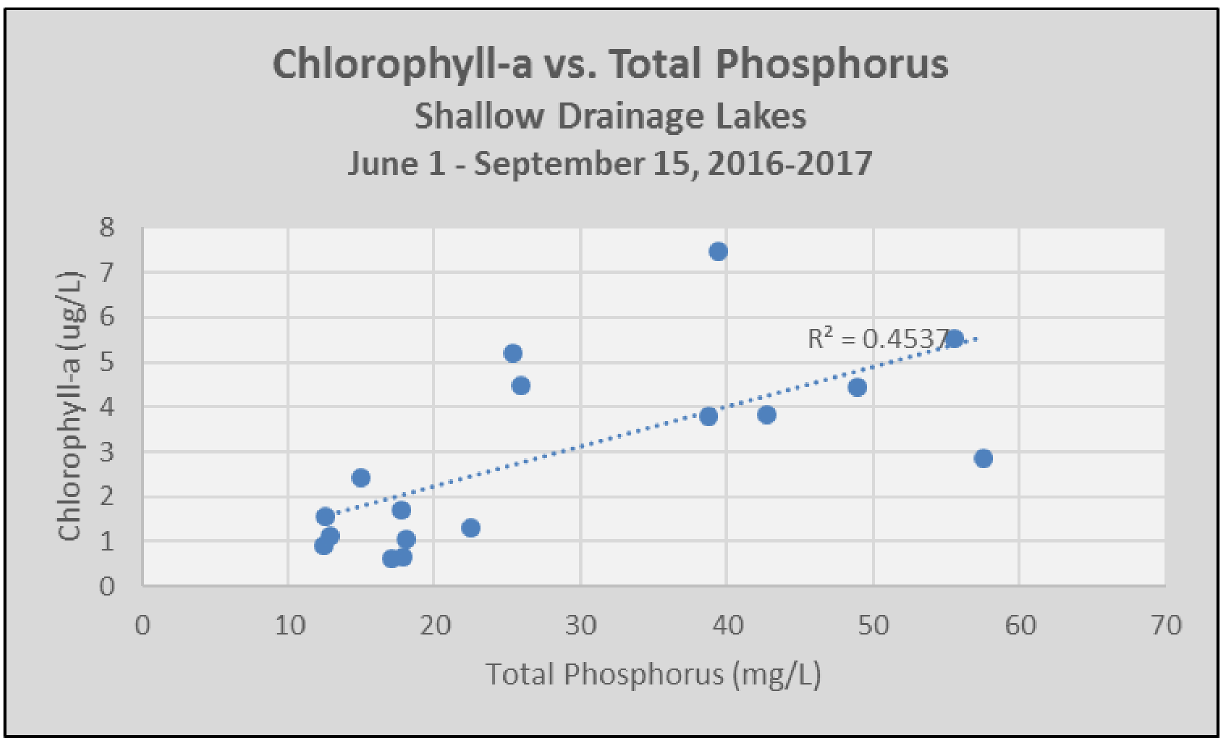


FIGURE 21. CHLOROPHYLL-*A* AND PHOSPHORUS CONCENTRATIONS (MG/L) IN SAMPLES COLLECTED FROM SHALLOW DRAINAGE LAKE TYPES IN OCONTO COUNTY. SUMMER 2016 AND 2017.

HARDNESS

The types and amounts of minerals in a lake depend upon the geology in the lake's watershed and how the water travels to the lake. In Waushara County, many of the lakes have strong connections with groundwater. The groundwater travels through the sandy aquifer which often contains calcium and magnesium. These minerals are easily dissolved and are carried with the groundwater to the local lakes and streams. Lakes with high concentrations of calcium and magnesium are called hard water lakes. When there is an abundance of calcium entering a lake, the calcium can precipitate out of the water and form a soft (often light-colored) sediment called marl. The marl can help to protect the lake from phosphorus by incorporating phosphorus into the marl particle's structure, thereby decreasing its availability for use by algae and aquatic plants. However, certain conditions at the bottom of a lake may re-dissolve some of the marl, re-releasing phosphorus into the bottom waters.

In the Oconto County study lakes, the average concentrations of total hardness ranged from 62.5 to 189 mg/L (Figure). In general, lakes with hardness concentrations less than 90 mg/L show a greater response by algae to inputs of phosphorus.

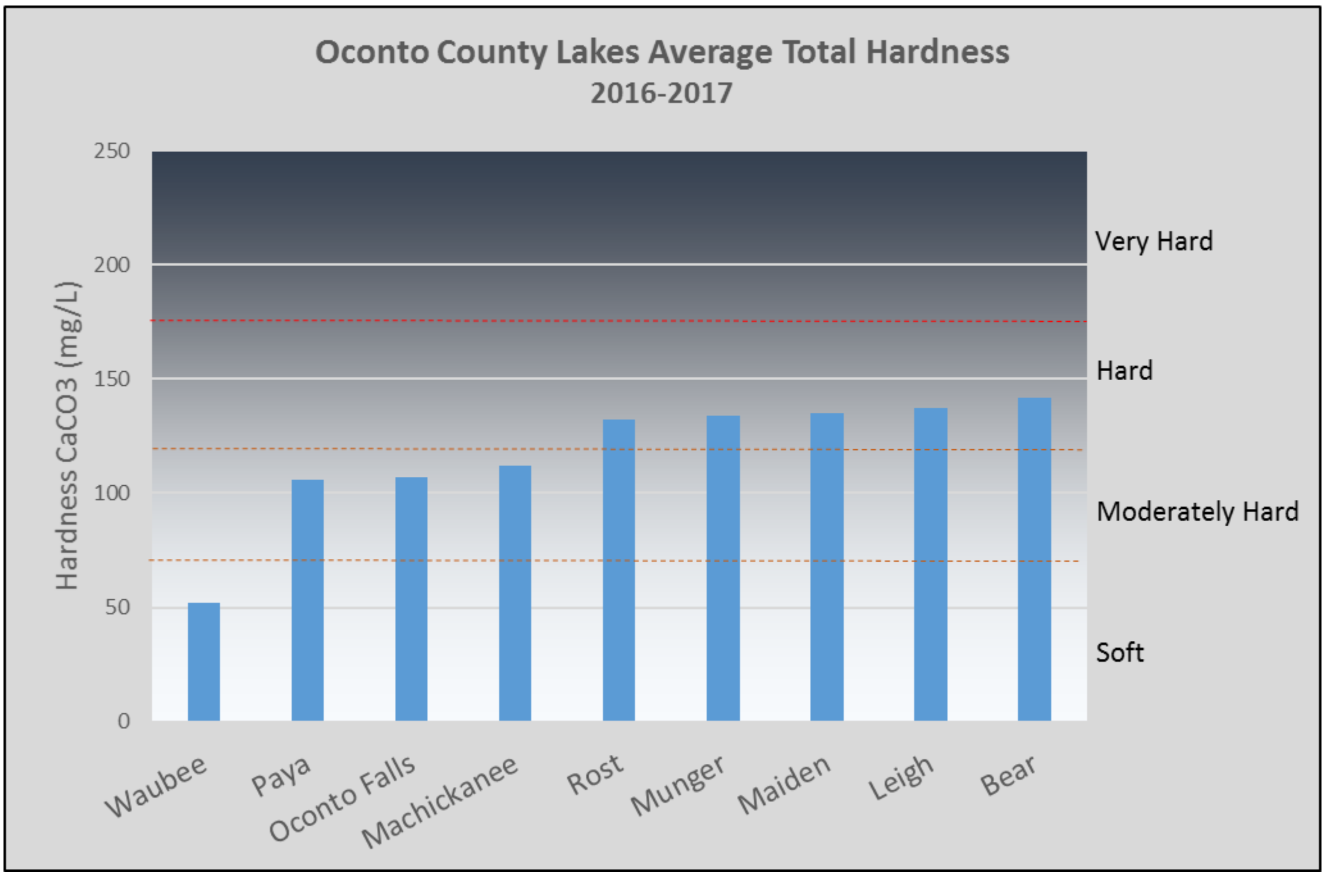


FIGURE 22. AVERAGE TOTAL HARDNESS CONCENTRATIONS (MG/L) MEASURED IN OCONTO COUNTY LAKES IN SPRING AND FALL OVERTURN SAMPLES (2016-2017).

CONTAMINANT INDICATORS

Concentrations of chloride, sodium, and potassium are naturally low in Wisconsin groundwater and surface water. Therefore, these ions be used as indicators of the effects of land management practices on local water quality. Sources of chloride and sodium include septic systems, animal waste, road salt, and some manufacturing and industrial processes.

A wide range of average chloride concentrations exists in the Oconto County lakes, ranging from 1.1 mg/L in Maiden Lake, to elevated concentrations of 11.7 mg/L in Waubee Lake (Figure). Sodium concentrations also had a wide range of 1.2 in Paya Lake to 7.5 mg/L Rost Lake (Figure 9). Concentrations of potassium in the Oconto County lakes averaged less than 2 mg/L, which is considered natural background concentrations for this part of the state (Figure 10).

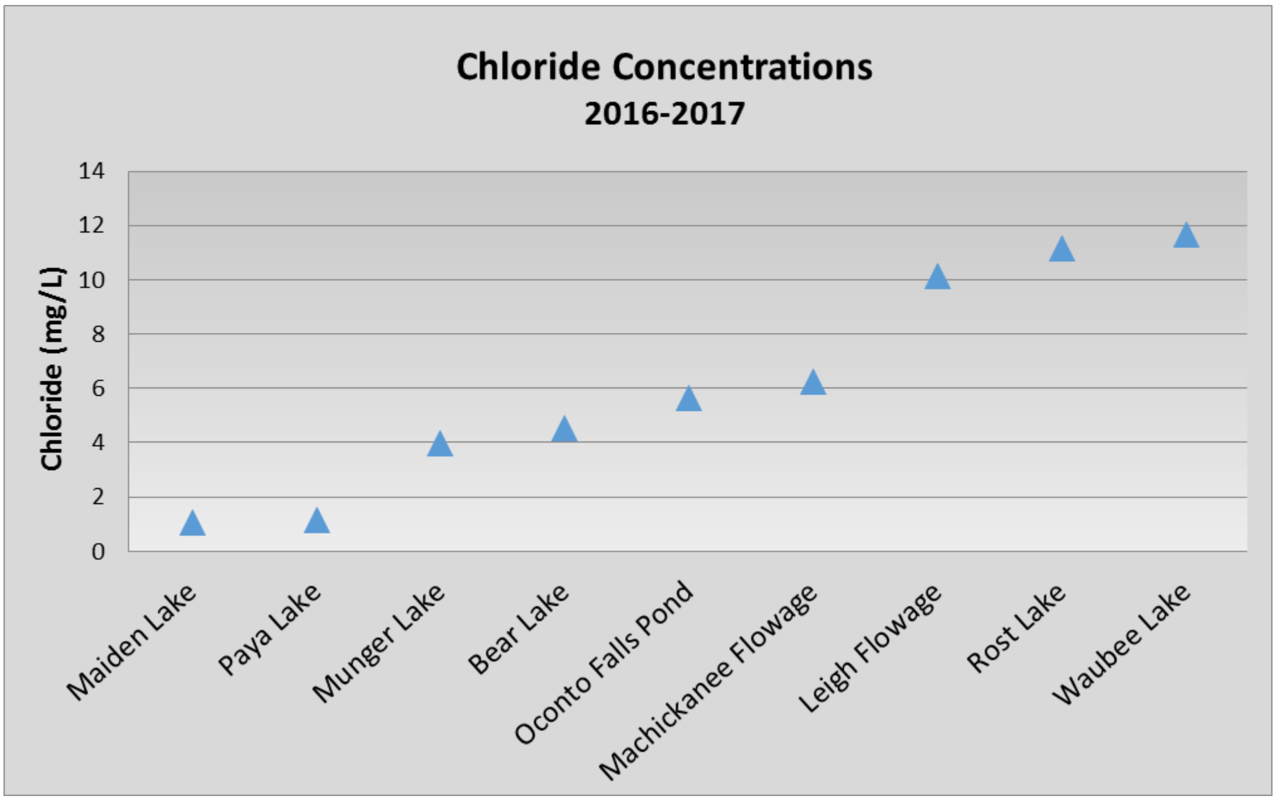


FIGURE 23. AVERAGE SPRING AND FALL OVERTURN CHLORIDE CONCENTRATIONS (MG/L) IN OCONTO COUNTY LAKES, (2016-17).

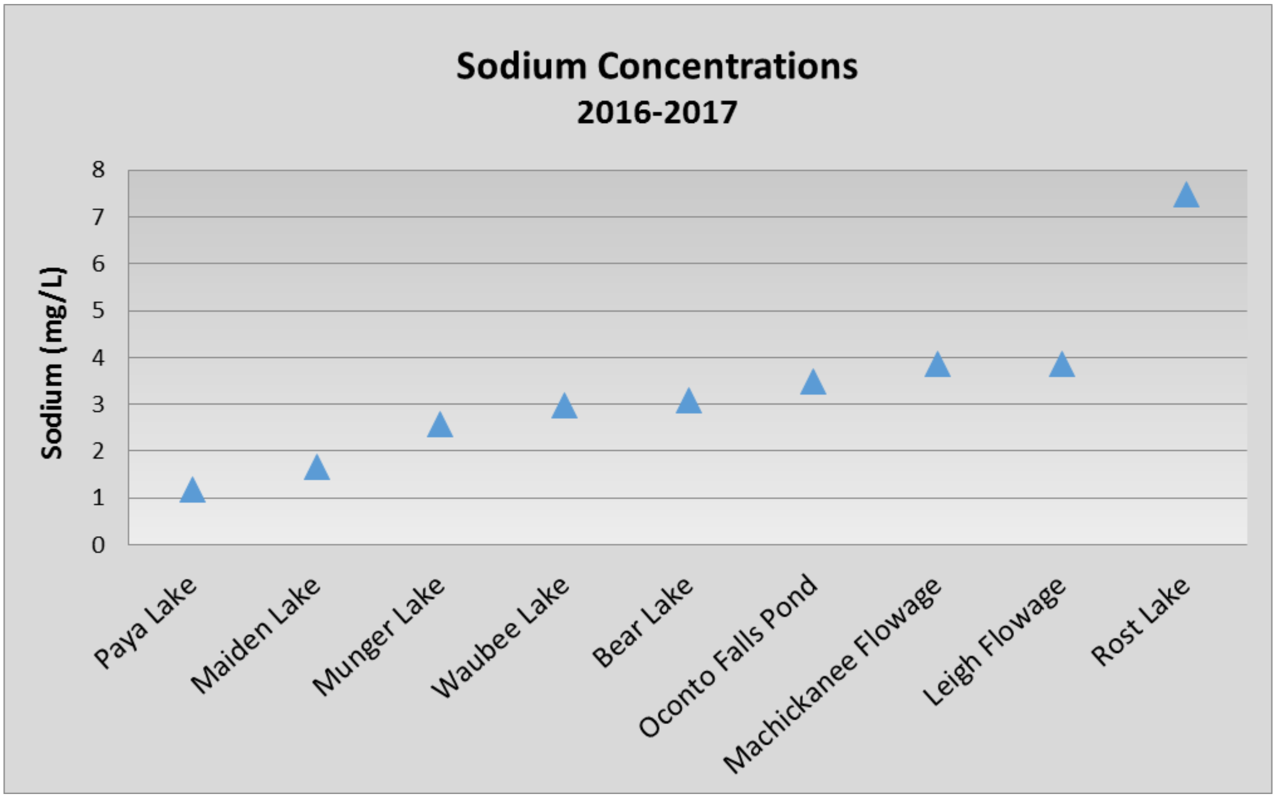


FIGURE 9. AVERAGE SPRING AND FALL OVERTURN SODIUM CONCENTRATIONS (MG/L) IN OCONTO COUNTY LAKES (2016-2017).

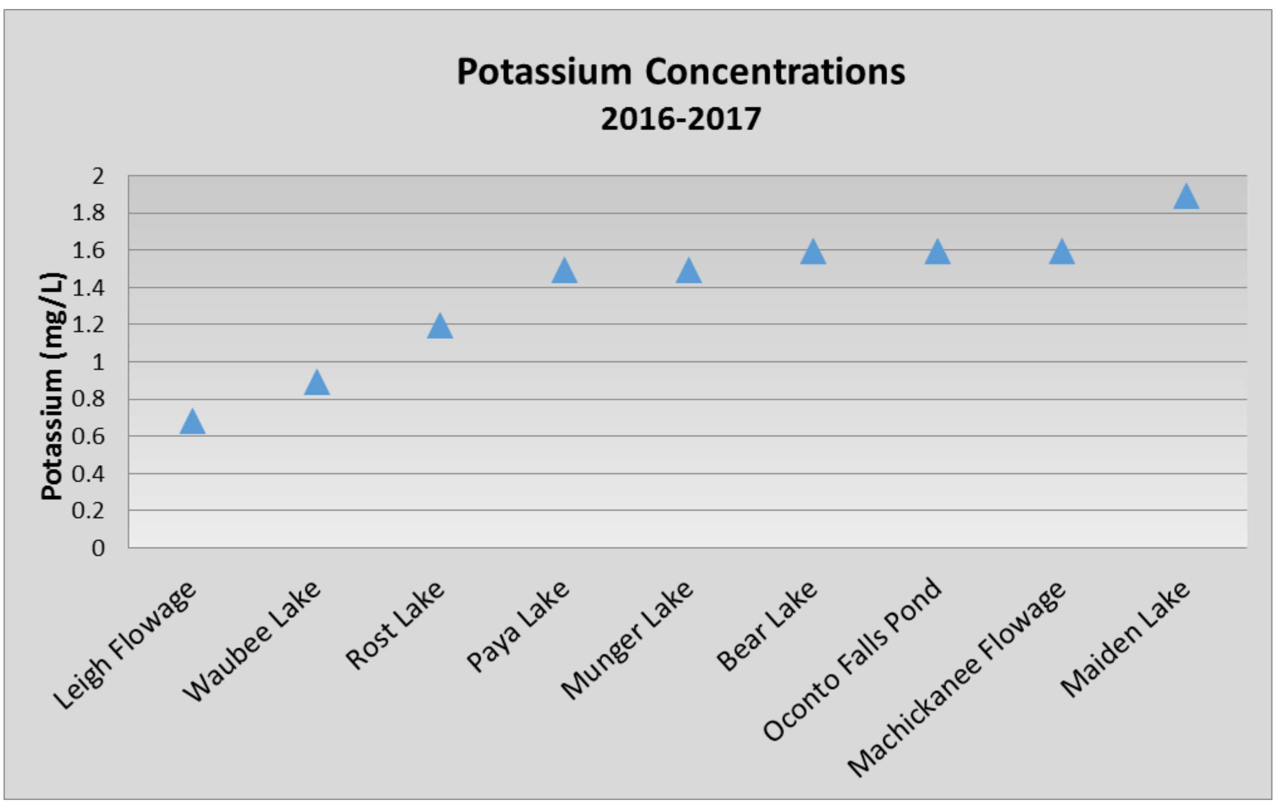


FIGURE 10. AVERAGE SPRING AND FALL OVERTURN POTASSIUM CONCENTRATIONS (MG/L) IN OCONTO COUNTY LAKES (2016-2017).

Aquatic Plants

Aquatic plants play a large role in the health of an aquatic ecosystem. They provide habitat for aquatic insects, fish, frogs, and turtles, stabilize the sediment, and infuse oxygen into the water. The native plant community in a lake is sensitive to changes in nutrient levels (nitrogen and phosphorus), sedimentation, water clarity, temperature, invasive species, and bottom disturbance from wind, boats and construction of docks and piers. Aquatic plant communities that are out of balance often exhibit overabundance of some species. Preventing disturbance of native plant communities by good planning and through the education of shoreland property owners can be a good investment because attempts to correct or control this condition can be costly in both time and money and in some situations cannot be reversed.

The composition of the native plant community reflects the overall health of the aquatic ecosystem. Typically, a greater number of species and presence of sensitive species indicate a healthier and more resilient aquatic ecosystem. However, the complexity of the shape and depth of the lake, sediment type, pH, and minerals in the water can also affect the diversity of plants in a lake. The aquatic plant community was surveyed in all the Oconto County study lakes. The number of aquatic plant species identified in each Oconto County lake is shown in Figure 11; lakes with "species of special concern" in Wisconsin are identified in red.

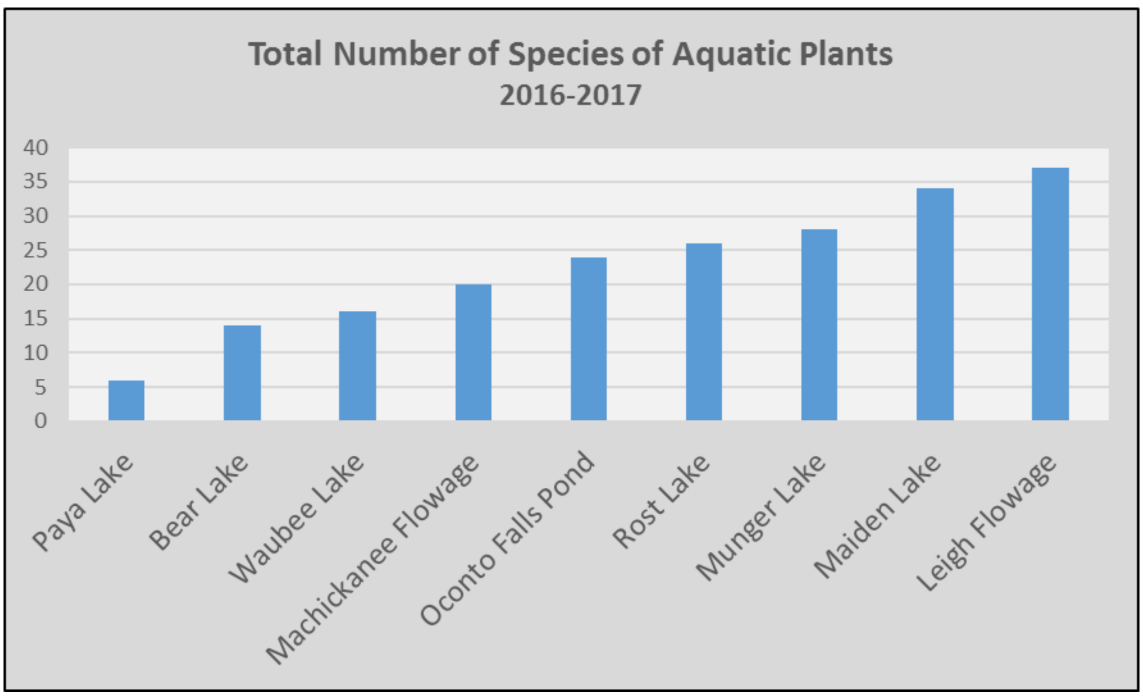


FIGURE 11. TOTAL NUMBER OF SPECIES OF AQUATIC PLANTS FOUND IN OCONTO COUNTY LAKES BASED ON 2016-2017 FIELD SURVEYS. RED BARS INDICATE LAKES WITH SPECIES OF SPECIAL CONCERN.

The **coefficient of conservatism** ("c-value") indicates on a scale of 0 to 10 the degree to which an aquatic species can tolerate disturbance. Disturbance may be natural, through wind and wave action or loosely packed sediments that that lack stability for roots. Disturbance may be enhanced in parts of a lake by higher-speed boating, installation of structures in the lake, dredging, and chemical, mechanical, or hand removal of plants or woody substrate. Aquatic plants with lower c-values tend to occur in a wide range of more-or-less disturbed plant communities. Species with higher c-value at or near 10 are unique and often found in relatively undisturbed areas.

The number of species with c-values greater than 8 in each of the Oconto County lakes are shown in Figure 27. A c-value of 0 is assigned to non-native species. The c-values are used in calculating the Floristic Quality Index for each lake.

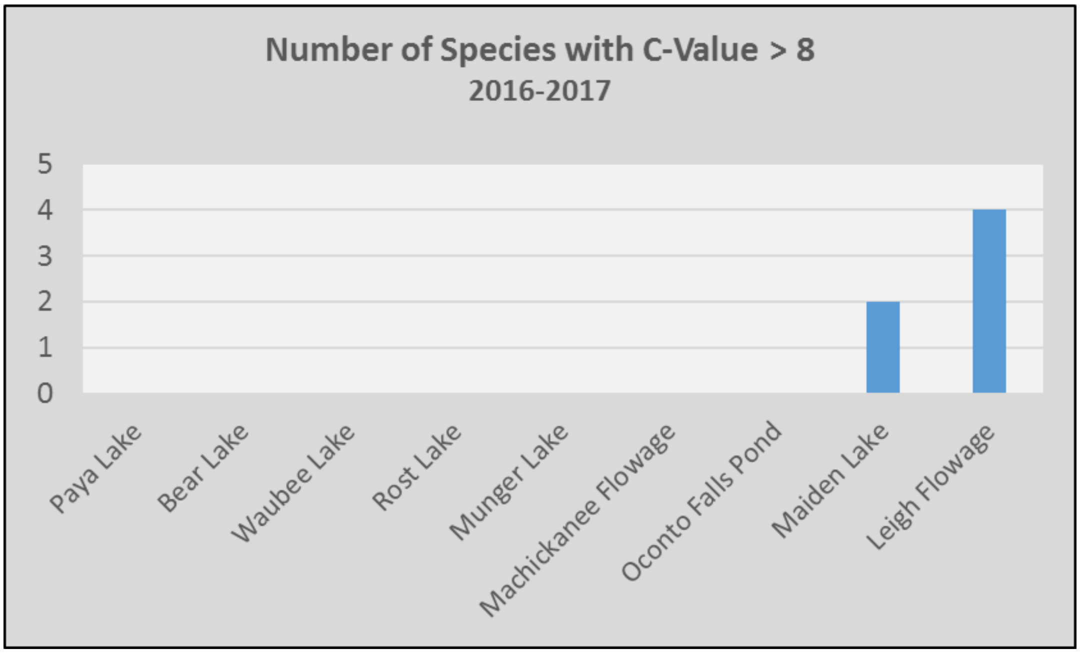


FIGURE 12. THE NUMBER OF SPECIES WITH A C-VALUE GREATER THAN 8 IN OCONTO COUNTY LAKES, BASED ON 2016-2017 FIELD SURVEYS.

The floristic quality index (FQI) is a standardized method of evaluating natural plant communities. It is produced for a given site by multiplying the average c-value for all species by the square root of the total number of species found at that lake. A high FQI, such as 60, indicates a higher floristic quality and biological integrity and a lower level of disturbance impacts. Disturbance impacts may include waves (natural or boating induced), presence of aggressive aquatic plant species, excessive algal growth, a simple lake shape and/or depth, and the removal of aquatic plants. The range of FQI values for the Oconto County study lakes are shown in Figure 13.

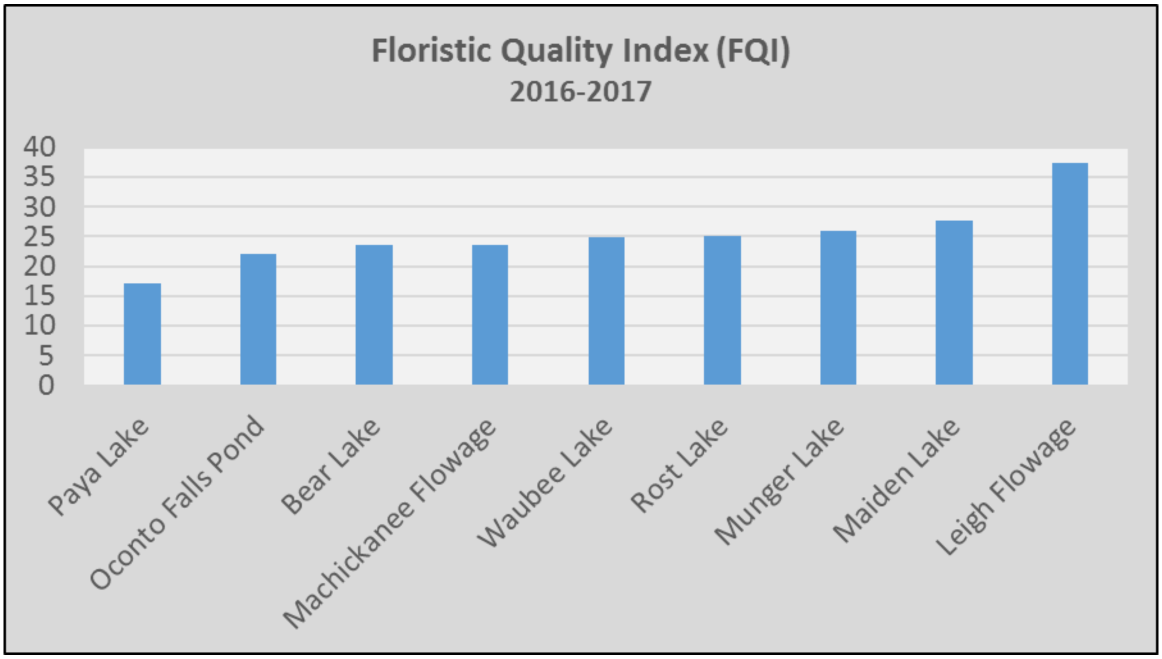


Figure 13. Floristic Quality Index (FQI) based on aquatic plant surveys conducted in the Oconto County study lakes. Summer 2016-2017.

AQUATIC INVASIVE SPECIES

Aquatic invasive species (AIS) are spreading throughout Wisconsin, including Oconto County. Distribution from lake to lake occurs primarily via boats, trailers, and equipment carrying plant material, seeds, eggs, and larvae from lake to lake. Raking and clearing an area of aquatic plants can significantly change the composition of plants in a lake and can lead to dominance by fewer, more tolerant species of plants. Frequently the establishment of these hardier more aggressive species can result in nuisance levels of growth. Barren sediment can also provide ideal habitat for invasive aquatic plant species such as Eurasian water milfoil (EWM) or curly leaf pondweed (CLP). Another effect of aquatic plant removal can be increasing the growth and abundance of algae in a lake. A list of invasive aquatic plant species known to be present in the study lakes **as of Fall 2017** can be found in

TABLE .

TABLE 6. AQUATIC INVASIVE SPECIES IN OCONTO COUNTY LAKES, BASED ON 2017 WISCONSIN DEPARTMENT OF NATURAL RESOURCES RECORDS.

Lake Name	Invasive Aquatic Plant Species (2017)
Bear Lake	Banded Mystery Snail
Leigh Flowage	Banded Mystery Snail, Chinese Mystery Snail, Phragmites, Zebra Mussel
Machickanee Flowage	Curly-Leaf Pondweed, Eurasian Water-Milfoil, Flowering Rush, Purple Loosestrife, Zebra Mussel
Maiden Lake	Banded Mystery Snail, Eurasian Water-Milfoil, Rusty Crayfish
Munger Lake	Banded Mystery Snail, Eurasian Water-Milfoil*
Oconto Falls Pond	Chinese Mystery Snail, Curly-Leaf Pondweed, Eurasian Water-Milfoil, Flowering Rush, Yellow Iris, Zebra Mussel
Paya Lake	Rusty Crayfish
Rost Lake	Chinese Mystery Snail, Phragmites, Purple Loosestrife
Waubee Lake	Banded Mystery Snail, Chinese Mystery Snail, Phragmites

Shorelands

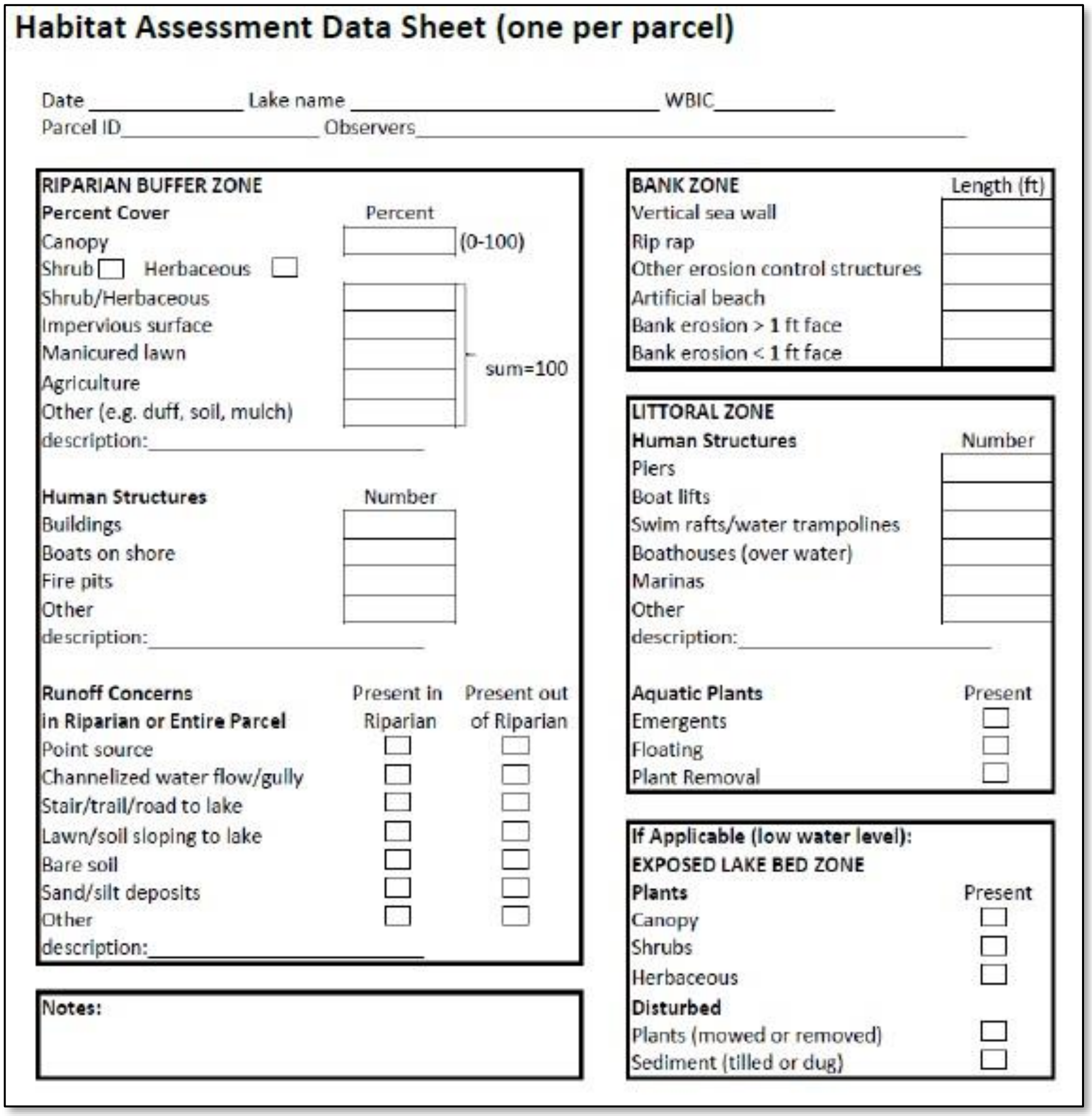
Shoreland vegetation is critical to a healthy lake's ecosystem. It provides habitat for many aquatic and terrestrial animals including birds, frogs, turtles, and many small and large mammals. Shoreland vegetation also helps to improve the quality of the runoff that is flowing across the landscape towards the lake. Healthy shoreland vegetation includes a mix of native unmowed grasses/flowers, shrubs and trees which extend at least 35 feet landward from the water's edge.

The changes to the landscape from shoreline development increase runoff and decrease water quality, wildlife habitat and natural scenic beauty. When runoff increases, this water bypasses the natural water filter provided by soil, microbial action and vegetation and carries additional sediment, nutrients and other materials in its path directly to surface waters. This increased transport of materials from land to water can be a substantial source of nutrient and sediment loading.

Shorelands are especially sensitive to development activities because of their close proximity to surface waters. Driveways, rooftops and patios near the shoreland area increase the total area of impervious surfaces. Runoff from these surfaces can be a source of pollutants and sediments flowing into a nearby lake. Minimizing the presence of impervious surfaces in the shoreland area can help reduce the amount of phosphorus and sediment to the lake.

Over-developed shorelines cannot support the fish, wildlife, and clean water that attracted people to the lake in the first place. Even features like riprap, seawalls, and docks contribute to an unhealthy shoreline. While it might seem that one lot's development may not have a quantifiable impact on the water quality of the lake, the collective effects of many properties can be significant.

To better understand the health of the Oconto County lakes, shorelands were evaluated by the Center for Watershed Science and Education and WDNR as a part of the Oconto County Lakes Study. Shorelines for each lake were continuously evaluated in conformance with the WDNR's 2016 Draft Lake Shoreland & Shallows Habitat Monitoring Field Protocol. This survey assessed the vegetation present around the shoreline and identified man-made structures at or near the water's edge to assess the potential effect of lakeshore development on in-lake and shoreland habitat which may affect water quality, fish spawning grounds, shoreland wildlife habitat, and shoreline beauty (Figure 29).



Habitat Assessment Data Sheet (one per parcel)

Date ____________ Lake name ______________________ WBIC__________
Parcel ID________________ Observers____

RIPARIAN BUFFER ZONE

Percent Cover	Percent	
Canopy		(0-100)
Shrub ☐ Herbaceous ☐		
Shrub/Herbaceous		sum=100
Impervious surface		
Manicured lawn		
Agriculture		
Other (e.g. duff, soil, mulch)		

description:________________________

Human Structures	Number
Buildings	
Boats on shore	
Fire pits	
Other	

description:________________________

Runoff Concerns in Riparian or Entire Parcel	Present in Riparian	Present out of Riparian
Point source	☐	☐
Channelized water flow/gully	☐	☐
Stair/trail/road to lake	☐	☐
Lawn/soil sloping to lake	☐	☐
Bare soil	☐	☐
Sand/silt deposits	☐	☐
Other	☐	☐

description:________________________

Notes:

BANK ZONE	Length (ft)
Vertical sea wall	
Rip rap	
Other erosion control structures	
Artificial beach	
Bank erosion > 1 ft face	
Bank erosion < 1 ft face	

LITTORAL ZONE

Human Structures	Number
Piers	
Boat lifts	
Swim rafts/water trampolines	
Boathouses (over water)	
Marinas	
Other	

description:____________________

Aquatic Plants	Present
Emergents	☐
Floating	☐
Plant Removal	☐

If Applicable (low water level):
EXPOSED LAKE BED ZONE

Plants	Present
Canopy	☐
Shrubs	☐
Herbaceous	☐
Disturbed	
Plants (mowed or removed)	☐
Sediment (tilled or dug)	☐

FIGURE 14. HABITAT ASSESSMENT DATA SHEET, PROVIDED BY WDNR, USED FOR SHORELAND SURVEYS IN THE OCONTO COUNTY STUDY LAKES. SUMMER 2016-2017.

SHORELAND SURVEY RESULTS

In summary, the Oconto County shoreland assessment found (Figure 30 and Figure 31):

- 9 lakes with shoreland assessments encompassing 35 miles of shore, 971 lakefront parcels and 1,616 acres of water.
- 11 miles (32%) of the inventoried shoreline is disturbed
- 8 miles (23%) of the inventoried shoreline is mowed lawn
- 4 miles (11%) of the inventories shoreline is sea wall and/or rip rap
- 1.2 miles (3.5%) of the inventories shoreline is impervious surface modification

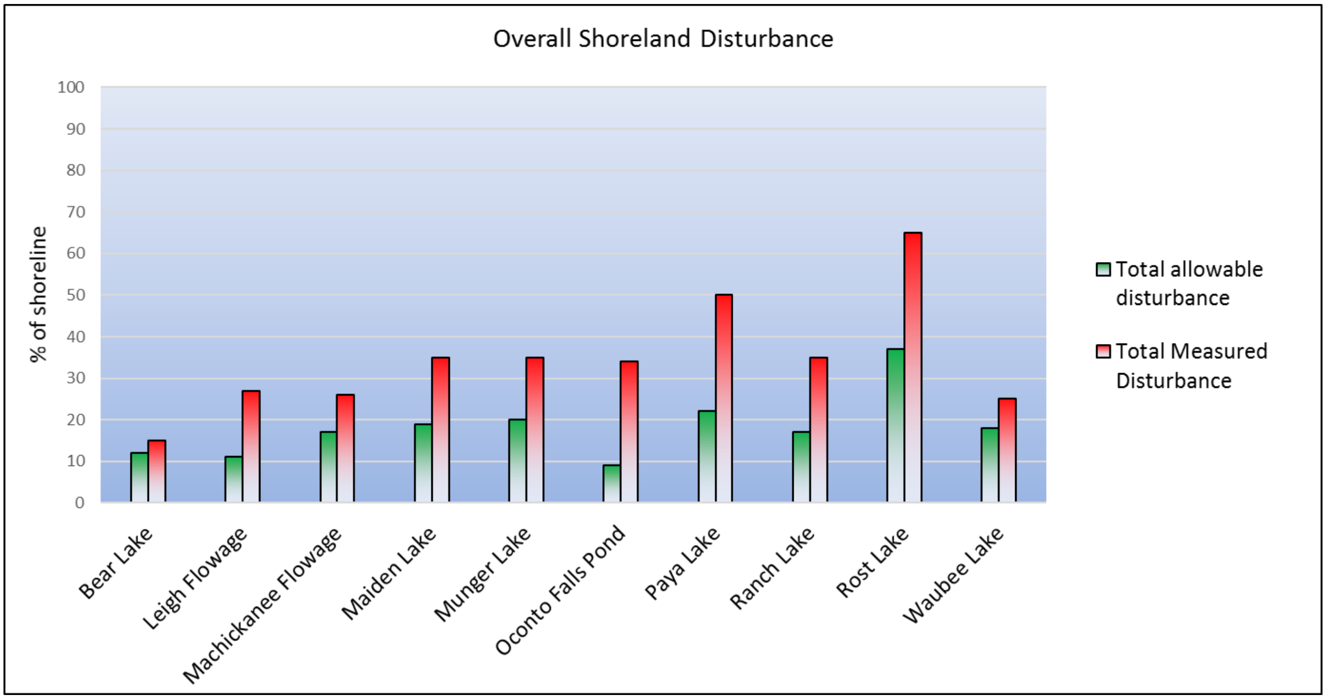


FIGURE 30. OVERALL SHORELAND DISTURBANCE, OCONTO COUNTY STUDY LAKES. SUMMER 2016-2017.

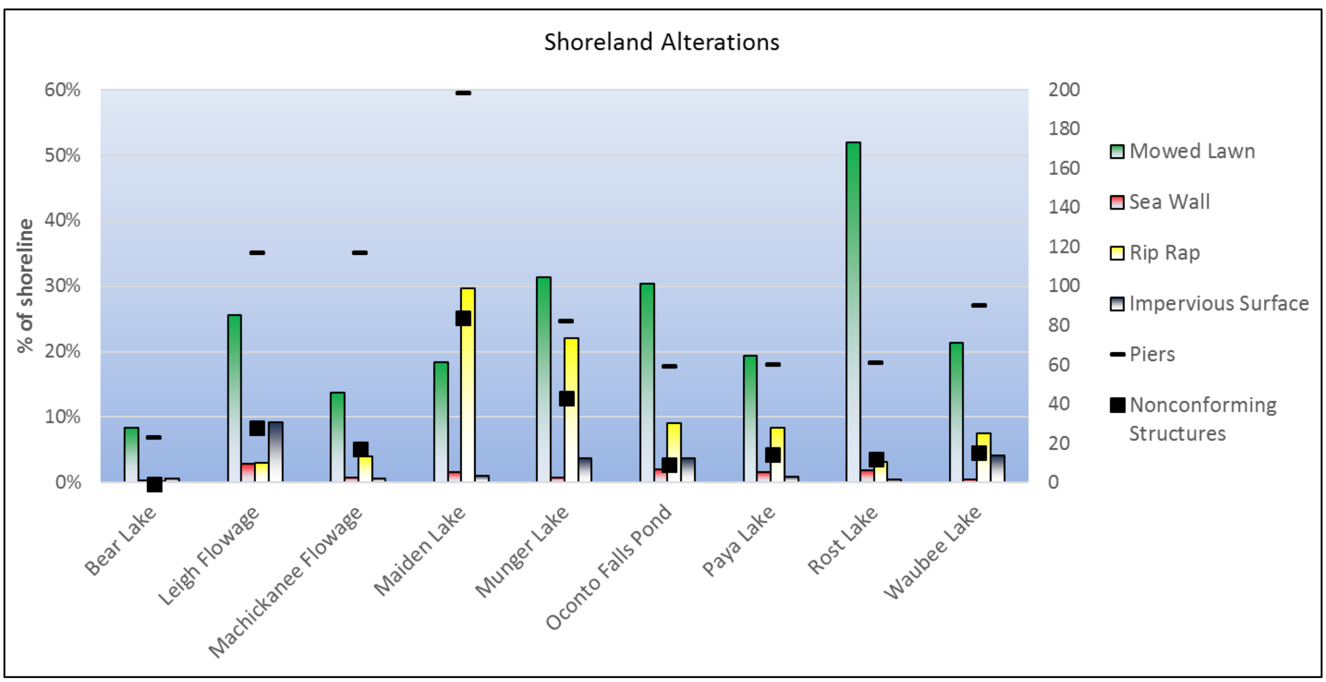


FIGURE 31. SHORELAND ALTERATIONS, OCONTO COUNTY STUDY LAKES. SUMMER 2016-2017.

GLOSSARY

Algae:

One-celled (phytoplankton) or multicellular plants either suspended in water (Plankton) or attached to rocks and other substrates (periphyton). Their abundance, as measured by the amount of chlorophyll a (green pigment) in an open water sample, is commonly used to classify the trophic status of a lake. Numerous species occur. Algae are an essential part of the lake ecosystem and provides the food base for most lake organisms, including fish. Phytoplankton populations vary widely from day to day, as life cycles are short.

Ammonia:

A form of nitrogen found in organic materials and many fertilizers. It is the first form of nitrogen released when organic matter decays. It can be used by most aquatic plants and is therefore an important nutrient. It converts rapidly to nitrate (NO3) if oxygen is present. The conversion rate is related to water temperature. Ammonia is toxic to fish at relatively low concentrations in pH-neutral or alkaline water. Under acid conditions, non-toxic ammonium ions (NH4+) form, but at high pH values the toxic ammonium hydroxide (NH4OH) occurs. The water quality standard for fish and aquatic life is 0.02 mg/l of NH4OH. At a pH of 7 and a temperature of 68 Deg F (20 Deg. C), the ratio of ammonium ions to ammonium hydroxide is 250:1; at pH 8, the ratio is 26:1.

Biomass:

The total quantity of plants and animals in a lake. Measured as organisms or dry matter per cubic meter, biomass indicates the degree of a lake system's eutrophication or productivity.

Blue-Green Algae:

Algae that are often associated with problem blooms in lakes. Some produce chemicals toxic to other organisms, including humans. They often form floating scum as they die. Many can fix nitrogen (N2) from the air to provide their own nutrient.

Calcium (Ca++):

The most abundant cation found in Wisconsin lakes. Its abundance is related to the presence of calcium-bearing minerals in the lake watershed. Reported as milligrams per liter (mg/1) as calcium carbonate (CaCO3), or milligrams per liter as calcium ion (Ca++).

Chloride (Cl-):

Chlorine in the chloride ion (Cl-) form has very different properties from chlorine gas (Cl2), which is used for disinfecting. The chloride ion (Cl-) in lake water is commonly considered an indicator of human activity. Agricultural chemicals, human and animal wastes, and road salt are the major sources of chloride in lake water.

Chlorophyll a:

Green pigment present in all plant life and necessary for photosynthesis. The amount present in lake water depends on the amount of algae and is therefore used as a common indicator of water quality.

Coefficient of Conservatism (c-value):

Indicates on a scale of 0 to 10 the degree to which an aquatic species can tolerate disturbance. Disturbance may be natural, through wind and wave action or loosely packed sediments that that lack stability for roots. Disturbance may be enhanced in parts of a lake by higher-speed boating, installation of structures in the lake, dredging, and chemical, mechanical, or hand removal of plants or woody substrate. Aquatic plants with lower c-values tend to occur in a wide range of more-or-less disturbed plant communities. Species with higher c-value at or near 10 are unique and often found in relatively undisturbed areas.

Color:

Measured in color units that relate to a standard. A yellow-brown natural color is associated with lakes or rivers receiving wetland drainage. The average color value for Wisconsin lakes is 39 units, with the color of state lakes ranging from zero to 320 units. Color also affects light penetration and therefore the depth at which plants can grow.

Concentration units:

Expresses the amount of a chemical dissolved in water. The most common ways chemical data is expressed is in milligrams per liter (mg/l) and micrograms per liter (ug/l). One milligram per liter is equal to one part per million (ppm). To convert micrograms per liter (ug/l) to milligrams per liter (mg/l), divide by 1000 (e.g. 30 ug/l = 0.03 mg/1). To convert milligrams per liter (mg/l) to micrograms per liter (ug/l), multiply by 1000 (e.g. 0.5 mg/l = 500 ug/l). Microequivalents per liter (ueq/l) is also sometimes used, especially for alkalinity; it is calculated by dividing the weight of the compound by 1000 and then dividing that number into the milligrams per liter.

Drainage lakes:

Lakes fed primarily by streams and with outlets into streams or rivers. They are more subject to surface runoff problems but generally have shorter residence times than seepage lakes. Watershed protection is usually needed to manage lake water quality.

Epilimnion:

see "Stratification."

Eutrophication:

The process by which lakes and streams are enriched by nutrients, and the resulting increase in plant and algae. The extent to which this process has occurred is reflected in a lake's trophic classification: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).

Filamentous Algae:

Algae that forms filaments or mats attached to sediment, weeds, piers, etc.

Floristic Quality Index (FQI):

The FQI is a standardized method for evaluating natural plant communities by multiplying the average c-value for all species by the square root of the total number of species found at that lake; an additional point is added to the index for each state-listed special concern species, two points added for a threatened species, and three points added for an endangered species. A higher floristic quality index, such as FQI=60, indicates a higher floristic quality and biological integrity and a lower level of disturbance impacts. A lower floristic quality index, such as FQI=20, indicates a lower floristic quality and biological integrity and a higher level of disturbance impacts.

Food Chain:

The sequence of algae being eaten by small aquatic animals (zooplankton) which in turn are eaten by small fish which are then eaten by larger fish and eventually by people or predators. Certain chemicals, such as PCBS, mercury, and some pesticides, can be concentrated from very low levels in the water to toxic levels in animals through this process.

Groundwater drainage lake:

Often referred to a spring-fed lake, has large amounts of groundwater as its source, and a surface outlet. Areas of high groundwater inflow may be visible as springs or sand boils. Groundwater drainage lakes often have intermediate retention times with water quality dependent on groundwater quality.

Hardness:

The quantity of multivalent cations (cations with more than one +), primarily calcium (Ca^{++}) and magnesium (Mg^{++}) in the water expressed as milligrams per liter of $CaCO_3$. Amount of hardness relates to the presence of soluble minerals, especially limestone, in the lake watershed.

Hypolimnion:

see "Stratification."

Impoundment:

Manmade lake or reservoir usually characterized by stream inflow and always by a stream outlet. Because of nutrient and soil loss from upstream land use practices, impoundments ordinarily have higher nutrient concentrations and faster sedimentation rates than natural lakes. Their retention times are relatively short.

Insoluble:

incapable of dissolving in water.

Kjeldahl nitrogen:

The most common analysis run to determine the amount of organic nitrogen in water. The test includes ammonium and organic nitrogen.

Limiting factor:

The nutrient or condition in shortest supply relative to plant growth requirements. Plants will grow until stopped by this limitation; for example, phosphorus in summer, temperature or light in fall or winter.

Macrophytes:

see "Rooted aquatic plants."

Marl:

White to gray accumulation on lake bottoms caused by precipitation of calcium carbonate ($CaCO_3$) in hard water lakes. Marl may contain many snail and clam shells, which are also calcium carbonate. While it gradually fills in lakes, marl also precipitates phosphorus, resulting in low algae populations and good water clarity. In the past, marl was recovered and used to lime agricultural fields.

Metalinmion:

see "Stratification."

Nitrate (NO3-):

An inorganic form of nitrogen important for plant growth. Nitrogen is in this stable form when oxygen is present. Nitrate often contaminates groundwater when water originates from manure pits, fertilized fields, lawns or septic systems. High levels of nitrate-nitrogen (over 10 mg/1) are dangerous to infants and expectant mothers. A concentration of nitrate-nitrogen (NO3-N) plus ammonium-nitrogen (NH4-N) of 0.3 mg/l in spring will support summer algae blooms if enough phosphorus is present.

Nitrite (NO2-):

A form of nitrogen that rapidly converts to nitrate (NO3-) and is usually included in the NO3- analysis.

Overturn:

Fall cooling and spring warming of surface water increases density, and gradually makes temperature and density uniform from top to bottom. This allows wind and wave action to mix the entire lake. Mixing allows bottom waters to contact the atmosphere, raising the water's oxygen content. However, warming may occur too rapidly in the spring for mixing to be effective, especially in small sheltered kettle lakes.

Phosphorus:

Key nutrient influencing plant growth in more than 80% of Wisconsin lakes. Soluble reactive phosphorus is the amount of phosphorus in solution that is available to plants. Total phosphorus includes the amount of phosphorus in solution (reactive) and in particulate form.

Photosynthesis:

the process by which green plants convert carbon dioxide (CO2) dissolved in water to sugar and oxygen using sunlight for energy. Photosynthesis is essential in producing a lake's food base and is an important source of oxygen for many lakes.

Retention Time:(flushing rate)

The average length of time water resides in a lake, ranging from several days in small impoundments to many years in large seepage lakes. Retention time is important in determining the impact of nutrient inputs. Long retention times result in recycling and greater nutrient retention in most lakes. Calculate retention time by dividing the volume of water passing through the lake per year by the lake volume.

Respiration:

The process by which aquatic organisms convert organic material to energy. It is the reverse reaction of photosynthesis. Respiration consumes oxygen (0_2) and releases carbon dioxide (CO_2). It also takes place as organic matter decays.

Rooted Aquatic Plants:(macrophytes)

Refers to higher (multi-celled) plants growing in or near water. Macrophytes are beneficial to lakes because they produce oxygen and provide substrate for fish habitat and aquatic insects. Overabundance of such plants, especially problem species, is related to shallow water depth and high nutrient levels.

Sedimentation:

Accumulated organic and inorganic matter on the lake bottom. Sediment includes decaying algae and weeds, marl, and soil and organic matter eroded from the lake's watershed.

Seepage lakes:

Lakes without a significant inlet or outlet, fed by rainfall and groundwater. Seepage lakes lose water through evaporation and groundwater moving on a down gradient. Lakes with little groundwater inflow tend to be naturally acidic and most susceptible to the effects of acid rain. Seepage lakes often have long residence times and lake levels fluctuate with local groundwater levels. Water quality is affected by groundwater quality and the use of land on the shoreline.

Soluble:

capable of being dissolved.

Stratification:

The layering of water due to differences in density. Water's greatest density occurs at 39 Deg.F (4 Deg.C). As water warms during the summer, it remains near the surface while colder water remains near the bottom. Wind mixing determines the thickness of the warm surface water layer (epilimnion), which usually extends to a depth of about 20 ft. The narrow transition zone between the epilimnion and cold bottom water (hypolimnion) is called the metalimnion or thermocline.

Suspended Solids:

A measure of the particulate matter in a water sample, expressed in milligrams per liter. When measured on inflowing streams, it can be used to estimate the sedimentation rate of lakes or impoundments.

Thermocline:

see "Stratification."

Trophic State:

see "Eutrophication."

Zooplankton:

Microscopic or barely visible animals that eat algae. These suspended plankton are an important component of the lake food chain and ecosystem. For many fish, they are the primary source of food.

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