Oconto County Lakes Project

STATE OF THE OCONTO COUNTY LAKES

GROUP 1-8 LAKES

2016-2024

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ACKNOWLEDGEMENTS

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Oconto County Lakes and Waterways Association
Oconto County Staff and Citizens
Oconto County UW Extension
Wisconsin Department of Natural Resources
Wisconsin Department of Natural Resources Surface Water Grant Program
UW-Stevens Point Water and Environmental Analysis Lab

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BACKGROUND

This report is intended to summarize and compare the condition of Oconto County lakes. It is based on lake studies conducted by Oconto County, Extension, Oconto County Land Conservation Department, University of Wisconsin – Stevens Point, and the Wisconsin Department of Natural Resources. This iteration of the report is the fourth lake condition summary and uses data from 41 of the lakes in the county that was collected from 2016 through 2024. In the coming years, additional groups of 5-9 new lakes will be studied each year and added to this report. In addition to providing a summary of the lake condition, the data collected in this project was used to develop individual lake management plans. Those plans are appended to this report.

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 (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. Figure 1 shows the location of the lakes included in this study.

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.

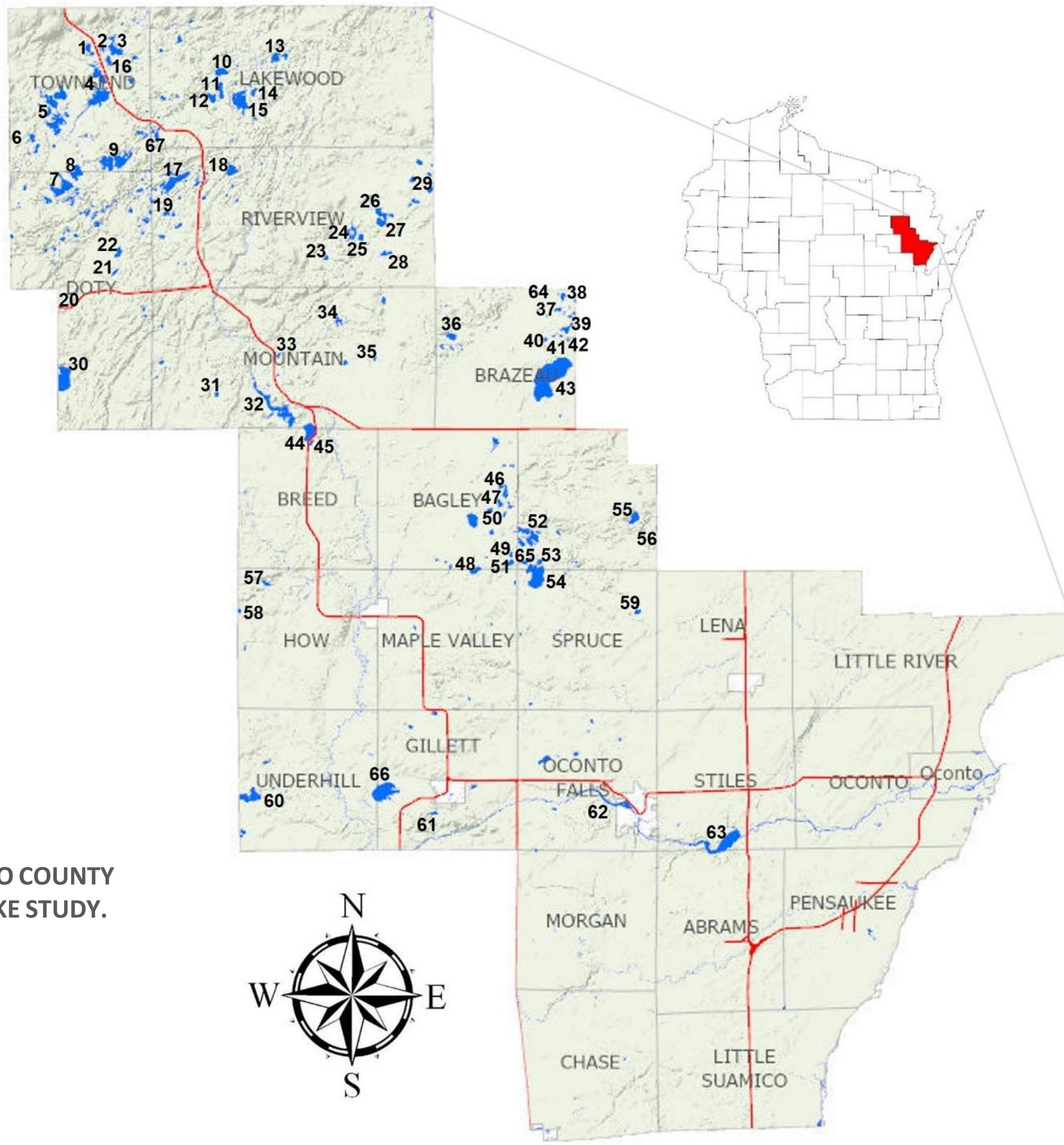


FIGURE 1. OCONTO COUNTY LAKES IN THE LAKE STUDY.

Oconto County Lakes Study									
1	Surprise Lake	**16**	Smoke Lake	**31**	McComb Lake	**46**	Ucil Lake	**61**	Finnegan Lake
2	Little Pickerel	**17**	Maiden Lake	**32**	Chute Pond	**47**	Wescott Lake	**62**	Oconto Falls Pond
3	Pickerel Lake	**18**	Paya Lake	**33**	Green Lake	**48**	Cooley Lake	**63**	Machickanee Flowage
4	Townsend Flowage	**19**	Little Gillett Lake	**34**	Bear Paw Lake	**49**	Underwood Lake	**64**	Pickerel Lake
5	Reservoir Pond	**20**	Hills Pond	**35**	Farr Lake	**50**	Pecor Lake	**65**	Long Lake
6	Mary Lake	**21**	Shadow Lake	**36**	Shay Lake	**51**	White Lake	**66**	Christie Lake
7	Boot Lake	**22**	Star Lake	**37**	Halfmoon Lake	**52**	Leigh Flowage	**67**	Chain Lake
8	Bass Lake	**23**	Sunrise Lake	**38**	Yankee Lake	**53**	Round Lake		
9	Archibald Lake	**24**	Waupee Flowage	**39**	Ranch Lake	**54**	Kelly Lake		
10	Lake John	**25**	Grindle Lake	**40**	Holt Lake	**55**	Rost Lake		
11	Munger Lake	**26**	Crooked Lake	**41**	Reader Lake	**56**	Montana Lake		
12	Bear Lake	**27**	Gilkey Lake	**42**	Perch Lake	**57**	Wiscobee Lake		
13	Waubee Lake	**28**	Nelligan Lake	**43**	White Potato Lake	**58**	Grignon Lake		
14	Pine Ridge Lake	**29**	Boundary Lake	**44**	Anderson Lake	**59**	Porcupine Lake		
15	Wheeler Lake	**30**	Boulder Lake	**45**	Moody Lake	**60**	Berry Lake		

Quaternary Geology of Oconto County

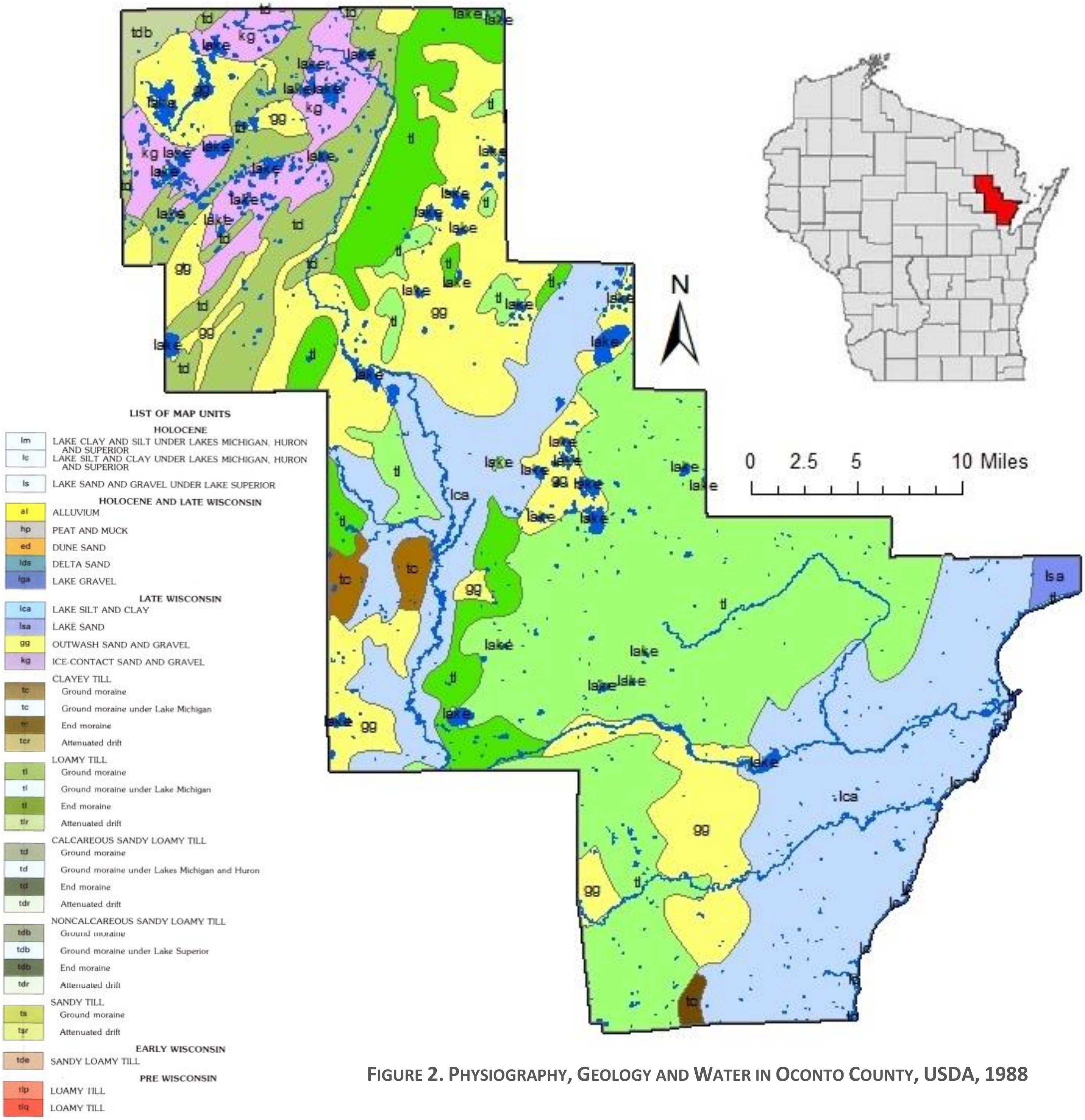


FIGURE 2. PHYSIOGRAPHY, GEOLOGY AND WATER IN OCONTO COUNTY, USDA, 1988

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 via 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).

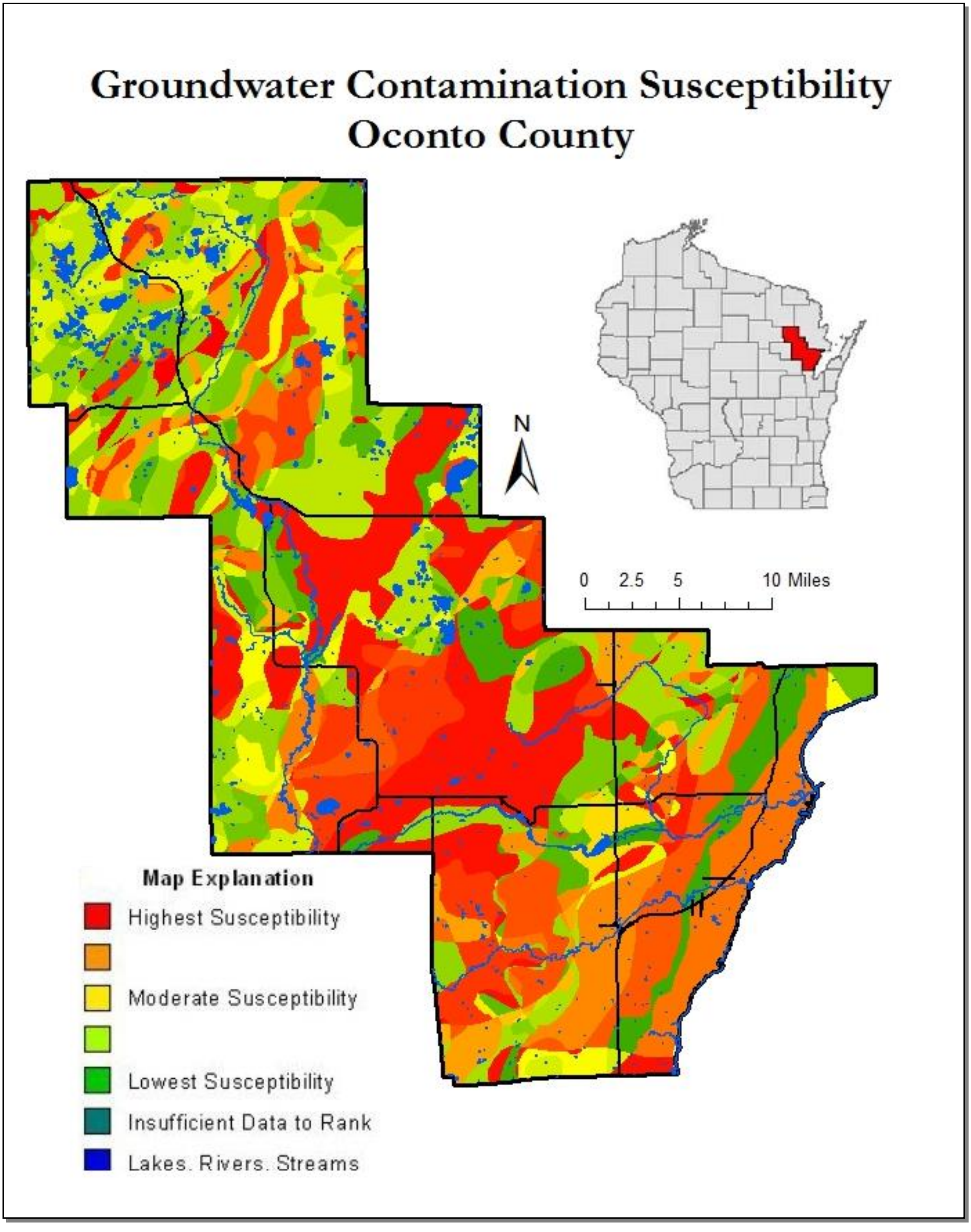


FIGURE 3. GROUNDWATER CONTAMINATION SUSCEPTIBILITY IN WISCONSIN (WGNHS, 1989).

HUMAN ACTIVITIES AND STRUCTURES IMPACT SURFACE AND GROUNDWATER ON ALL TYPES OF LANDSCAPES -DALE MOHR, UW EXTENSION OCONTO COUNTY, 2022

Since the time man first stepped upon the lands that comprise Oconto County, they began to impact water systems flowing and seeping to the Bay of Green Bay. The harvesting of woody habitat, the draining of wetlands, the construction of artificial drainage systems have altered how the land collects and moves water, throughout the county. Today, the natural environment is starkly different than during the times after the Ice Age. The vast forests and shore land wetlands once covering the county are largely negatively impacted with urban sprawl, urban development and scattered farmsteads. Figure 4 shows projected development within the county. These woodlands and wetlands effectively managed recharge and flow rates and impacted the causation of flooding and water contamination.

How many woodlands and wetlands exist and where are they located?

Oconto County encompasses approximately 650,700 acres of lands. Of this total approximately 38,000 acres (6%) are currently developed. Development pressure on Oconto's lands have changed over the centuries. With the Westward Expansion driving the need for timber, Oconto's old growth forests were harvested to meet the demands leaving rich agricultural lands behind. Today, some 170,000 agricultural lands exist while approximately 396,843 acres of woodlands do. Figure 5 identifies the 2007 land use inventory of existing woodlands. The map's classification identifies upland woodlands to be approximately 268,000 acres and lowland woodlands (defined as woodlands within wetlands) at around 128,700 acres.

What Pressures on woodlands and wetlands are anticipated?

The county's proximity to the city of Green Bay and its sprawling metropolis just south of the county, comprised of efficient transportation systems, mixed residential developments, commercial nodes and corridors adds to increased development pressures. An increasing number of people are projected to be living within Oconto County by the year 2035. It is anticipated that growth trends in residential housing is going to pressure lands around the county's waterways especially the second tier lands adjacent to existing shoreline development. The County Comprehensive Land Use Plan further identifies development pressure to continue to increase along sensitive environmental corridors, public woodlands and prime agricultural lands. All of this pressure establishes a need for greater storm water regulation to lower risks of flooding; incorporating sanitary districts to lower effects of pollution and contamination of the water system; additionally land use regulations need to be strengthened to minimize negative effects of dwellings and resulting transportation systems. It is anticipated, by Oconto County, that some 5,000 acres will be developed to accommodate the population growth by 2035.

Who controls these woodlands'?

The ongoing fragmentation of natural areas limits the ability to implement and sustain management plans. Over the centuries, since 1848 and the founding of the county, ownership of vast tracks of the landscape have changed hands. Today, ownership of the approximately 396,800 acres of woodlands is complex. Purchases of Federal and State parcels were made to protect and manage resources while county owned lands are utilized also as a resource for recreation and timber sales but were largely obtained due to tax delinquency during the years of the Great Depression. The federal lands are managed by the U.S. Forest Service. The state lands are managed by the Department of Natural Resources, County Lands by the Parks and Recreation Department. The private lands are owned by individuals or corporations. Understanding the complexity of bringing such a complex social group of people together is part of having a scientific understanding of everyone's interests and goals while working to establish common ground around building local capacity to get things done. Figure 6 shows the land ownership of woodlands within the county.

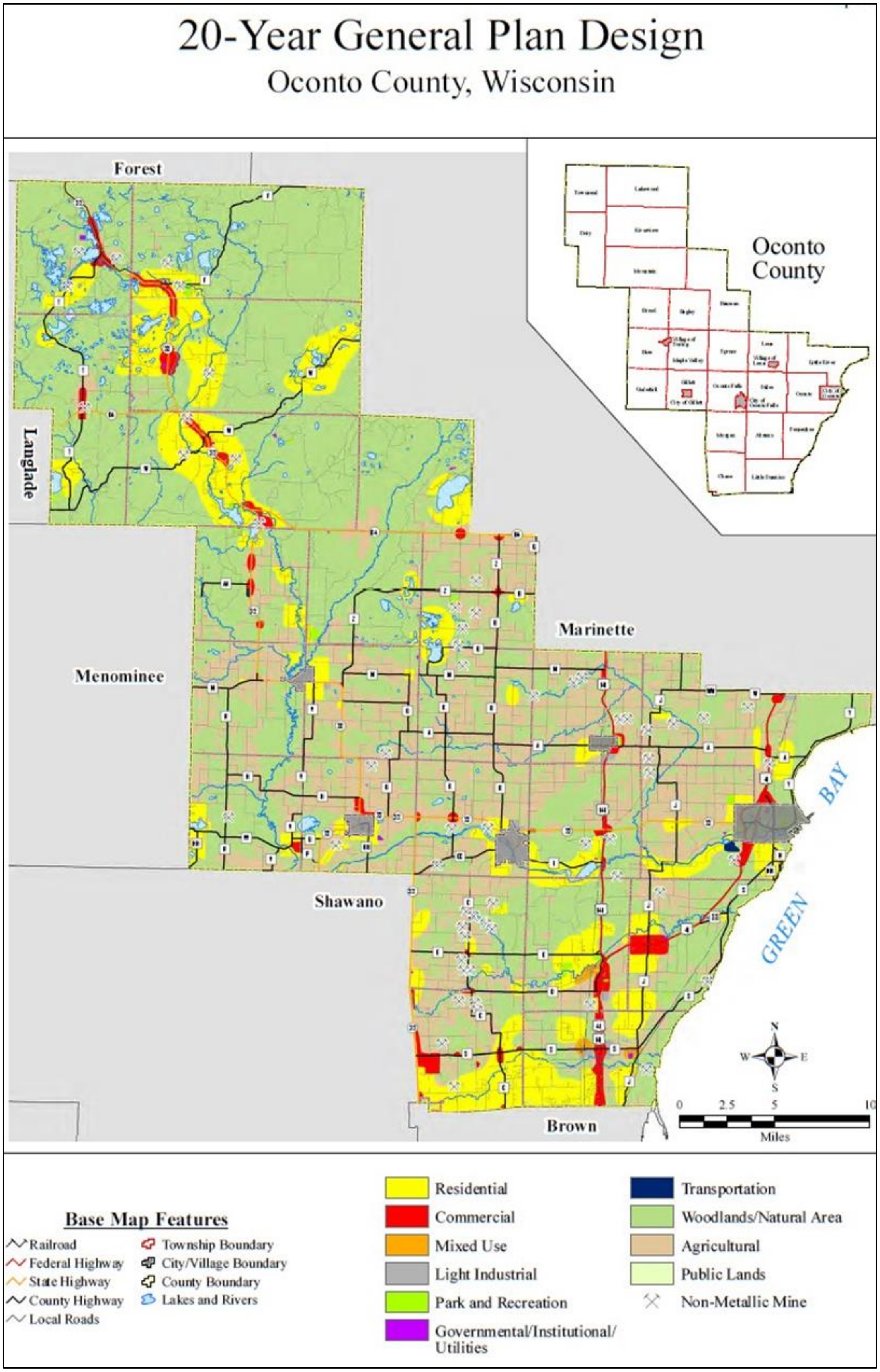


FIGURE 4. PROJECTED DEVELOPMENT IN OCONTO COUNTY (UW EXTENSION, 2022).

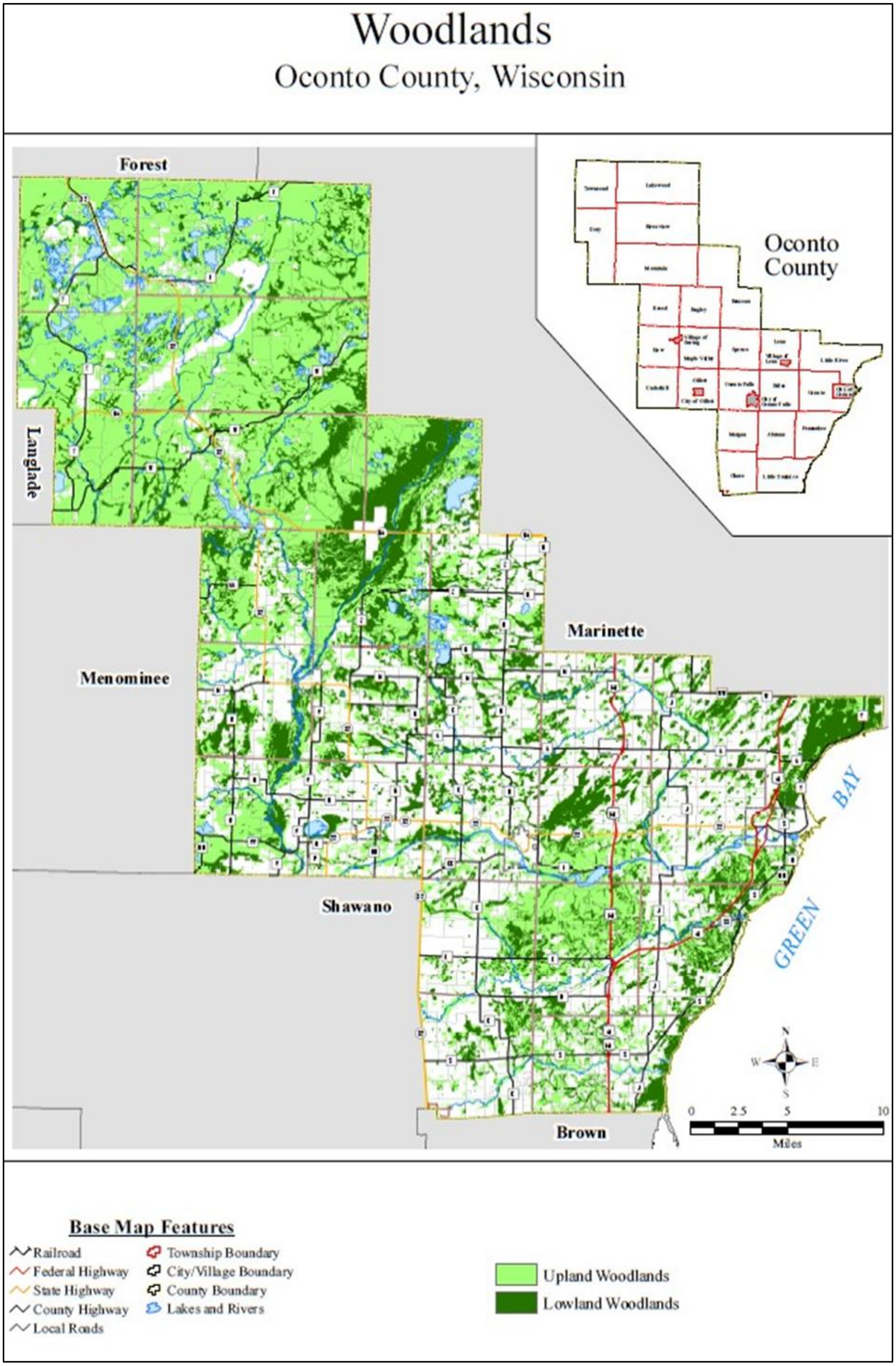


FIGURE 5. 2007 LAND USE INVENTORY OF EXISTING WOODLANDS (UW EXTENSION, 2022).

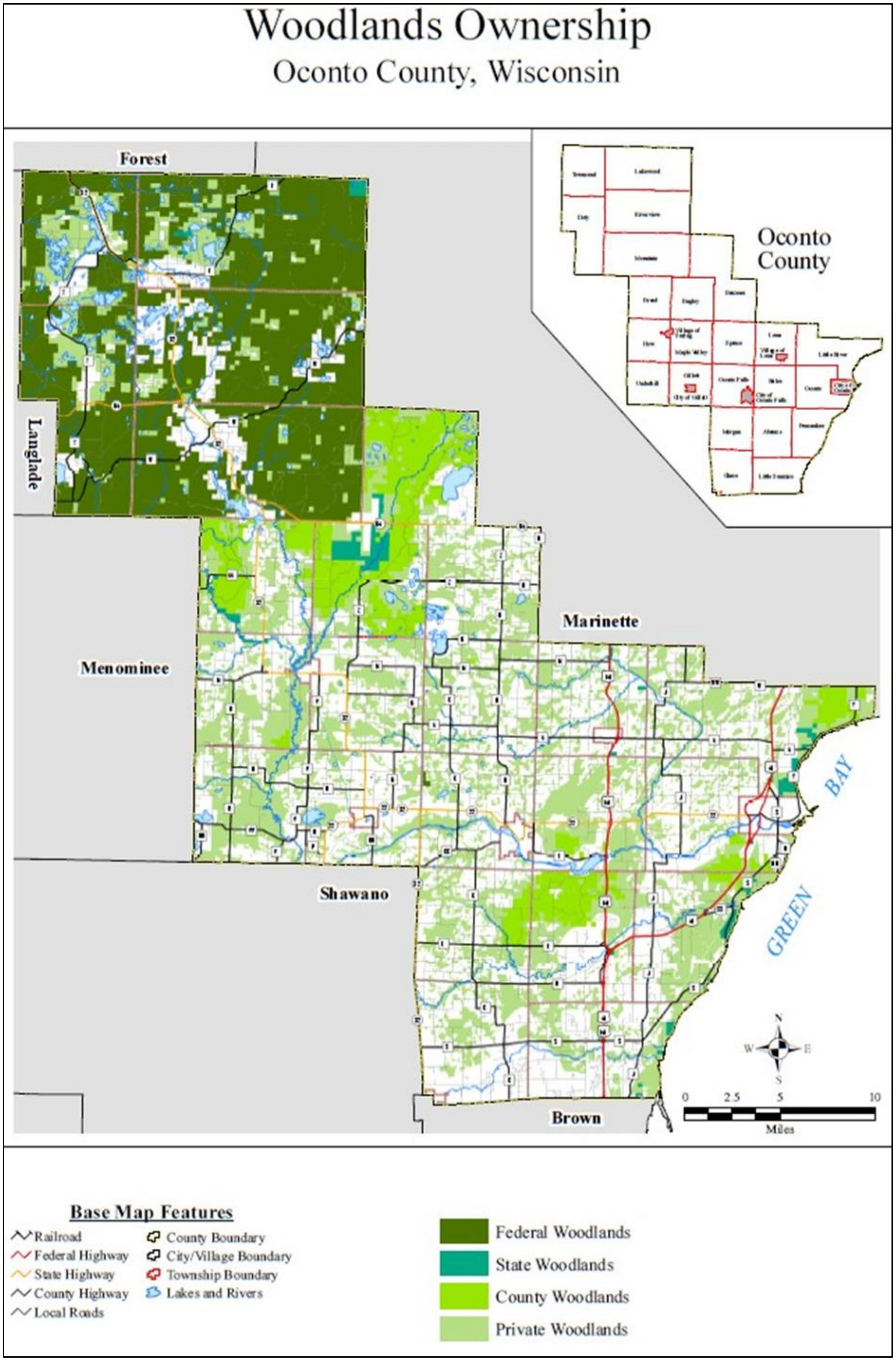


FIGURE 6. LAND OWNERSHIP OF WOODLANDS IN OCONTO COUNTY (UW EXTENSION, 2022).

LAKE AND WATER CHARACTERISTICS

LAKE TYPES

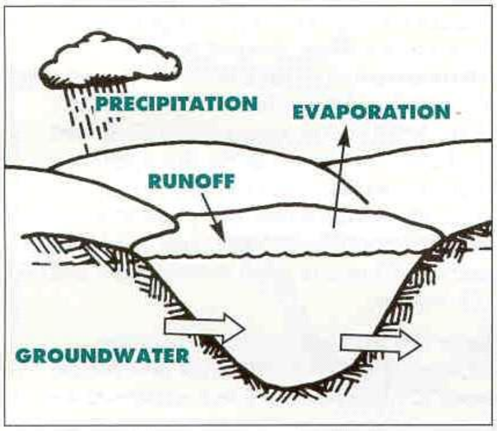
Oconto County lakes are the products of thousands of years of rain falling on the landscape, after the last glacier receded approximately 10,000 years ago. This has created a continuous layer of water below the ground surface, which is visible as lakes when the ground surface is below the top of this "groundwater." Oconto County 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.

How this water enters and leaves the lake provides a way to classify lakes, as well as insight about how a lake responds to contamination and invasive species, and what types of fish can be managed. Water enters lakes through groundwater, runoff across the ground surface that enters the lake directly, or precipitation on the lake surface. The amount of water that enters a lake each year is called a water budget. The total amount of water is important to understanding how long the water spends in a lake. How that water is distributed between Oconto County lakes can be divided into four general categories based on how water enters and leaves the lake: 1) seepage lakes, 2) groundwater drainage lakes, 3) drainage lakes, and 4) impoundments. Figure illustrates the differences between the four lake types (Figure 7).

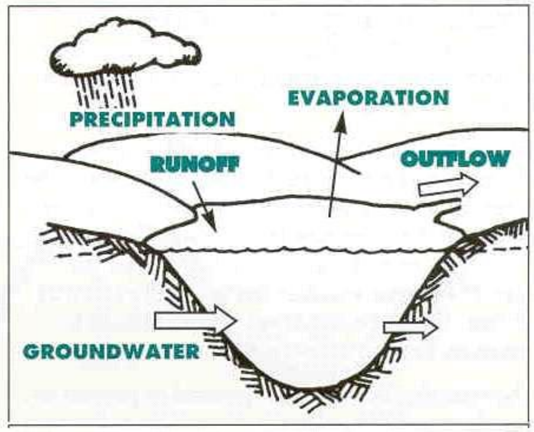
Many of the lakes in Oconto County are **seepage lakes** mostly fed by groundwater and without stream inlets or outlets. These lakes could be formed by the melting ice blocks left behind by the last glacier. When the ice melted, it left a depression in the ground surface that extends below the water table. Water still flows through 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, because the permeability of the ground is variable, 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, although usually a small land area for seepage lakes). Land-use practices on the end of the lake where groundwater enters can influence both the groundwater quality and runoff water quality. Fertilizers and septic systems in these areas can result in nutrient leaching and movement to the lake via groundwater.

Groundwater drainage and drainage lakes have stream outlets where water leaves 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 those for groundwater drainage lakes and are the most important areas impacting water quality. Inlet streams are impacted by both surface runoff and groundwater inflow.

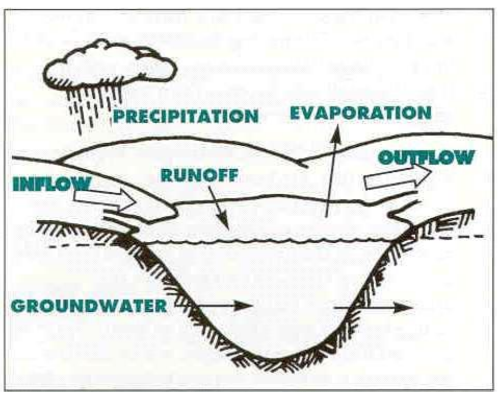
Impoundments are the ponds/lakes created when stream flow is restricted. Impoundments are often created by dams that were installed for other purposes. The primary water source for these lakes is a river, which typically drains a large area of land. Organic material and nutrients are carried into impoundments 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.



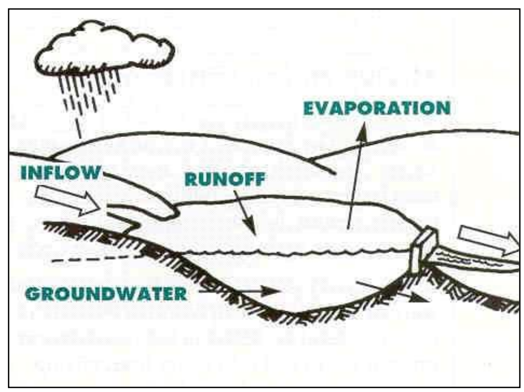
1. SEEPAGE LAKE – a natural lake fed by precipitation, limited runoff and groundwater. It does not have a stream outlet.



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 7. 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 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: 191 years (Quinn, 1992).

Nutrients that accumulate over the 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. This usually reflects the relatively low rate of water input, and therefore a lower rate of nutrient addition. The longer residence time allows a higher fraction of incoming nutrient load to be incorporated into biomass and removed from the water (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 can enter lakes directly or enter streams that drain to lakes. This groundwater can contribute a large percentage of water that enters the lake and thus has an important influence on the lake. For example, the rate of groundwater entry controls the water replacement rate, and groundwater chemistry determines the pH buffering and loading of essential elements, such as calcium and silica (Pint et al., 2006; Kenoyer and Anderson, 1989; Hurley et al., 1985; Krabbenhoeft and Webster, 1995).

This study uses groundwater flow modeling to identify the land area contributing groundwater to Oconto County lakes. Because groundwater is the portion of precipitation that moves through the soil and plant root zone, then moves in the aquifer eventually draining to lakes and streams, the knowledge of that land area that contributes groundwater can be used to estimate the quantity of groundwater entering a lake. With that information, the groundwater contribution of nutrients can also be estimated. This area should be considered an upper bound because this study will use two-dimensional groundwater flow that does not consider the possibility that some groundwater from the contributing area could flow under the lake. This is considered a reasonable approximation in Oconto County because the lakes are largely in relatively permeable glacial outwash or till within a relatively shallow unconfined surficial aquifer. When the lakes are relatively large compared to the aquifer thickness and there are relatively permeable zones near the edge of the lake for groundwater to enter, it is expected that most of the groundwater would move into and through the lake (Hunt et al., 2003; McGinley, 2008).

The groundwater simulation model was developed using GFLOW (Haitjema Software, Version 2.1.2, 2007). This is an analytic element model that uses streams, aquifer properties and groundwater recharge to simulate the water table. Once developed, the model can be used to track the water movement from points in the model backward through time. This tracking feature can be used to identify the area where water passing through the lake would originate. The GFLOW model can then be used to develop a water table map and project corresponding groundwater flow directions by tracking the particles backward from the lake.

The GFLOW model and submodels developed for the Oconto Lake Study was used to identify the groundwater flow direction to the lakes and begin to estimate the groundwater contributing areas for each lake.

Figure 8 illustrates the result, with groundwater flow across the county trending in a northwest to southeast direction, toward the Green Bay. See the complete Groundwater Flow Model Technical Memorandum attached to this report for more information.

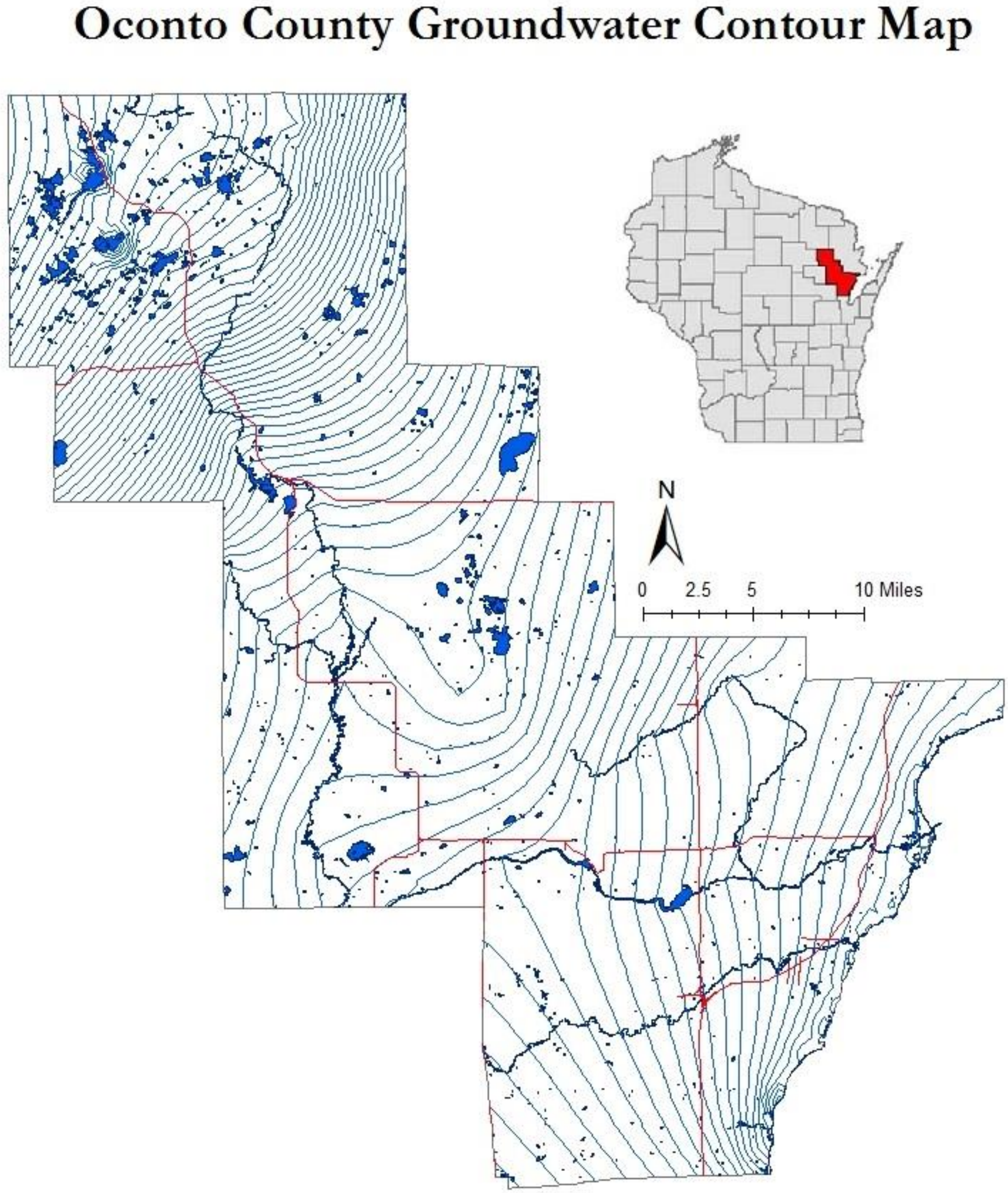


FIGURE 8. OCONTO COUNTY GROUNDWATER CONTOUR MAP. THE GROUNDWATER FLOW DIRECTION IS PERPENDICULAR TO CONTOUR LINES.

MIXING AND LAYERING

Another important characteristic of a lake is the degree of water mixing that occurs (Figure 9). Lakes that mix regularly from top to bottom generally have more uniform temperature and oxygen throughout. 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.

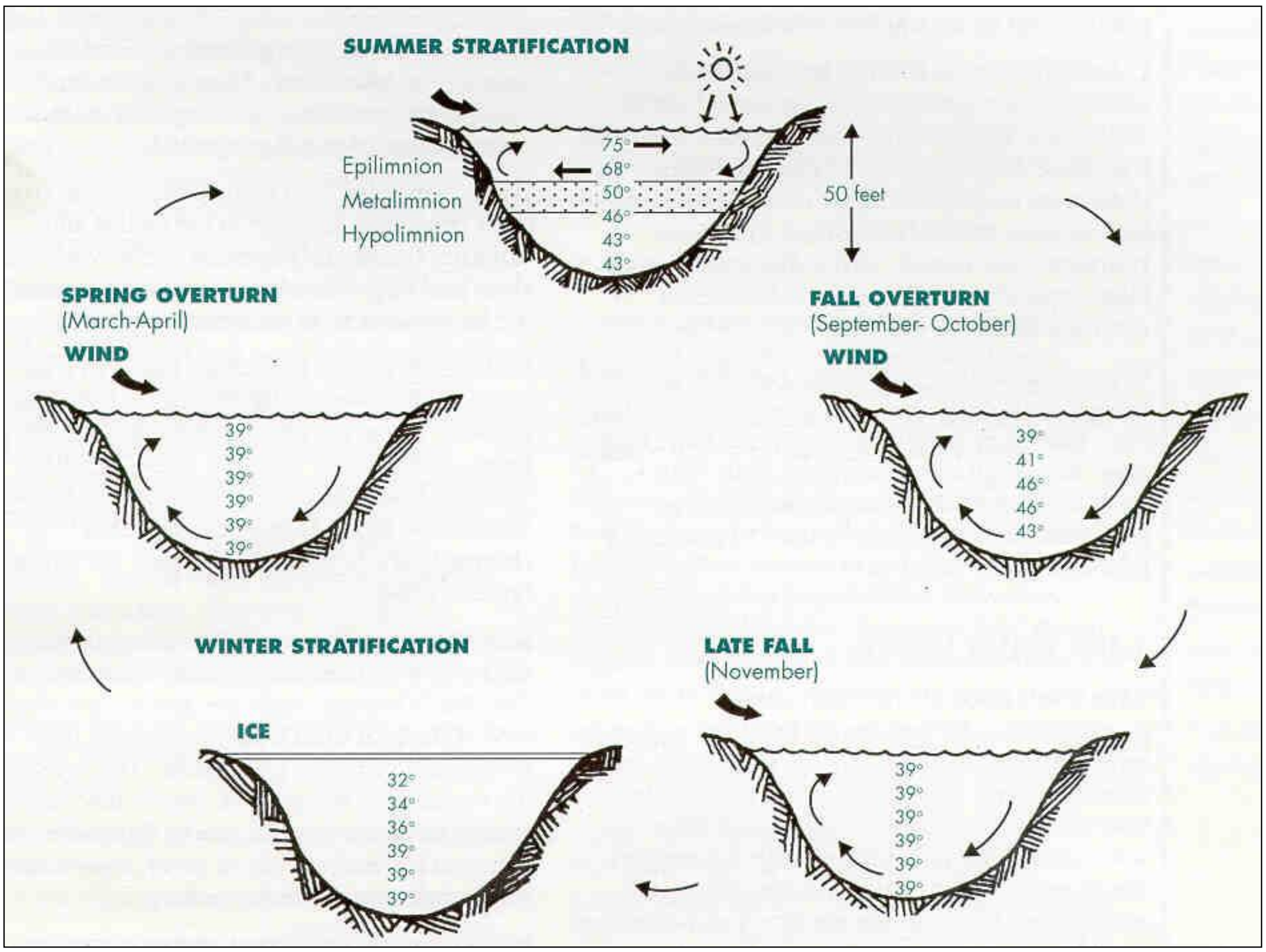


FIGURE 9. SCHEMATIC SHOWING LAKE MIXING AND LAYERING BY SEASON IN A TYPICAL WISCONSIN YEAR (SHAW ET. AL. 2000).

To evaluate how mixing varies within Oconto 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.

The temperature ratios show mixing differences among the lakes. 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 2. Oconto County Study lakes listed by lake type

These categories relate to the Wisconsin State phosphorus standards.

TABLE 2. OCONTO COUNTY STUDY LAKES LISTED BY LAKE TYPE

Shallow Seepage (Mixed)	Deep Seepage (Stratified)	Shallow Drainage (Mixed)	Deep Drainage (Stratified)
Bear Paw Lake Green Lake Long Lake (Brazeau) Moody Lake Nelligan Lake Pickerel Lake (Brazeau) Star Lake Surprise Lake White Potato Lake Yankee Lake	Bass Lake Boot Lake Chain Lake Finnegan Lake Grindle Lake Halfmoon Lake Paya Lake Pecor Lake Pine Ridge Lake Ranch Lake Rost lake Shay Lake Sunrise Lake Underwood Lake Waubee Lake Wescott Lake	Bass Lake (Riverview) Bear Lake Boulder Lake Boundary Lake Christie Lake Gilkey Lake Lake John Machickanee Flowage Mary Lake Munger Lake Pickerel Lake (Townsend) Shadow Lake Smoke Lake Ucil Lake	Anderson Lake Cooley Lake Crooked Lake Grignon Lake Leigh Flowage Little Pickerel Maiden Lake Oconto Falls Pond Porcupine Lake Round Lake White Lake Wiscobee Lake

WATER QUALITY

Different processes influence the water quality of different sources of water. 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 and 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.

DISSOLVED OXYGEN

Dissolved oxygen is essential to most aquatic organisms. Oxygen enters lake water by contact with the atmosphere and is also produced by algae and aquatic plants. Microorganisms consume oxygen as the decompose plant and animal matter. During periods when oxygen is not being replenished, dissolved oxygen concentrations drop. Winter ice cover is one such period, particularly in lakes without inflowing streams.

TABLE 3. MINIMUM DEPTH OF LAKE WATER WITH DISSOLVED OXYGEN CONCENTRATIONS LESS THAN 5 MG/L DURING THE OCONTO COUNTY LAKE STUDY (2016-2024).

Lake Name	Minimum Depth (feet) of water with dissolved oxygen <5 mg/L	Lake Name	Minimum Depth (feet) of water with dissolved oxygen <5 mg/L
White Potato Lake	0	Grindle Lake	9
Little Pickerel Lake	0	Machickanee Flowage	9
Pickerel Lake (Townsend)	0	Shay Lake	9
Smoke Lake	0	Long Lake (Brazeau)	10
Chain lake	0	Nelligan Lake	12
Finnegan Lake	0	Oconto Falls Pond	12
Pickerel Lake (Brazeau)	0	Surprise Lake	12
Moody Lake	0	Wiscobee Lake	12
Round Lake	0	Anderson Lake	13
Christie Lake	2	Boundary Lake	13
Pecor Lake	3	Star Lake	13
Cooley Lake	3	Paya Lake	14
Porcupine Lake	3	Mary Lake	14
Boulder Lake	4	Waubee Lake	14
Gilkey Lake	4	Underwood Lake	17
Bass Lake (Riverview)	5	Pine Ridge lake	18
Bear Lake	5	Rost Lake	18
Green Lake	5	Sunrise Lake	18
Munger Lake	5	White Lake	22
Grignon Lake	6	Halfmoon Lake	20
Shadow Lake	6	Ranch Lake	23
Bear Paw Lake	7	Leigh Flowage	24
Lake John	7	Bass Lake	25
Ucil Lake	7	Boot Lake	25
Wescott Lake	7	Crooked Lake	28
Yankee Lake	8	Maiden Lake	30

When lakes are stratified, water at the bottom of the lake cannot be replenished with dissolved oxygen from the atmosphere or by plants growing in shallow depths. This anoxic (low oxygen) water releases nutrients from bottom sediments that eventually blend into upper waters during mixing. Lakes with water volumes of dissolved oxygen less than 5 mg/L may be prone to winter fish kills during long winters with snow/ice cover. The minimum water depth with dissolved oxygen concentrations of 5 mg/L or less during the lake study are displayed in Table 3.

WATER CLARITY

Water clarity is measured by observing the depth that a black and white disc can be seen when suspended 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 it can even change by the hour, depending upon season, weather, and motorized boating.

Average water clarity data for lakes in the Oconto County Lakes Study are summarized in Figures 10 and 11. 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 1970s is available for some lakes in Oconto County. The data were collected by citizens, consultants, and WDNR staff.

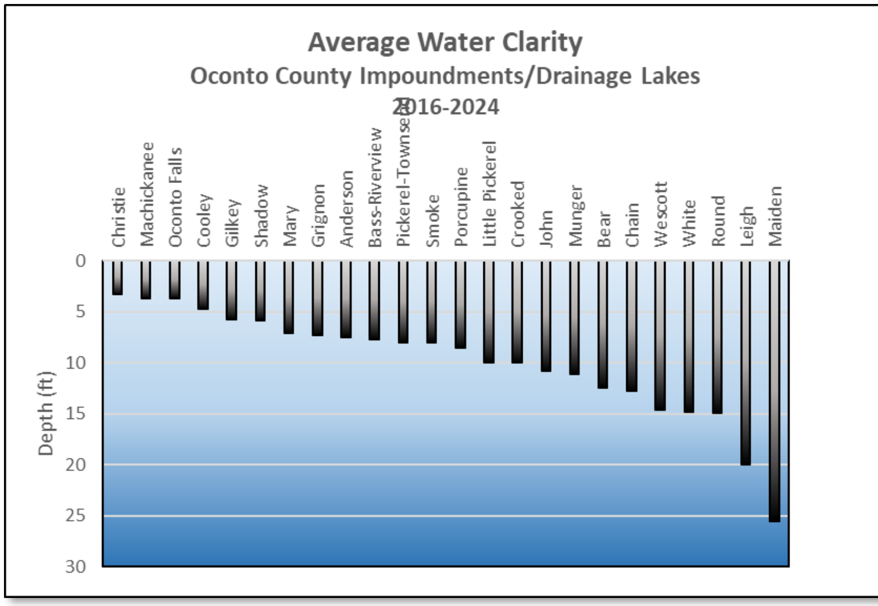


FIGURE 10. AVERAGE WATER CLARITY IN OCONTO COUNTY IMPOUNDMENTS AND DRAINAGE LAKE TYPES, 2016-2024.

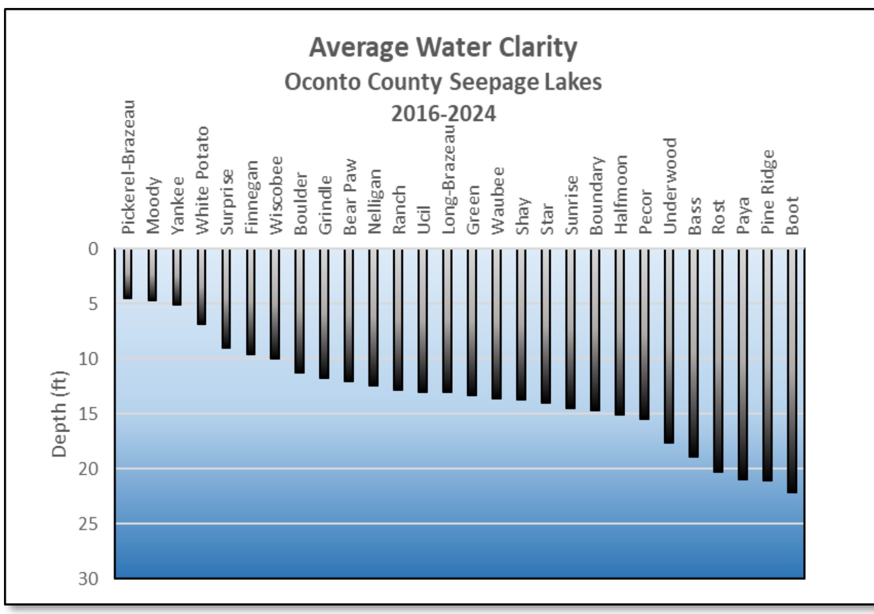


FIGURE 11. AVERAGE WATER CLARITY IN OCONTO COUNTY SEEPAGE AND SPRING-FED LAKE TYPES, 2016-2024.

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, macroinvertebrates, and small fish). High concentrations of calcium or iron in lake water can reduce the availability of phosphorus for algae growth. Algae form the base of a lake's food web but given the right conditions can grow to nuisance populations. 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 1.00 – 27.6 µg/L (Figure 12). 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.

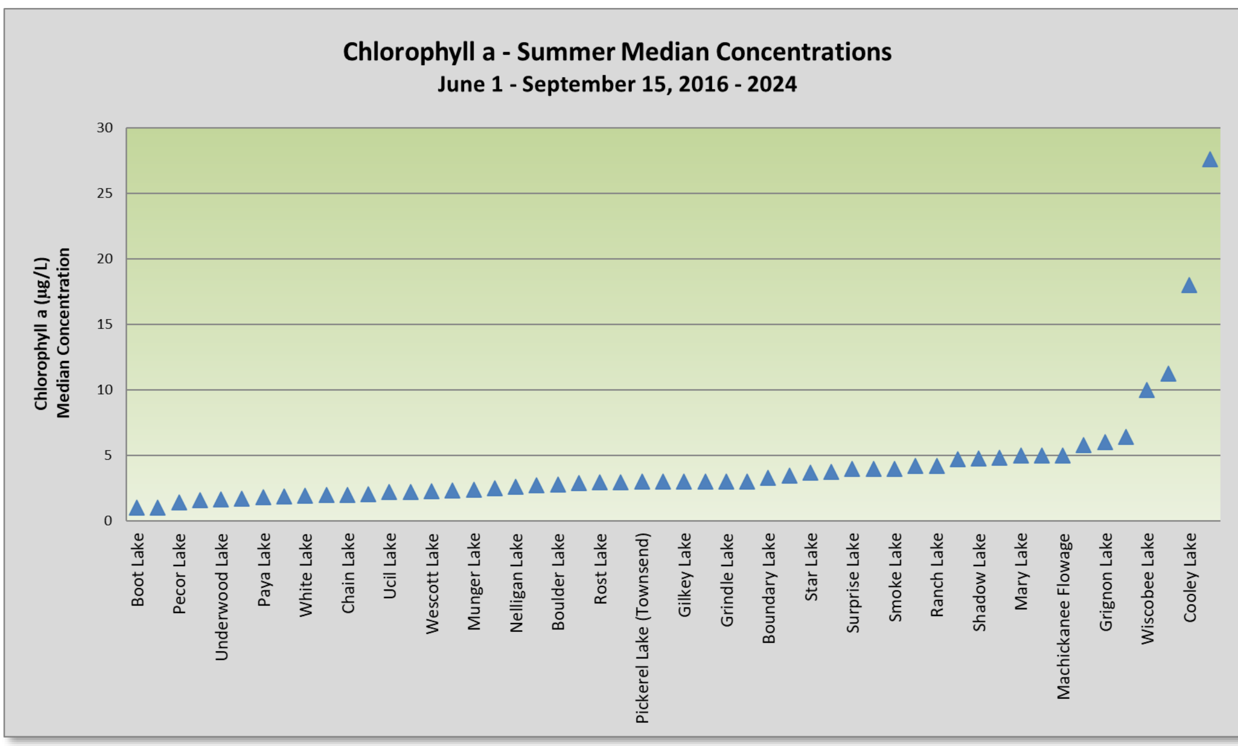


FIGURE 12. MEDIAN SUMMER CONCENTRATIONS OF CHLOROPHYLL-A (µG/L) IN OCONTO COUNTY LAKES (2016-2024).

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 3). 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 4).

Phosphorus is primarily transported to lakes in surface runoff. Phosphorus adheres to soil particles, so it 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 (like from septic drainfields or 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.

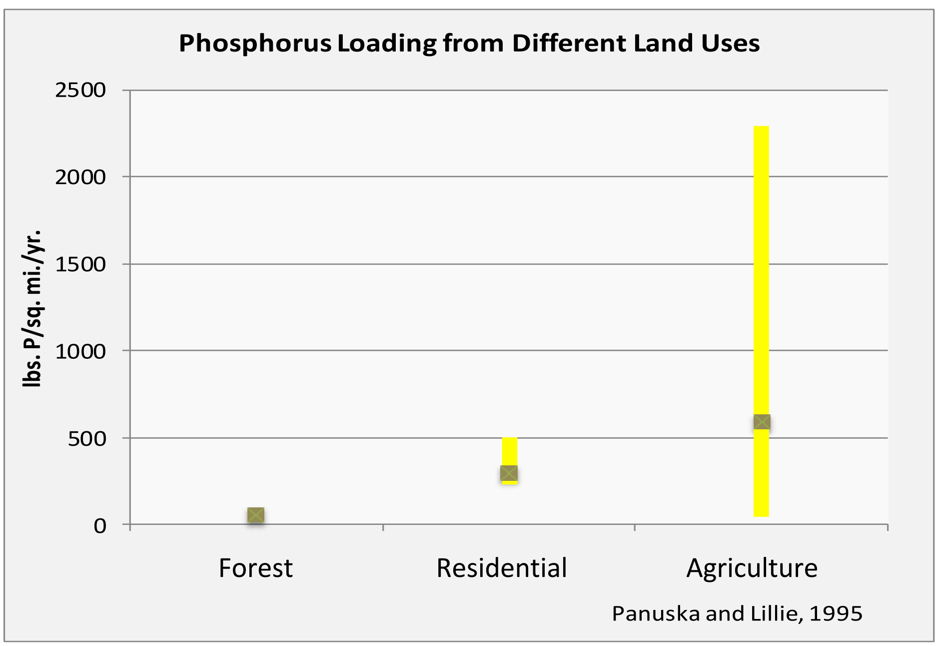


FIGURE 13. RANGE OF MEASURED PHOSPHORUS LOADING FROM DIFFERENT LAND-USES IN WISCONSIN. MEDIAN LOADS ARE REPRESENTED BY THE BROWN MARKERS (PANUSKA AND LILLIE, 1995).

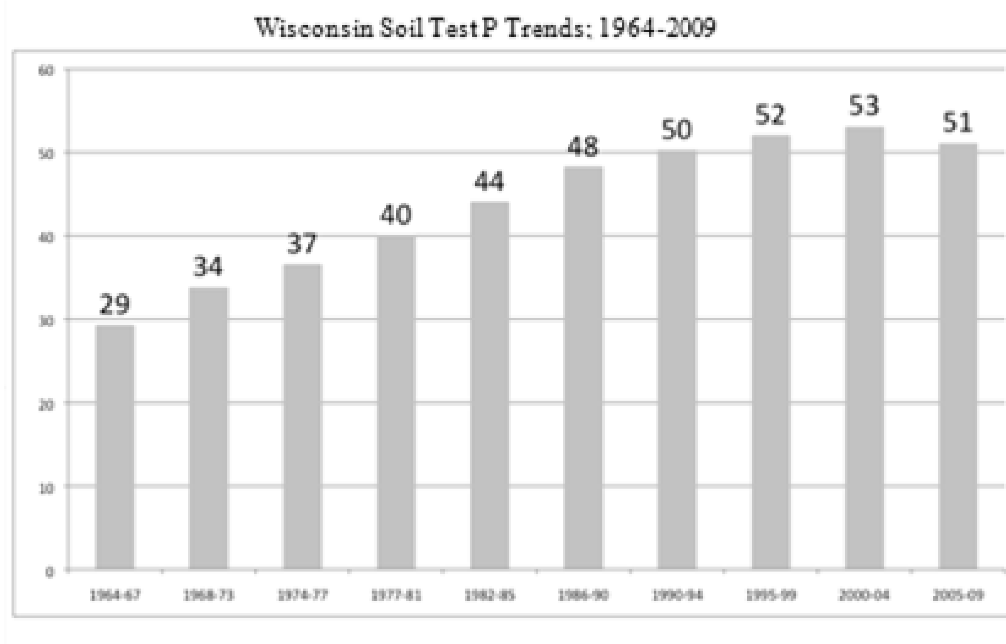


FIGURE 14. SOIL TEST PHOSPHORUS RESULTS (PPM) FROM WISCONSIN SOILS 1964-2009 (PETERS, 2011).

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 5).

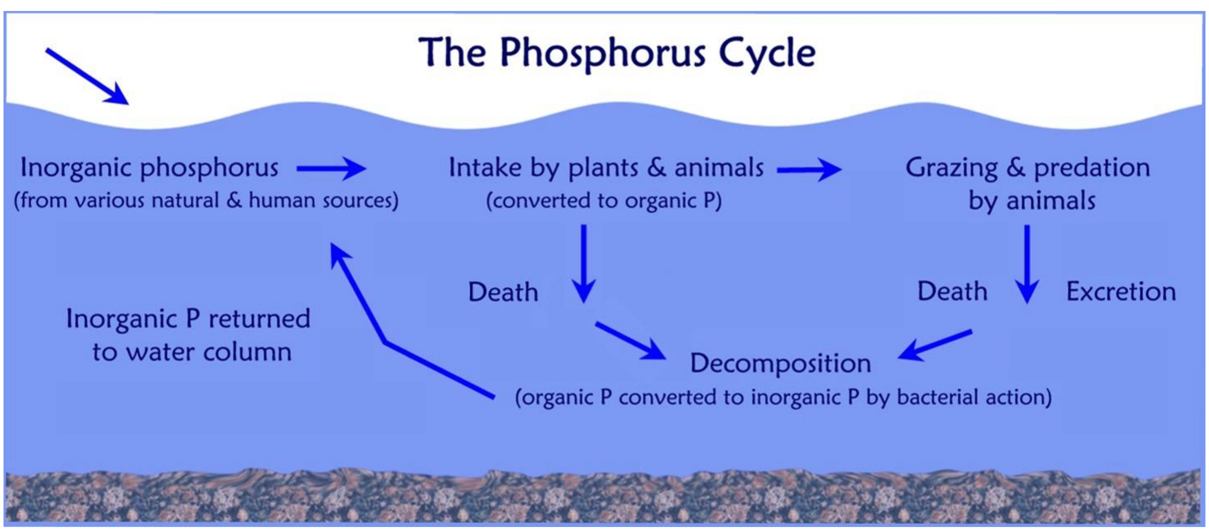


FIGURE 15. SCHEMATIC DEMONSTRATING PHOSPHORUS CYCLING WITHIN A LAKE.

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 4. 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 4. 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 each two-year lake study, total phosphorus was analyzed in the Oconto County lakes eight times/year between fall 2016 and fall 2024; 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 6 - Figure 20.

While occasional samples may have had concentrations above the phosphorus criteria, based on median concentrations for each year, only Machickanee Flowage, Oconto Falls Pond, Cooley Lake and Porcupine Lake **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.

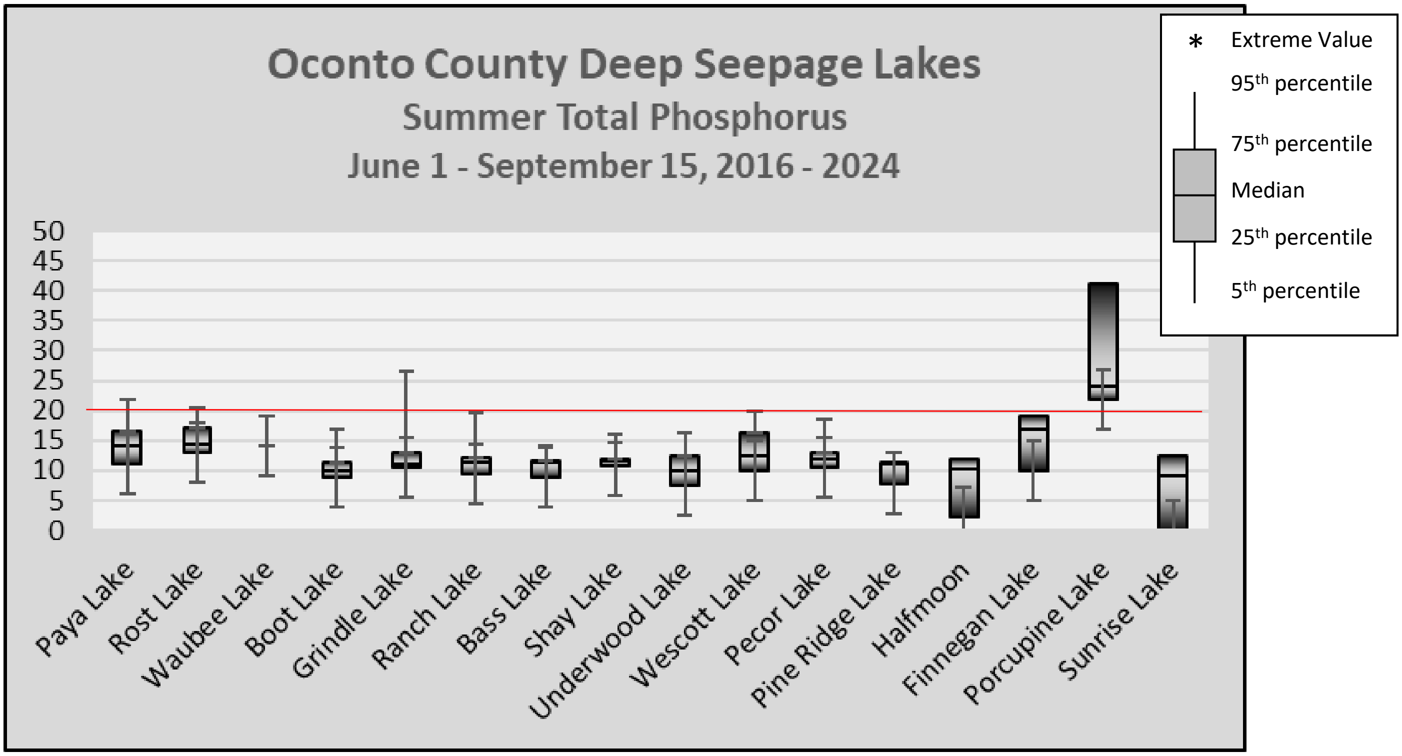


FIGURE 16. SUMMER TOTAL PHOSPHORUS CONCENTRATIONS IN DEEP SEEPAGE LAKES IN OCONTO COUNTY LAKES STUDY, 2016-2024.

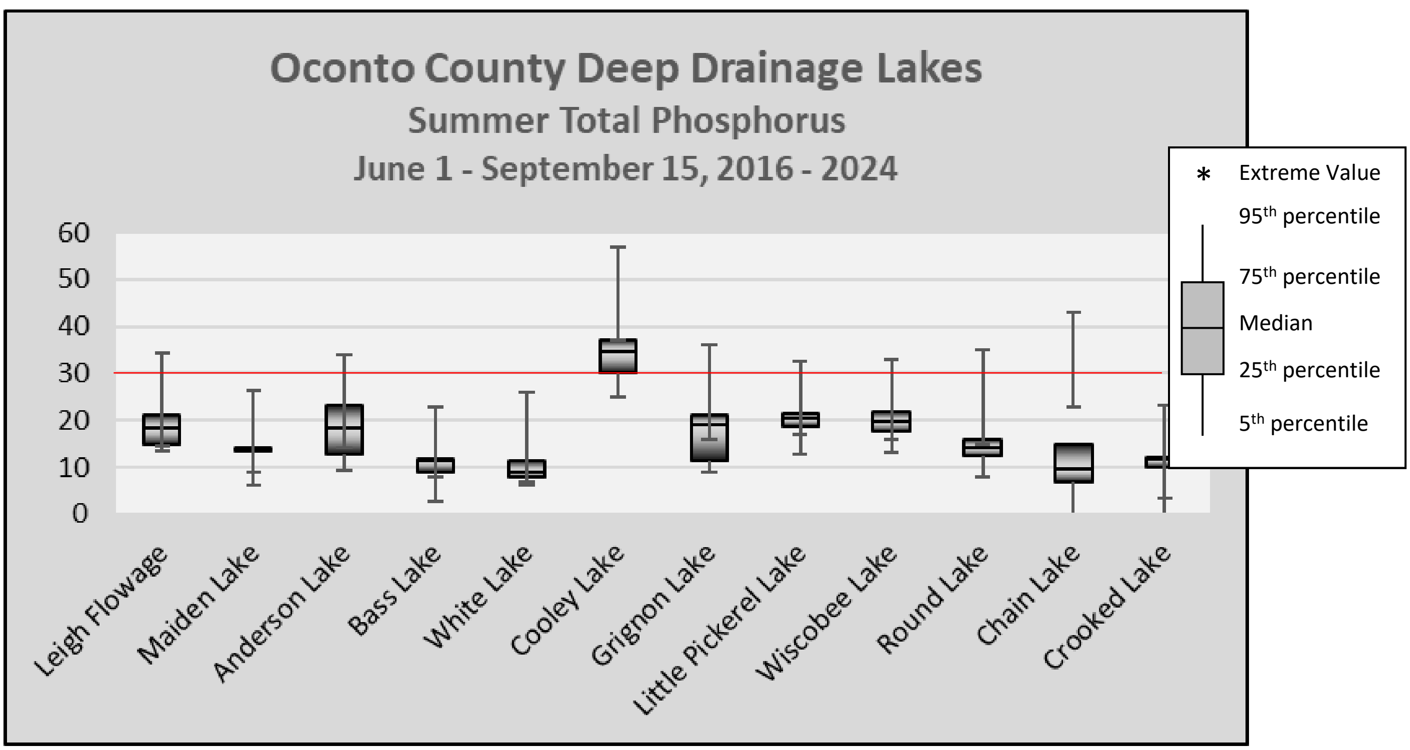


FIGURE 17. SUMMER TOTAL PHOSPHORUS CONCENTRATIONS IN DEEP DRAINAGE LAKES IN THE OCONTO COUNTY LAKES STUDY, 2016-2024.

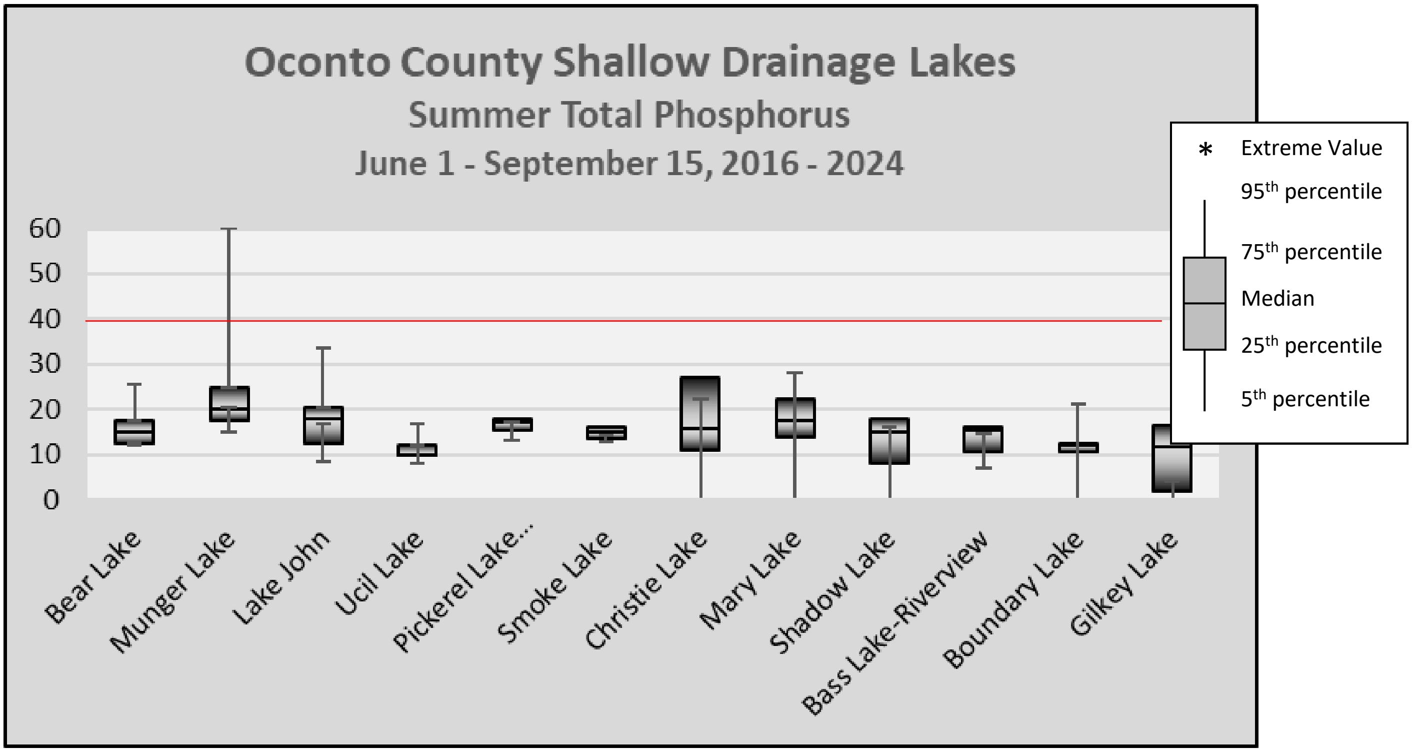


FIGURE 18. SUMMER TOTAL PHOSPHORUS CONCENTRATIONS IN SHALLOW DRAINAGE LAKES IN THE OCONTO COUNTY LAKES STUDY, 2016-2024.

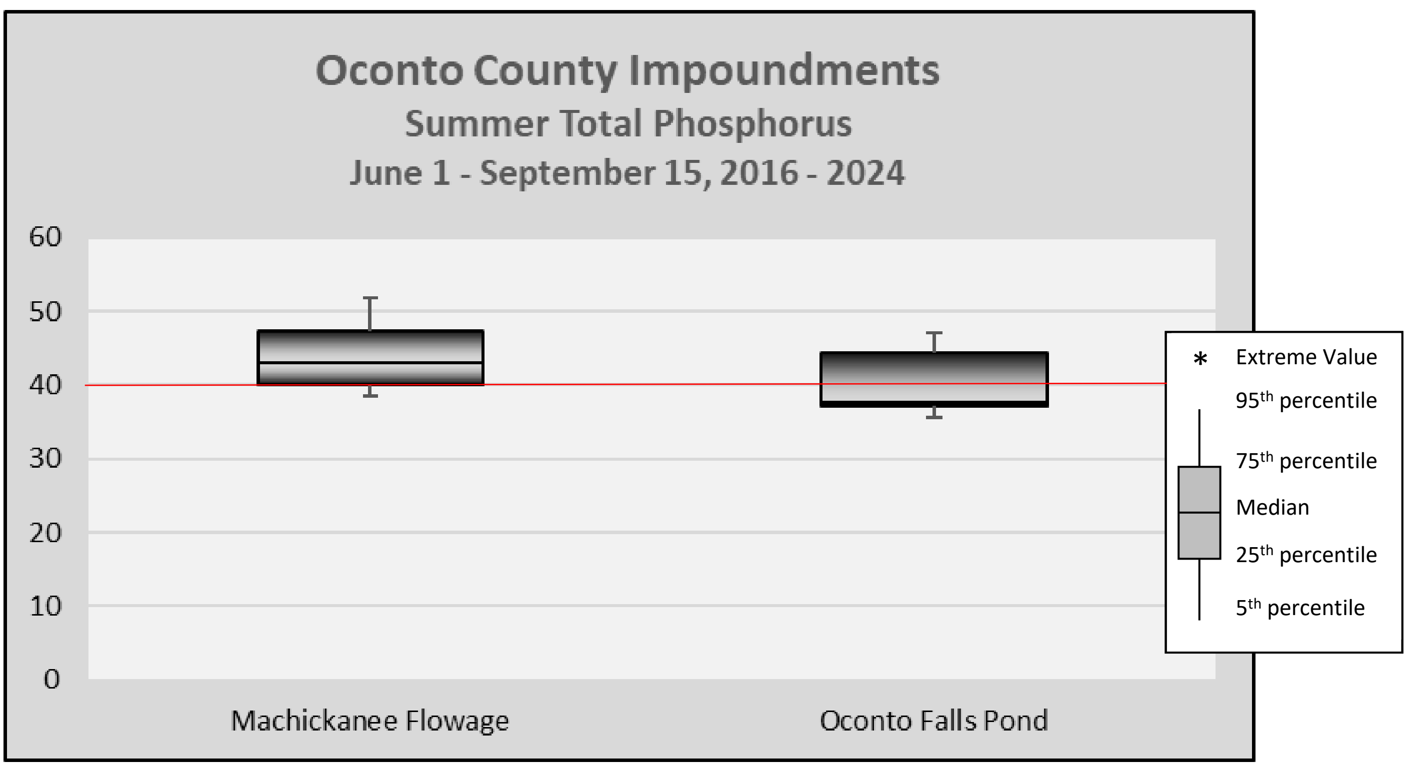


FIGURE 19. SUMMER TOTAL PHOSPHORUS CONCENTRATIONS IN IMPOUNDMENTS IN THE OCONTO COUNTY LAKES STUDY, 2016-2024.

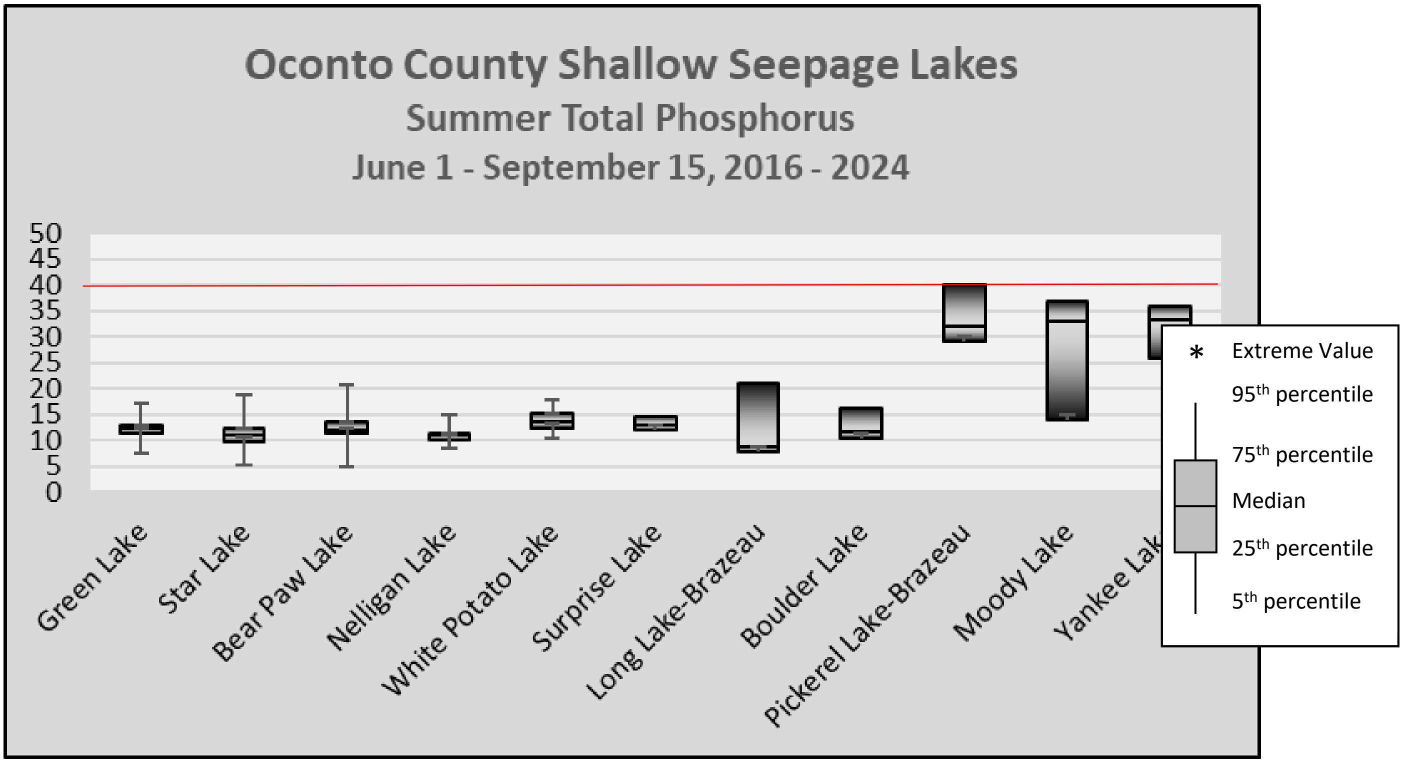


FIGURE 20. SUMMER TOTAL PHOSPHORUS CONCENTRATIONS IN SHALLOW SEEPAGE LAKES IN THE OCONTO COUNTY LAKES STUDY, 2016-2024.

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/agricultural fertilizers.

Nitrogen enters and exits lakes in many forms. The most common forms include ammonium (NH4+), nitrate (NO3-), and organic nitrogen bound up in plant and animal tissues. Aquatic plants and algae can readily use inorganic forms of nitrogen (NH4+, NO2-, NO3-). 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 21.

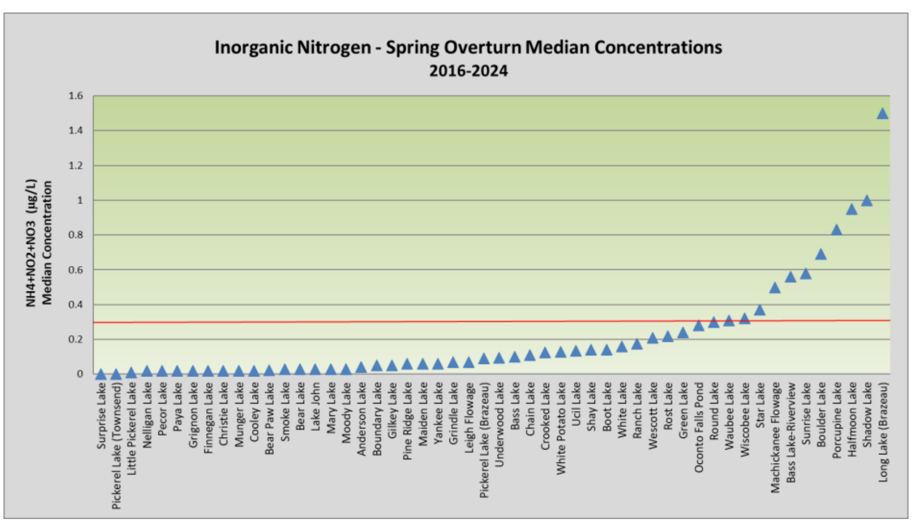


FIGURE 21. AVERAGE CONCENTRATIONS OF INORGANIC NITROGEN (MG/L) DURING THE SPRING. OCONTO COUNTY LAKES STUDY, 2016-2024.

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 22 - Figure 25. (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.)

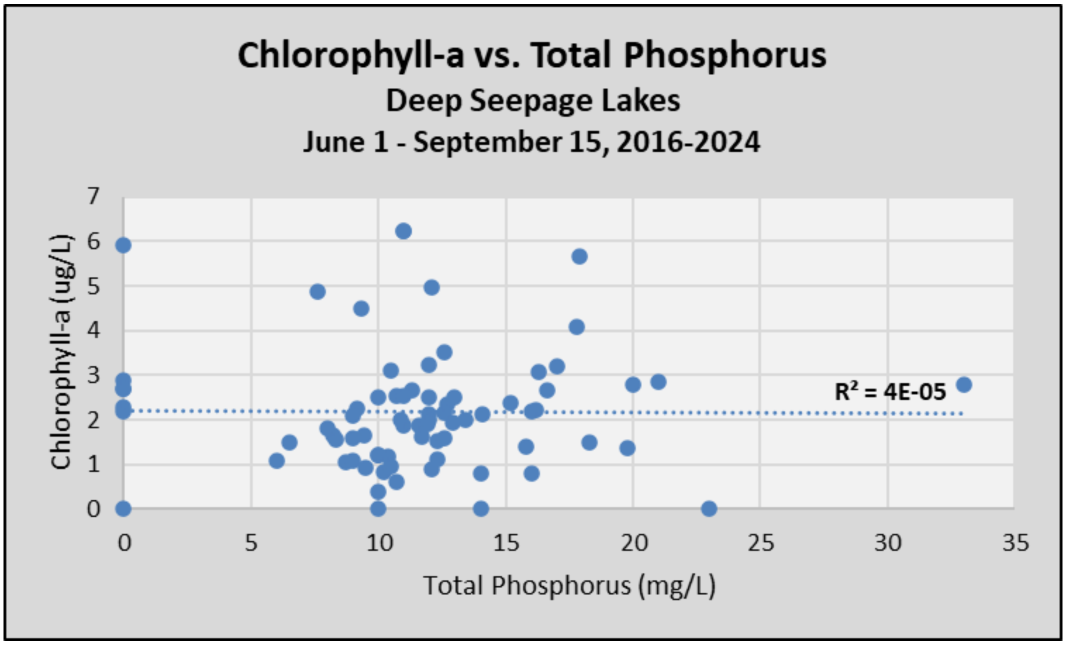


FIGURE 22. CHLOROPHYLL-A AND PHOSPHORUS CONCENTRATIONS (MG/L) IN SAMPLES COLLECTED FROM DEEP SEEPAGE AND SPRING LAKE TYPES IN OCONTO COUNTY. SUMMER 2016-2024.

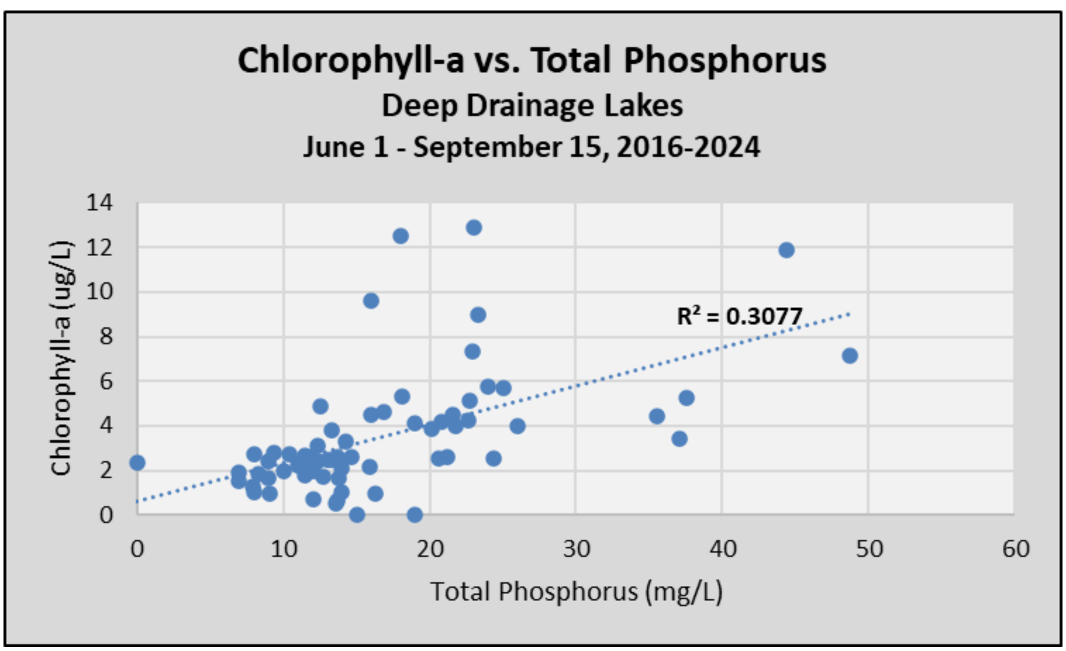


FIGURE 23. CHLOROPHYLL-A AND PHOSPHORUS CONCENTRATIONS (MG/L) IN SAMPLES COLLECTED FROM DEEP DRAINAGE LAKE TYPES IN OCONTO COUNTY. SUMMER 2016-2024.

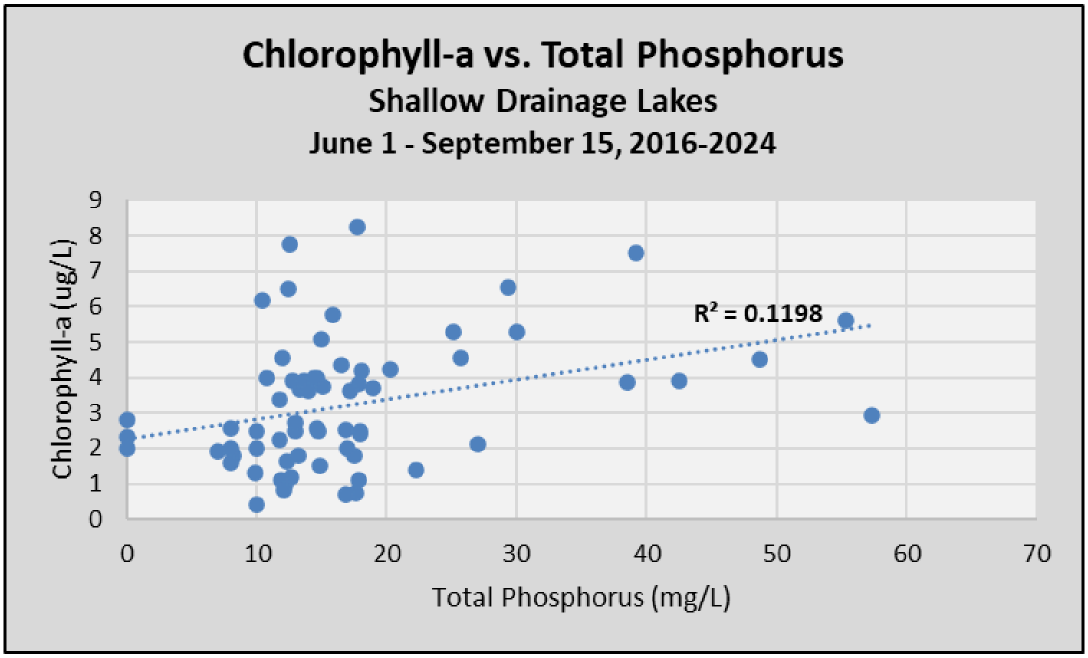


FIGURE 24. CHLOROPHYLL-A AND PHOSPHORUS CONCENTRATIONS (MG/L) IN SAMPLES COLLECTED FROM SHALLOW DRAINAGE LAKE TYPES IN OCONTO COUNTY. SUMMER 2016-2024.

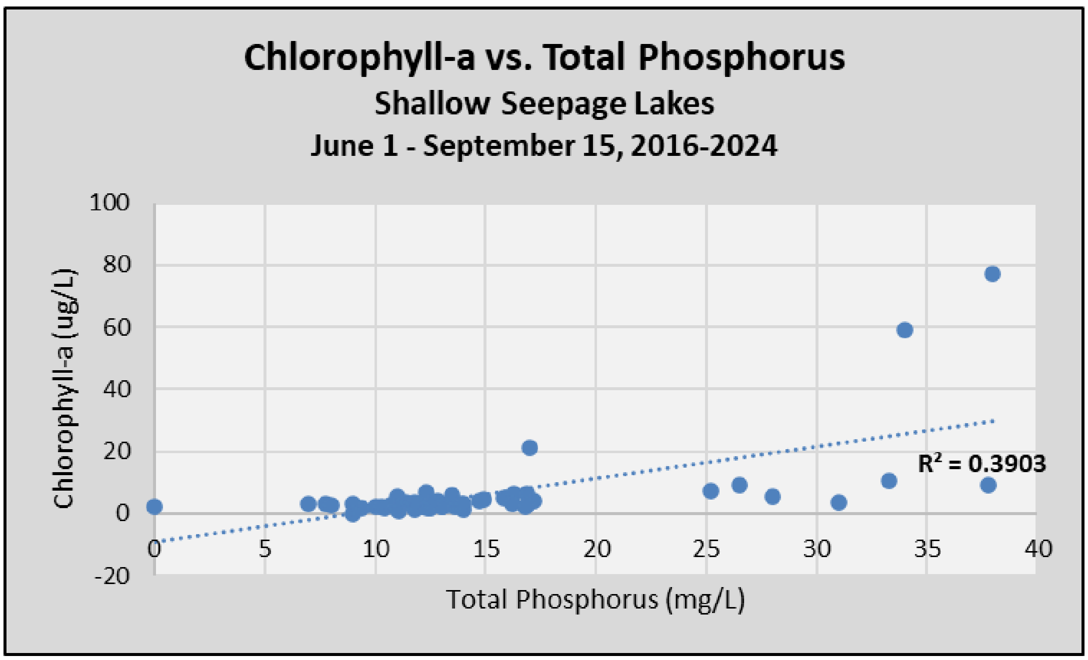


FIGURE 25. CHLOROPHYLL-A AND PHOSPHORUS CONCENTRATIONS (MG/L) IN SAMPLES COLLECTED FROM SHALLOW SEEPAGE LAKE TYPES IN OCONTO COUNTY. SUMMER 2016-2024.

HARDNESS

The types and amounts of minerals in a lake depend upon the watershed's geology and how the water travels to the lake. In Oconto 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 groundwater to 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 11 to 282 mg/L (Figure 26). In general, lakes with softer water show a greater response by algae to inputs of phosphorus.

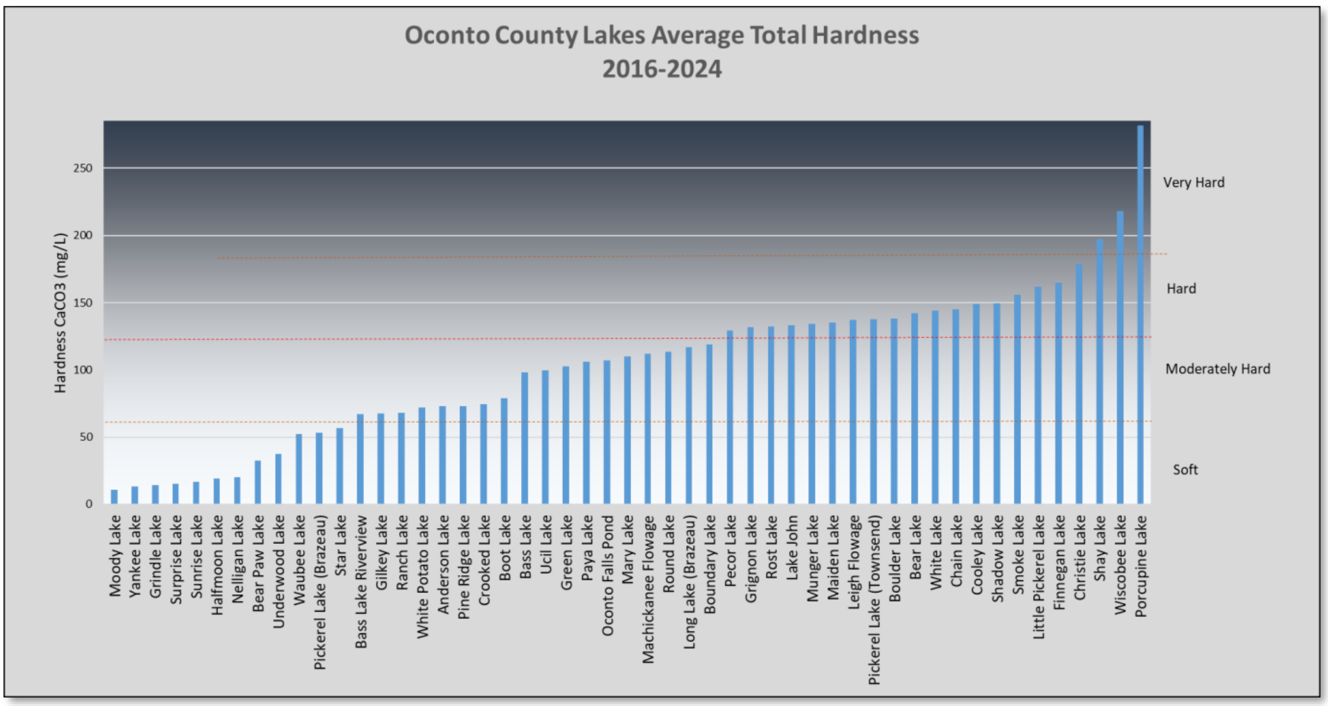


FIGURE 26. AVERAGE TOTAL HARDNESS CONCENTRATIONS (MG/L) MEASURED IN OCONTO COUNTY LAKES IN SPRING AND FALL OVERTURN SAMPLES (2016-2024).

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 exist in Oconto County lakes, ranging from 0 mg/L in Grindle, Halfmoon, Pickerel-Brazeau, Boulder, Mary, Surprise and Yankee Lake, to elevated concentrations of 30+ mg/L in Christie, Green and White Potato Lake (Figure 27). Sodium concentrations also had a wide range of 0.4 in Halfmoon Lake to 19.8 mg/L Green Lake (Figure 28). 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 29).

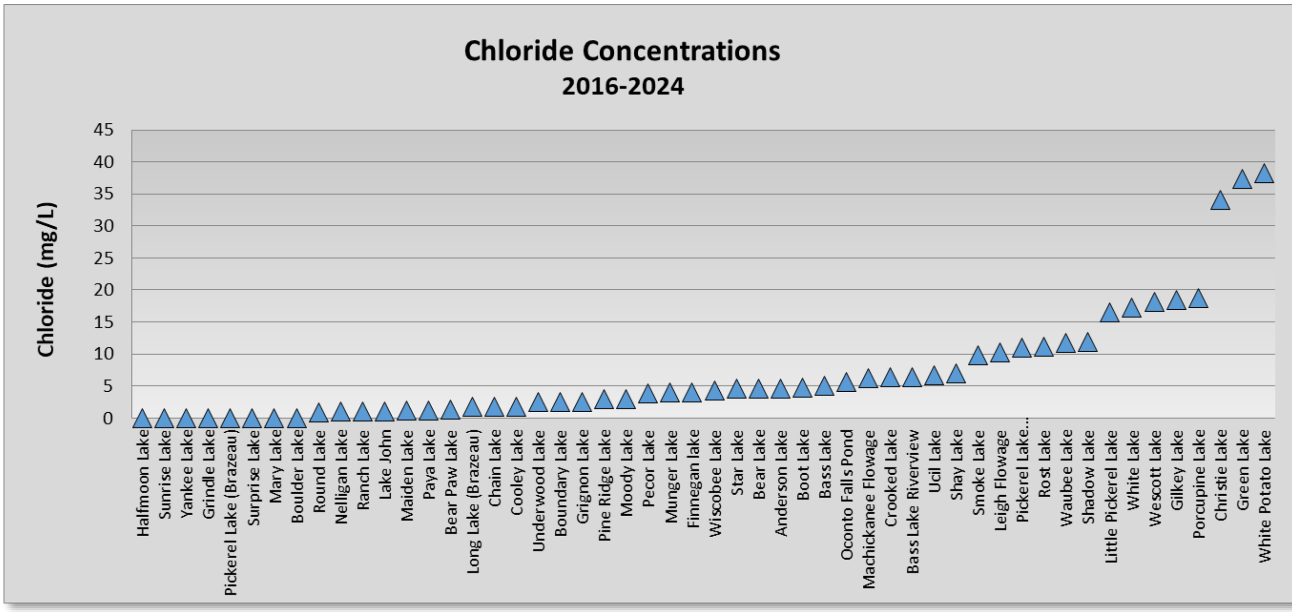


FIGURE 27. AVERAGE SPRING AND FALL OVERTURN CHLORIDE CONCENTRATIONS (MG/L) IN OCONTO COUNTY LAKES, (2016-2024).

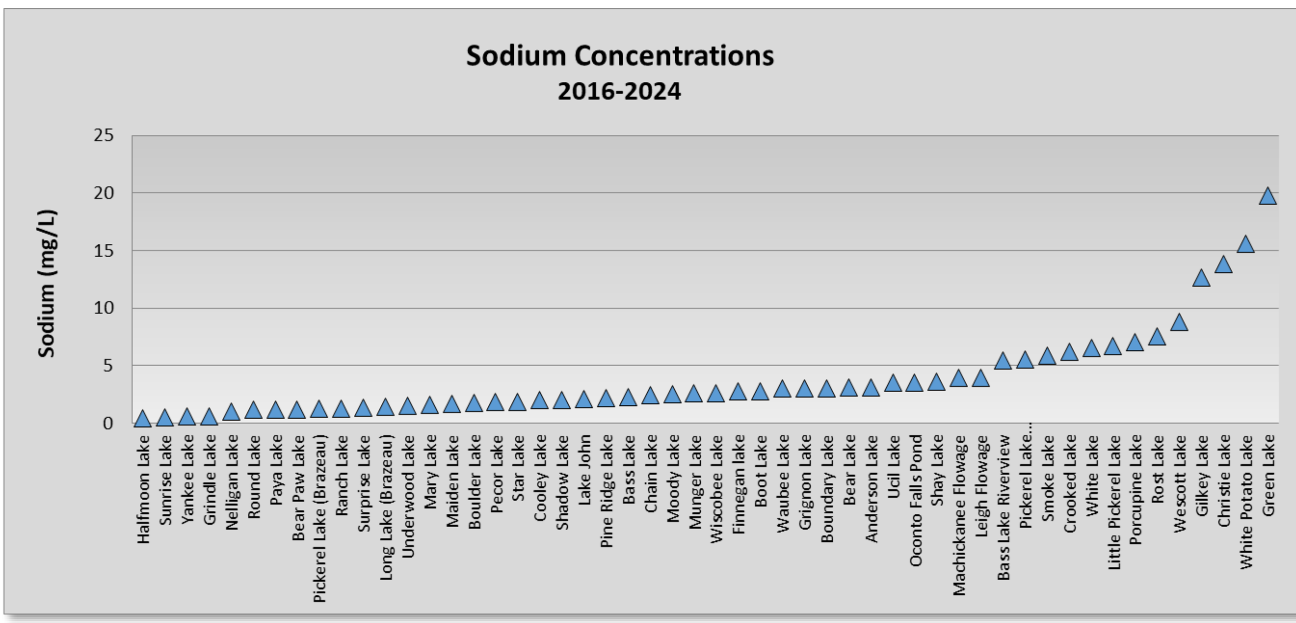


FIGURE 28. AVERAGE SPRING AND FALL OVERTURN SODIUM CONCENTRATIONS (MG/L) IN OCONTO COUNTY LAKES (2016-2024).

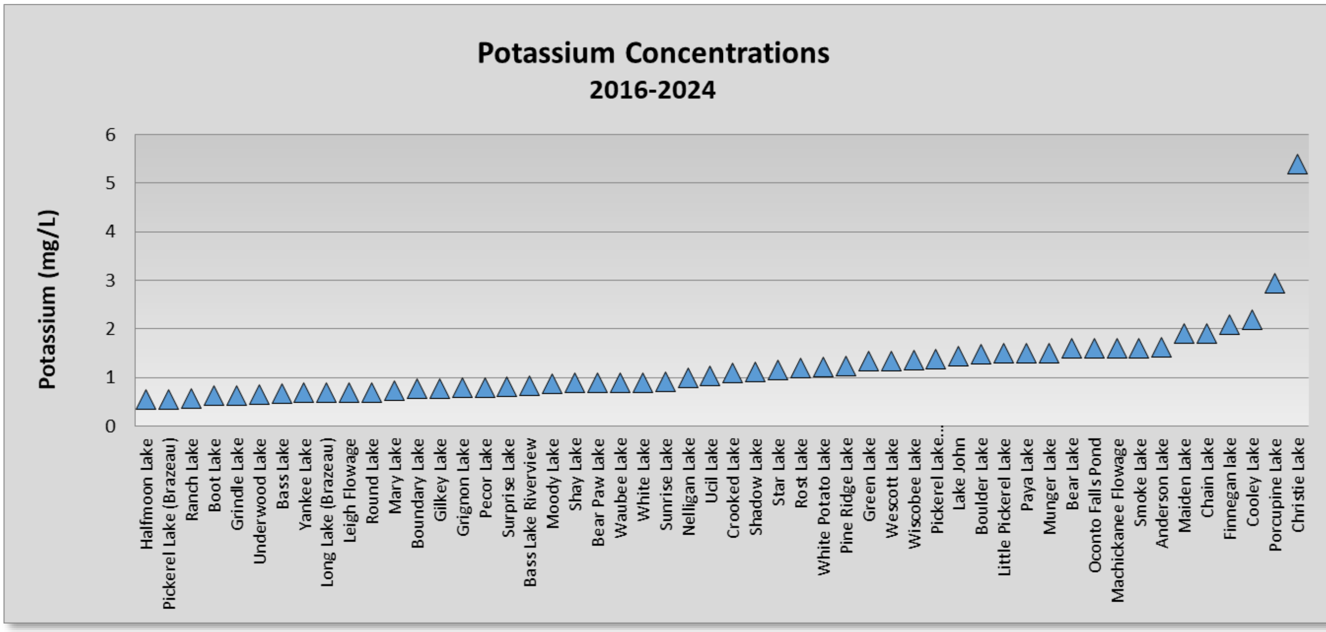


FIGURE 29. AVERAGE SPRING AND FALL OVERTURN POTASSIUM CONCENTRATIONS (MG/L) IN OCONTO COUNTY LAKES (2016-2024).

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 an 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 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 Oconto County study lakes. The number of aquatic plant species identified in each Oconto County lake is shown in Figure 30.

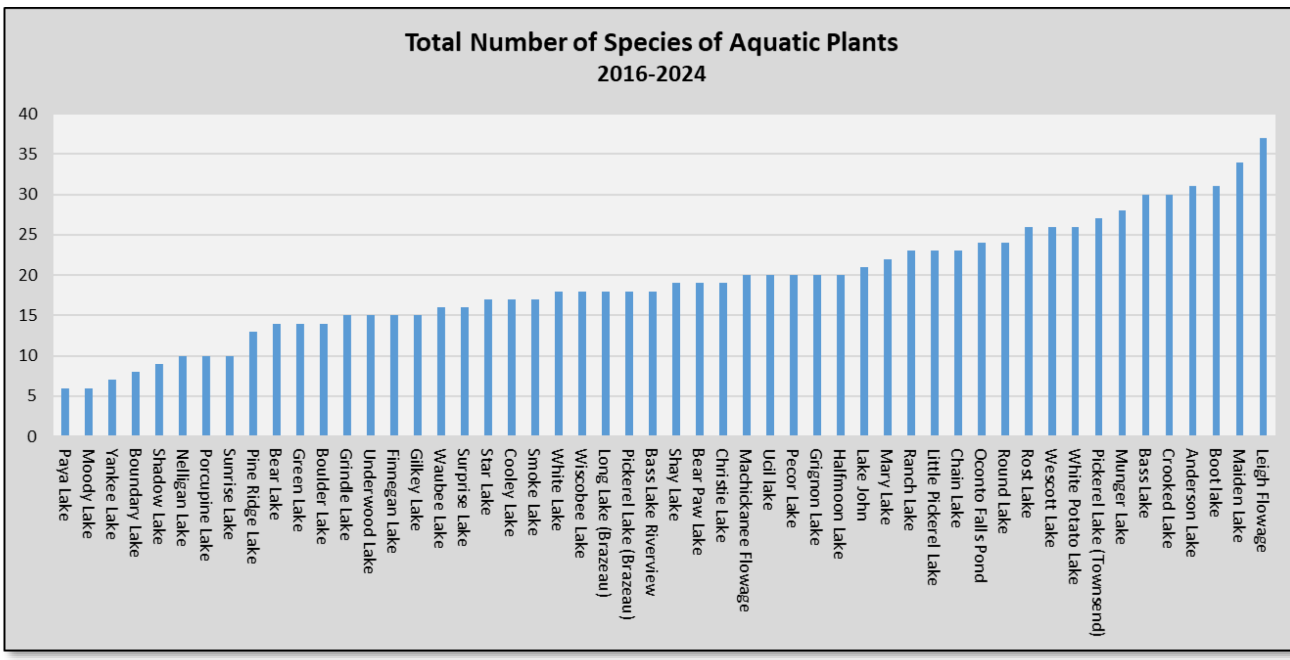


FIGURE 30. TOTAL NUMBER OF SPECIES OF AQUATIC PLANTS FOUND IN OCONTO COUNTY LAKES BASED ON 2016-2024 FIELD SURVEYS.

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 31. 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.

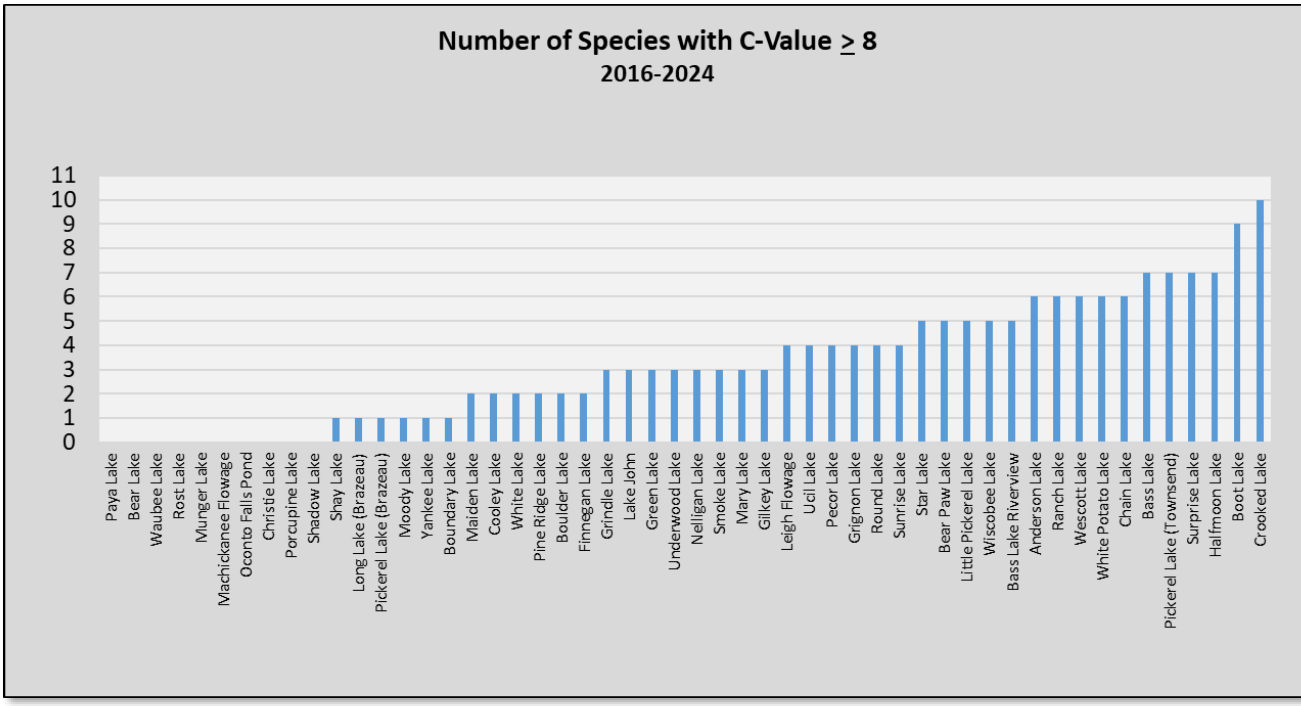


FIGURE 31. THE NUMBER OF SPECIES WITH A C-VALUE GREATER THAN 8 IN OCONTO COUNTY LAKES, BASED ON 2016-2024 FIELD SURVEYS.

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 32.

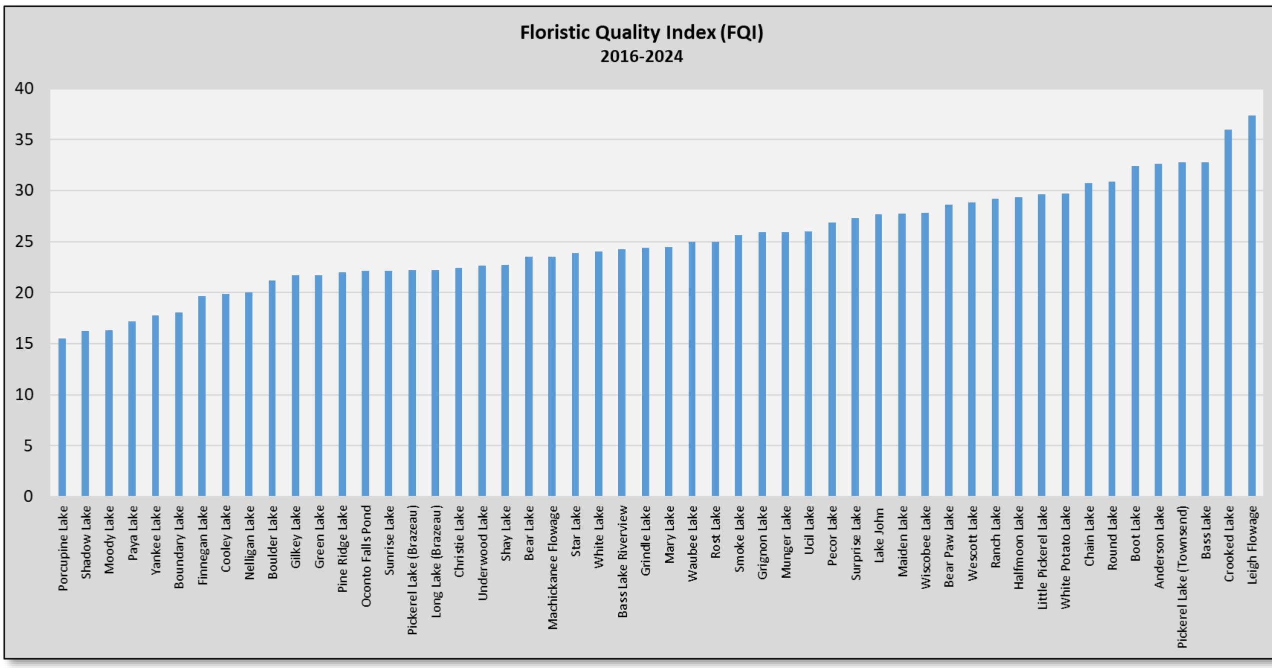


FIGURE 32. FLORISTIC QUALITY INDEX (FQI) BASED ON AQUATIC PLANT SURVEYS CONDUCTED IN THE OCONTO COUNTY STUDY LAKES. SUMMER 2016-2024.

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 the time of their survey** can be found in Table 5.

TABLE 5. AQUATIC INVASIVE SPECIES IN OCONTO COUNTY LAKES, BASED ON WISCONSIN DEPARTMENT OF NATURAL RESOURCES RECORDS.

Lake Name	Aquatic Invasive Species
Anderson Lake	Banded Mystery Snail, Chinese Mystery Snail, Eurasian Water-Milfoil, Rusty Crayfish
Bass Lake	Banded Mystery Snail, Chinese Mystery Snail, Rusty Crayfish, Phragmites
Bass Lake-Riverview	Curly-Leaf Pondweed, Eurasian Water-Milfoil
Bear Lake	Banded Mystery Snail, Chinese Mystery Snail
Bear Paw Lake	Banded Mystery Snail, Eurasian Water-Milfoil, Phragmites
Boot Lake	Banded Mystery Snail, Rusty Crayfish, Zebra mussel
Boulder Lake	Banded Mystery Snail, Eurasian water-milfoil
Boundary Lake	Banded Mystery Snail, Ornamental Water Lilies, Phragmites
Chain Lake	Banded Mystery Snail, Rusty Crayfish
Crooked Lake	Banded Mystery Snail, Chinese Mystery Snail, Curly-Leaf Pondweed, Eurasian Water-Milfoil, Purple Loosestrife, Zebra Mussel
Gilkey Lake	Banded Mystery Snail, Eurasian Water-Milfoil, Zebra Mussel
Green Lake	Banded Mystery Snail, Chinese Mystery Snail
Grindle Lake	Chinese Mystery Snail
Finnegan Lake	Banded Mystery Snail, Chinese Mystery Snail, Phragmites
Halfmoon Lake	Banded Mystery Snail, Chinese Mystery Snail, Phragmites
Lake John	Banded Mystery Snail, Rusty Crayfish
Leigh Flowage	Banded Mystery Snail, Chinese Mystery Snail, Phragmites, Zebra Mussel
Long Lake (Brazeau)	Phragmites
Machickanee Flowage	Curly-Leaf Pondweed, Eurasian/Hybrid Water-Milfoil, Flowering Rush, Phragmites, Purple Loosestrife, Zebra Mussel
Maiden Lake	Banded Mystery Snail, Eurasian Water-Milfoil, Rusty Crayfish
Mary Lake	Banded Mystery Snail, Phragmites
Moody Lake	Chinese Mystery Snail
Munger Lake	Banded Mystery Snail, Chinese 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
Pecor Lake	Banded Mystery Snail, Chinese Mystery Snail
Pickerel Lake (Brazeau)	Chinese Mystery Snail, Purple loosestrife
Pickerel Lake (Townsend)	Banded Mystery Snail, Chinese Mystery Snail, Rusty Crayfish

Pine Ridge Lake	Chinese Mystery Snail, Eurasian Water-Milfoil
Porcupine Lake	Purple loosestrife
Ranch Lake	Purple loosestrife
Rost Lake	Chinese Mystery Snail, Phragmites, Purple Loosestrife
Round Lake	Hybrid Eurasian/Northern water-milfoil
Shay Lake	Chinese Mystery Snail
Star Lake	Banded Mystery Snail, Ornamental water lilies
Sunrise Lake	
Surprise Lake	Ornamental water lilies, Purple loosestrife
Ucil Lake	Chinese Mystery Snail, Eurasian/Hybrid Water-Milfoil, Faucet Snail
Underwood Lake	Chinese Mystery Snail, Eurasian Water-Milfoil, Purple loosestrife
Waubee Lake	Banded Mystery Snail, Chinese Mystery Snail, Phragmites
Wescott Lake	Banded Mystery Snail, Chinese Mystery Snail, Curly-leaf pondweed, Yellow iris
White Potato Lake	Chinese Mystery Snail, Eurasian Water-Milfoil, Purple Loosestrife, Rusty Crayfish
Wiscobee Lake	Chinese Mystery Snail
Yankee Lake	Ornamental Water Lilies

*Reported but hasn't been seen in years.

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.

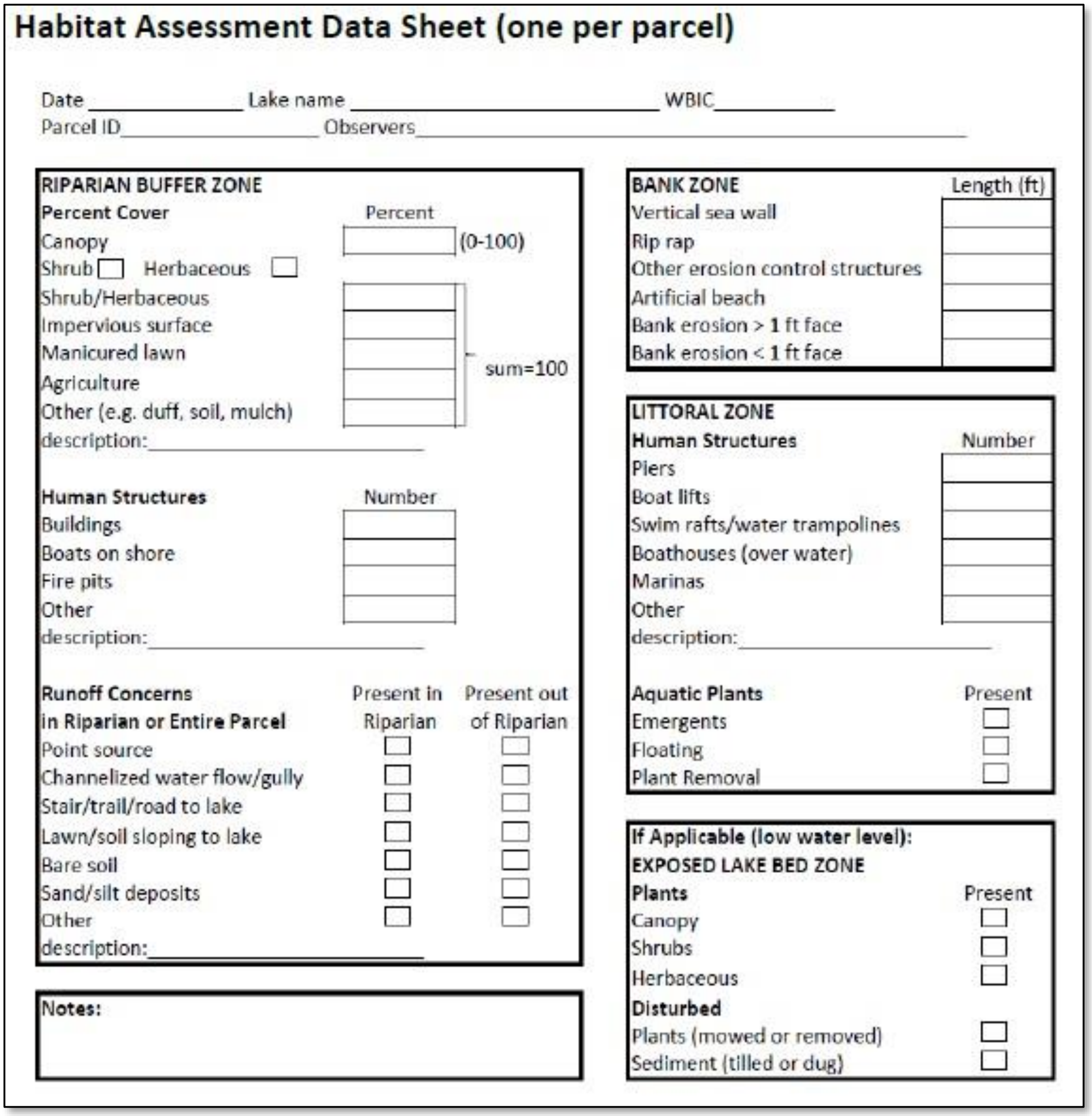
Coarse Woody Habitat (CWH)

Woody debris (i.e., branches, limbs, trees) that falls into the lake forms critical habitat for tiny aquatic organisms that feed bluegills, turtles, crayfish and other critters. Water insects such as mayflies graze on the algae that grow on decomposing wood. Dragonfly nymphs hunt for prey among the stems and branches. Largemouth and smallmouth bass often find food, shelter, or nesting habitat among these fallen trees.

Above water, a fallen tree is like a dock for wildlife. Ducks and turtles sun themselves on the trunk, muskrats use the tree as a feeding platform, predators such as mink and otter hunt for prey in the vicinity of fallen wood, and dead trees that remain along the shoreline are used as perches by belted kingfishers, ospreys and songbirds.

Undeveloped lakes typically contain hundreds of 'logs per mile' while they may completely disappear on developed lakes. Unless it is a hazard to navigation or swimming, consider leaving woody debris in the water.

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 33).



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 33. HABITAT ASSESSMENT DATA SHEET, PROVIDED BY WDNR, USED FOR SHORELAND SURVEYS IN THE OCONTO COUNTY STUDY LAKES. SUMMER 2016-2024.

SHORELAND SURVEY RESULTS

In summary, the Oconto County shoreland assessment found (Figure 34, Figure 35 and Figure 36):

- 52 lakes with shoreland assessments encompassing 107 miles of shore, 2,910 lakefront parcels and 6,153 acres of water.
- 34.7 miles (32%) of the inventoried shoreline is disturbed
- 25.6 miles (24%) of the inventoried shoreline is mowed lawn
- 10.2 miles (10%) of the inventoried shoreline is sea wall and/or rip rap
- 3.1 miles (2.9%) of the inventoried shoreline is impervious surface modification

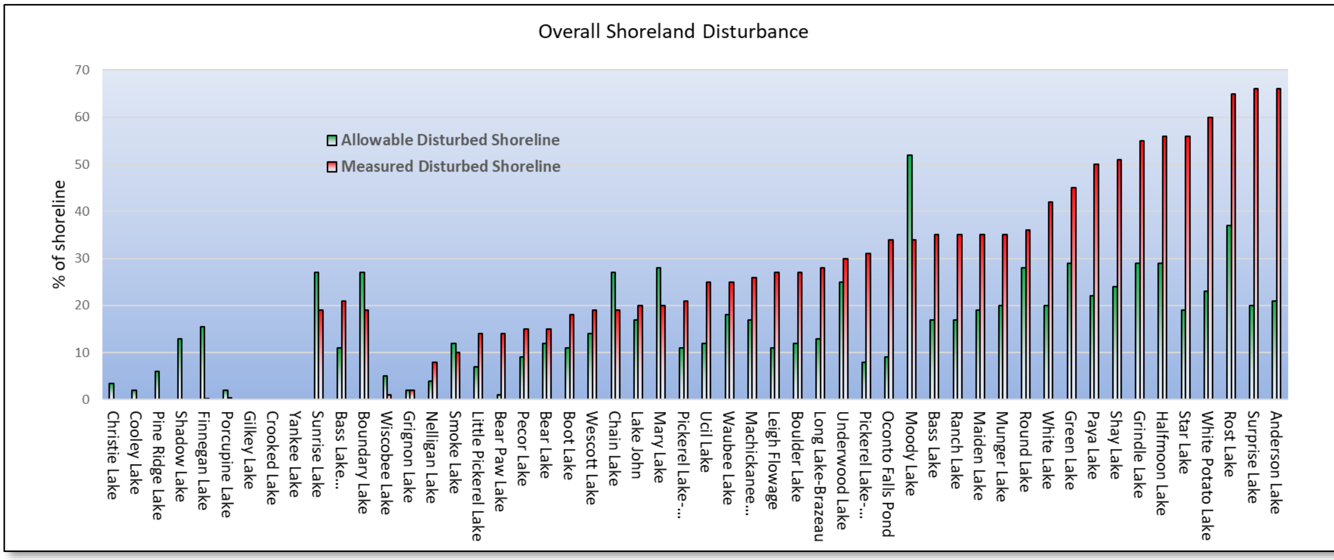


FIGURE 34. OVERALL SHORELAND DISTURBANCE, OCONTO COUNTY STUDY LAKES. SUMMER 2016-2024.

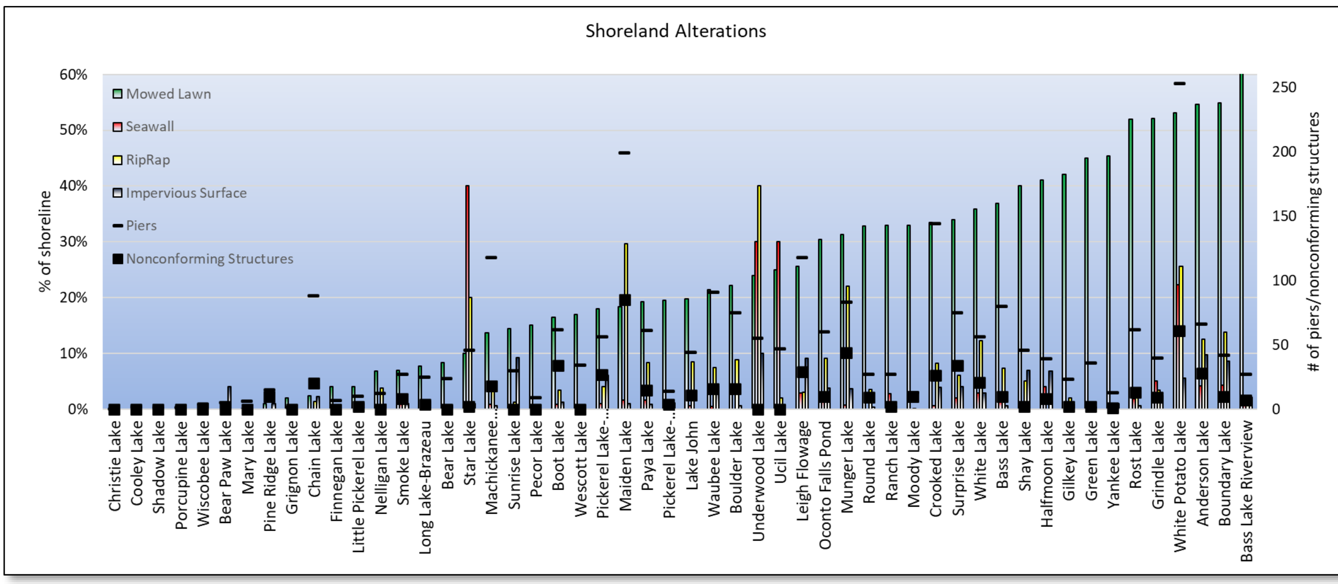


FIGURE 35. SHORELAND ALTERATIONS, OCONTO COUNTY STUDY LAKES. SUMMER 2016-2024.

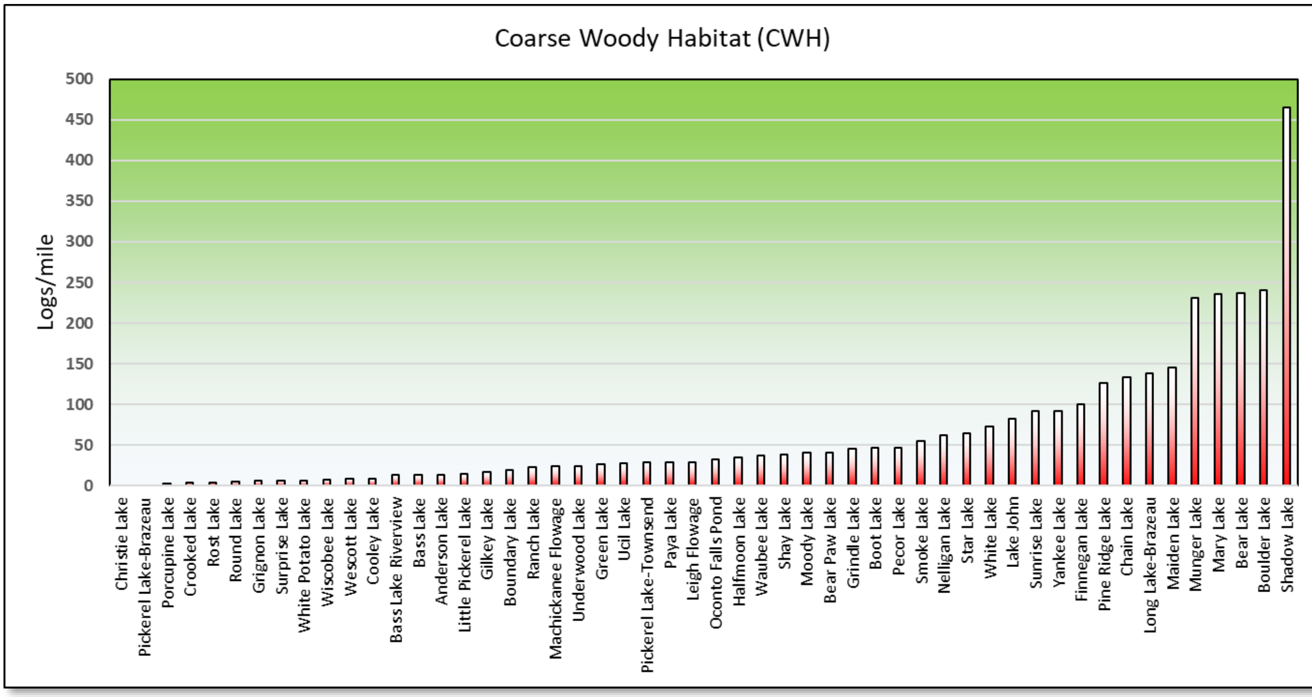


FIGURE 36. COARSE WOODY HABITAT, OCONTO COUNTY STUDY LAKES. SUMMER 2016-2024.

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 (NO_3) 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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GROUNDWATER FLOW MODEL TECHNICAL MEMORANDUM

CWSE Technical Memorandum

Groundwater Flow Model Development for Identifying Groundwater Contributing Areas to Lakes in Oconto County, Wisconsin

Paul McGinley and Ryan Haney
Center for Watershed Science &Education
2018 Update

Background and Purpose

Groundwater can enter lakes directly or enter the streams that drain to lakes. This groundwater can contribute a large percentage of the water that enters the lake and have an important influence on the lake. For example, the rate of groundwater entering controls the water replacement rate, and the chemistry of groundwater determines the pH buffering and loading of essential elements such as calcium and silica (Pint et al., 2006; Kenoyer and Anderson, 1989; Hurley et al., 1985; Krabbenhoeft and Webster, 1995). Although the groundwater contribution is often assumed based on the delineation of a topographic surface watershed, this assumes that the groundwater watershed and surface water watershed are coincident. As pointed out by Winter et al. (2003), in areas with a relatively permeable surficial aquifer, these boundaries may differ substantially.

This study used groundwater flow modeling to identify the land area contributing groundwater to the lakes in Oconto County. Because groundwater is that portion of the precipitation that moves through the soil and plant root zone and then moves in the aquifer eventually draining to lakes and streams, the knowledge of that land area that contributes groundwater can be used to estimate the quantity of groundwater that is entering a lake. With that information, the groundwater contribution of nutrients can also be estimated. This area should be considered an upper bound because this study will use two-dimensional groundwater flow that does not consider the possibility that some groundwater from the contributing area could flow under the lake. This is considered a reasonable approximation in Oconto County because the lakes are largely in relatively permeable glacial outwash or till within a relatively shallow unconfined surficial aquifer. When the lakes are relatively large compared to the aquifer thickness and there are relatively permeable zones near the edge of the lake for groundwater to enter, it is expected that most of the groundwater would move into and through the lake (Hunt et al., 2003; McGinley, 2008).

This Technical Memorandum describes the initial development of a groundwater flow model for the Oconto County Lakes Project. The model was developed as part of a county-wide lake characterization and planning project. The goal of the model is to estimate the groundwater contribution to the lakes to develop planning-level hydrologic and nutrient budgets. The model will continue to be expanded and improved as the project continues.

Methods

The groundwater simulation model was developed using GFLOW (Haitjema Software, Version 2.1.2, 2007). This is an analytic element model that uses streams, aquifer properties and groundwater recharge to simulate the water table. Once developed, the model can be used to track the water movement from points in the model backward through time. This tracking feature can be used to identify the area where water passing through the lake would originate.

The modeled area was all of Oconto County and portions of the neighboring counties. The area has a surface elevation that drops from almost 1750 feet above sea level to almost 600 feet above sea level near Lake Michigan. Figure 1 shows the orientation of Oconto County and the surface elevation variation. The area is a recently glaciated region where the surficial geology is a mixture of gravel, sand, silt and clay from glacial till and meltwater. McCartney (1983) and Attig and Ham (1999) identified a series of glacial drift units resulting from different glacial advances and retreats. These include till deposits identified from west to east in the modeled area as Mapleview, Silver Cliff and Kirby Lake. These are found with areas of dune sand and glacial lake planes. They are all underlain by Precambrian bedrock, except in the eastern portion of the area where Cambrian and younger bedrock is present. The thickness of the glacial deposits above the bedrock varies widely. Figure 2 shows how they range from more than 200 feet thick in some areas, and thin or absent in others where bedrock is at the surface.

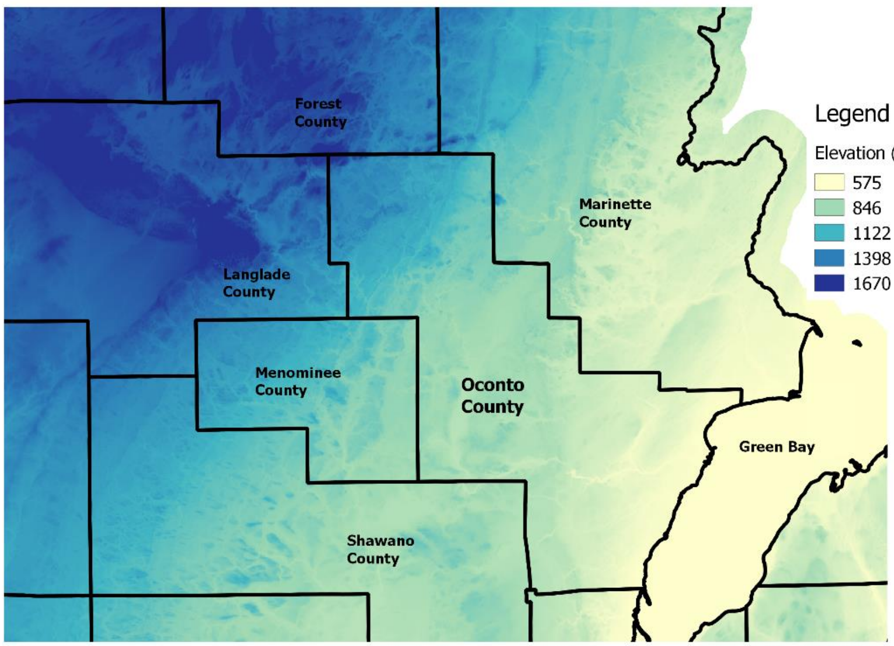

Figure 1. County boundaries and ground surface elevation in area that includes the GFLOW model for the Oconto County Lakes Project.

Several GFLOW models were developed to isolate portions of the study area by using natural hydrologic boundaries. Figure 3 shows the major river systems in the study area. The Wolf and Peshtigo Rivers provide boundaries to area with the Oconto River system providing internal drainage to the modeled areas and an opportunity to calibrate the models to match the measured stream flow. The models simulated the glacial drift as a surficial aquifer that contains the lakes and did not simulate flow in the Precambrian bedrock. Although there are wells in the bedrock in some parts of the study area, most of the groundwater flow is likely to occur in the much more permeable glacial drift. Variation in aquifer thickness was used in setting up the models. The glacial deposits are very thin and bedrock is at the surface along southwest to northeast line near Mountain (Figure 2). That and the Oconto River was used as a boundary between the Oconto North and Oconto South Models shown in Figure 4 and Figure 5. Several smaller models were also developed to examine lakes near this area. For example, Figure 6 shows a GFLOW model developed to examine Grindle Lake.

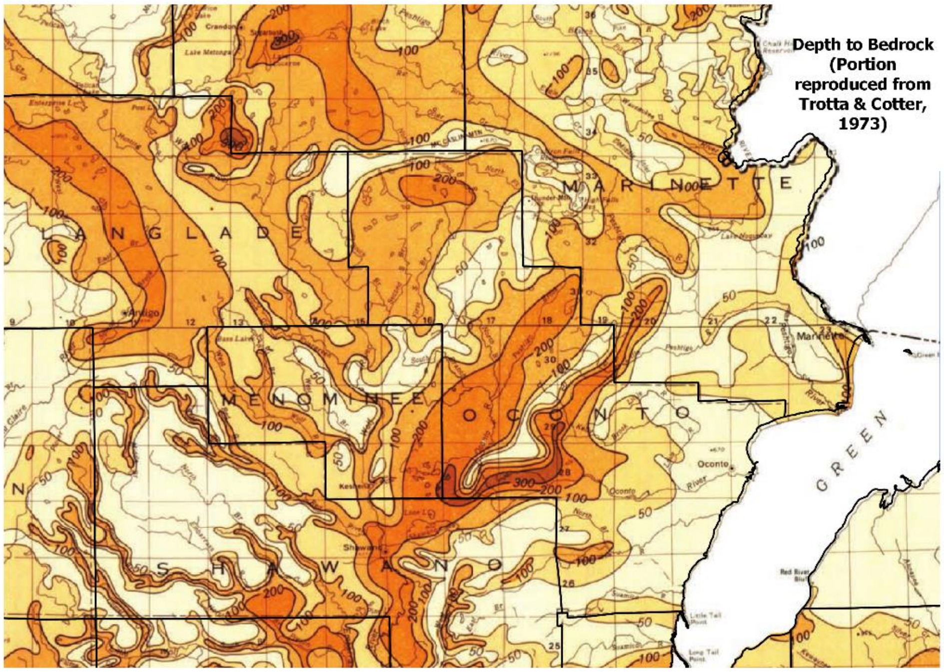

Figure 2. Depth to bedrock in the area that includes the GFLOW model for the Oconto County Lakes Project.

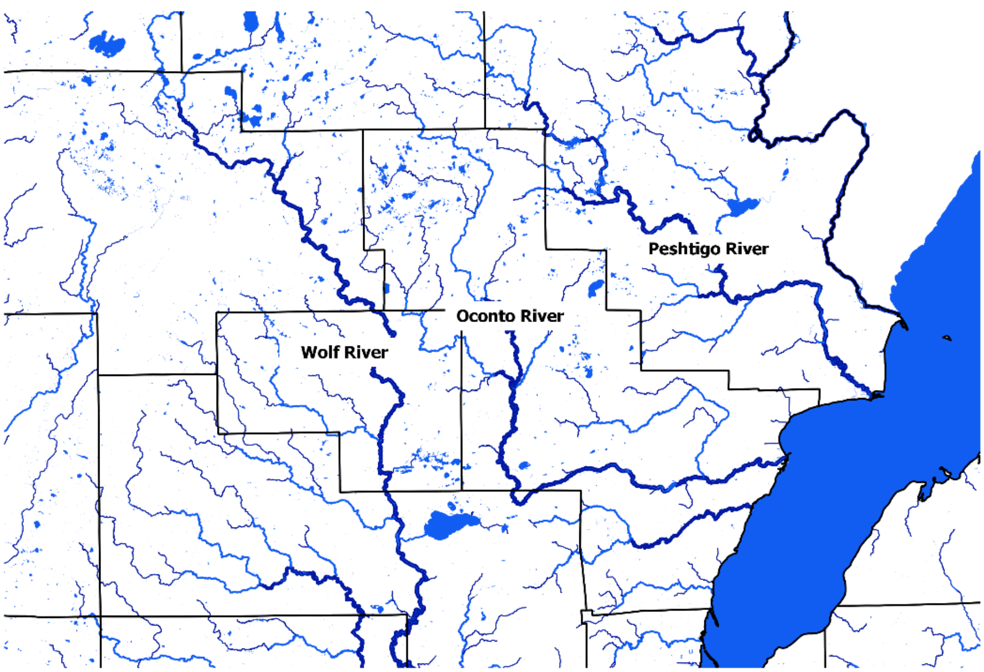

Figure 3. Major river systems in the area that includes the GFLOW model for the Oconto County Lakes Project.

GFLOW models are two-dimensional models that use aquifer depth and hydraulic conductivity to characterize the transmissivity of the aquifer. The GFLOW models developed for this project represented the aquifer with a constant aquifer bottom elevation and then used variations in hydraulic conductivity introduced as GFLOW inhomogeneities to characterize the variations in transmissivity that result from actual aquifer bottom elevations and hydraulic characteristics of the glacial drift. These become simplified representations of the rather complex and heterogeneous aquifer properties of Oconto County, but they were able to simulate the measured water table elevation and streamflow. The models represent stream in the area using linesinks with a water elevation and resistance to flow. We combined linesinks we developed using USGS topographic maps along with linesinks that were already developed as part of a GFLOW model for the Nicolet National Forest (Fehling et al., 2016) which we converted to WTM coordinates using R scripts developed for this project. All of our models started from the same set of linesinks, which we clipped for our different models using area polygons and some R scripting. Each of the models were then modified with more detailed linesinks added, or modified to meet the needs of each location. To evaluate the model fit, we used water table elevations previously identified from well construction reports by Fehling et al (2016) and lake elevations from USGS topographic maps. Similar to the selection of linesinks, we used R scripts to clip the calibration points to fit the different model boundaries and transform coordinates to WTM. Model calibration required adjusting the aquifer and recharge characteristics within each model. We used variations in aquifer hydraulic conductivity were incorporated based on information from several previous studies of the area (Thwaites, 1928; McCartney, 1983; Attig and Ham, 1999), well construction reports (WGHNS, obtained online in 2018) and calibration adjustments to better fit model calibration targets.

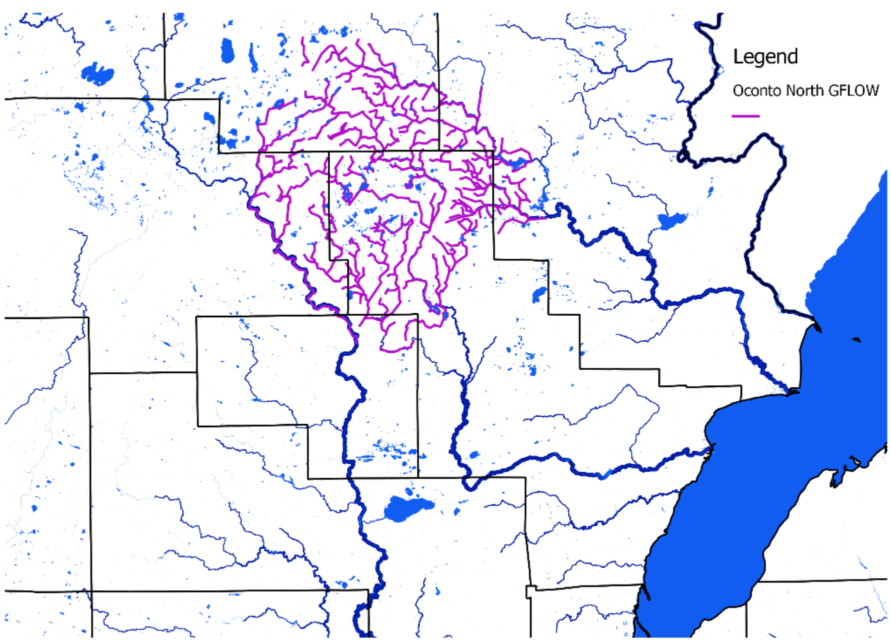

Figure 4. Linesink locations showing extent of the GFLOW model in the Oconto North GFLOW model developed for the Oconto County Lakes Project.

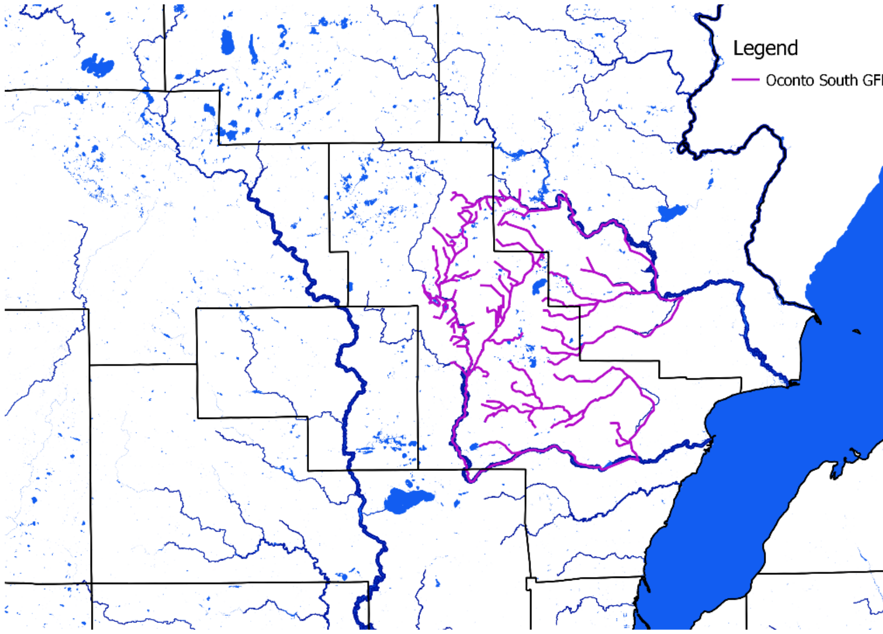

Figure 5. Linesink locations showing extent of the GFLOW model in the Oconto South GFLOW model developed for the Oconto County Lakes Project.

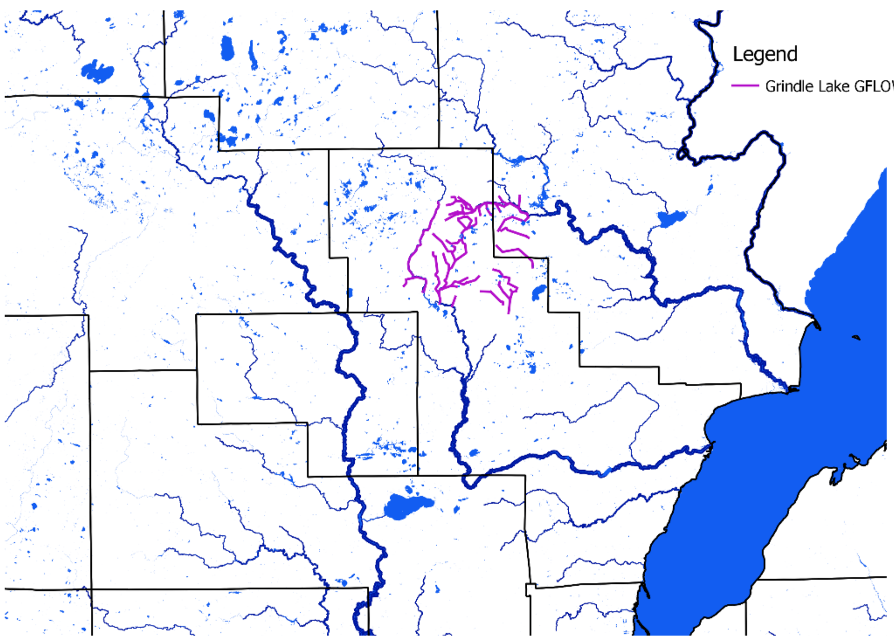

Figure 6. Linesink locations showing extent of the GFLOW model in one of the smaller Oconto GFLOW models (here the Grindle Lake Model) developed for the Oconto County Lakes Project.

The GFLOW model can be used to develop a water table map and project corresponding groundwater flow directions by tracking the particles backward from the lake. Figure 7 shows the application of the GFLOW model and reverse particle tracking to identify the groundwater flow direction to one of the lakes. The area within the particle tracks can be used to estimate the annual recharge volume entering the lake if we assume all the groundwater recharge in the particle-track region will eventually move through the lake.

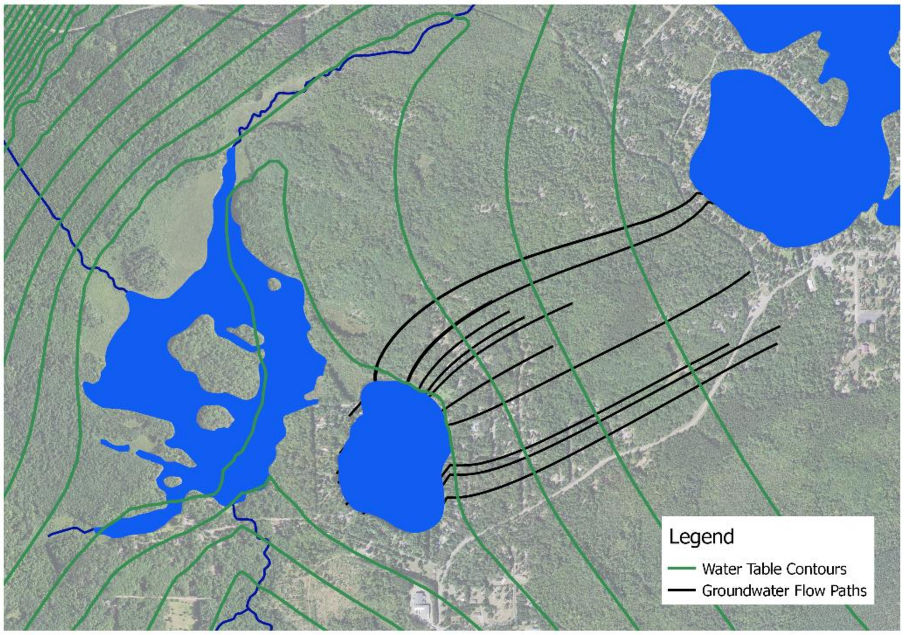

Figure 7. Example of a water table contours (green) and particle tracking to a lake (black lines) exported from the GFLOW model for the Oconto County Lakes Project.

Results

The GFLOW model and submodels developed for the Oconto Lake Study will be used to identify the groundwater flow direction to the lakes and begin to estimate the groundwater contributing areas for each lake. These models will continue to be refined as the Oconto County Lake Study continues.

For More Information

The results of the modeling will be shown in the lake reports and used in the planning process. Information on the scripts and GFLOW models used can be obtained from the authors.

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LAKE MANAGEMENT PLANS