State of the Waushara County Lakes
Lake Data Summary
2010-2012 Study

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And excerpts from *Understanding Water Quality Data* (Shaw et al., 2000)

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Background

Lakes and rivers are important parts of Waushara County's way of life. Local residents enjoy fishing, swimming, boating, and wildlife viewing on nearby lakes and rivers. By providing places to relax and recreate, healthy lakes add value to our communities while attracting visitors and stimulating tourism. Like other community infrastructure, lakes require attention and good management practices in order to maintain their quality in the midst of continuing use or development.

Waushara County is located in the southern part of central Wisconsin. It is bordered by Portage and Waupaca counties to the north, Winnebago County to the east, Green Lake and Marquette counties to the south, and Adams County to the west. It has a land area of 643 square miles, or 411,520 acres (Figure 1).

Thirty-three lakes in Waushara County were selected for the Waushara County Lakes Study, which focused on the lakes' water qualities, aquatic plant communities, shoreland habitats, and land use in their watersheds. The project included the lake studies and community planning processes, ultimately to aid people with informed lake management decisions. Data was collected between fall 2010 and fall 2012. The study reports and lake management plans can be found on the Waushara County website. This guide interprets the results and compares measurements common to all of the study lakes.

Geology and Soil

The geology and soil play significant roles in the chemistry within its lakes, as do the quantity and quality of surface runoff and groundwater feeding the lakes. Cambrian sandstone bedrock (Potsdam Formation) underlays glacial deposits at depths of 1-100 feet in Waushara County, with several outcrops occurring in Marion and Warren townships. The most recent glaciation left a variety of features ranging from broad, flat outwash plains and lake basins to rough, broken glacial moraines and areas of pitted outwash. Waushara County's western edge has a flat outwash plain that is part of the Central Wisconsin Sand Plain that also covers parts of Adams, Portage, and Wood counties (Drescher, 1956) (Figure 1). A glacial moraine complex occurs in a broad northeast-trending belt across the central part of Waushara County, extending through the villages of Coloma, Hancock and Plainfield, and forming the eastern boundary of the Central Sands. This sandy till consists of an unsorted mixture of clay, silt, sand, gravel and boulders. The eastern third of the county is a gently rolling lake plain of sand and silt deposits. These deposits blend with other glacial deposits and the boundary between them can be indistinct. Typically sorted and stratified, the deposits occasionally include interbedded red clay and silt.

Collectively, the glacial deposits covering Waushara County resulted in soil generally richer in carbonate minerals such as calcium and magnesium. Dissolution of these elements results in hard water in many of the lakes and also contributes to the production of shells and bones of aquatic organisms. The production of marl occurs in some of the Waushara County lakes, helping to make them more resilient to additions of phosphorus. About 35% of the land area consists of wetland soils.

Approximately 20,000 years ago, the Central Wisconsin Sand Plain was covered by glacial Lake Wisconsin. The lake extended from Waushara County south to Sauk and Columbia counties, and was fed by melting glaciers and streams. Water entering glacial Lake Wisconsin carried large quantities of sediment. Glacial Lake Wisconsin drained after the glacier's final retreat, depositing sand and gravel in depths up to several hundred feet deep. These deposits became the region's main aquifer.

The primary land uses that impact sensitive areas in Waushara County are agriculture and residential/urban development. These land use practices result in excessive phosphorus and sediment loading to surface water and groundwater, particularly in watersheds experiencing significant cropland erosion problems. To the west, the Wisconsin River Basin Plan has identified wind erosion as one of the greatest contributors to surface water pollution (Waushara County Land and Water Resource Management Plan, 2010).

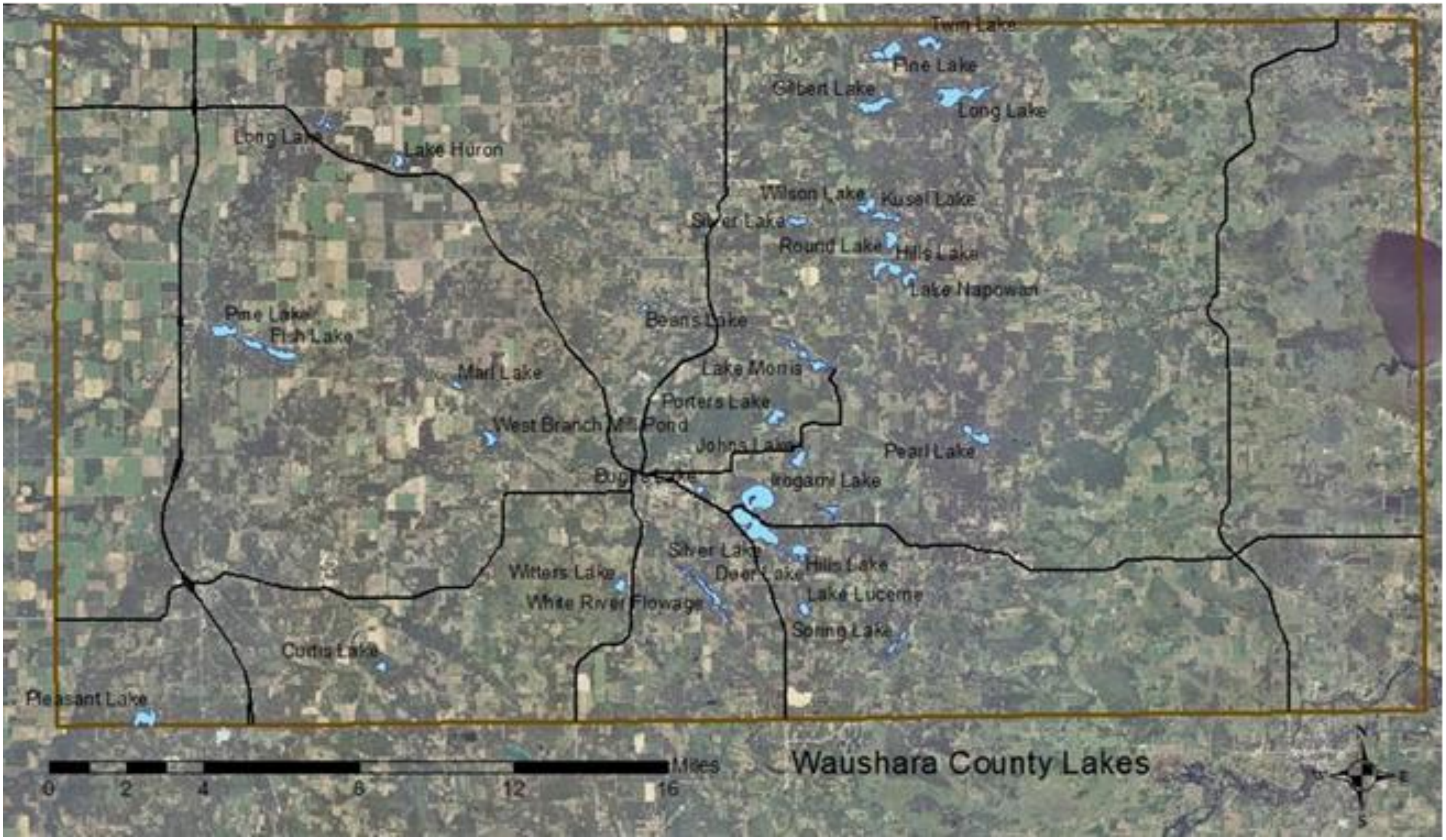


Figure 1. Map of Waushara County and the study lakes.

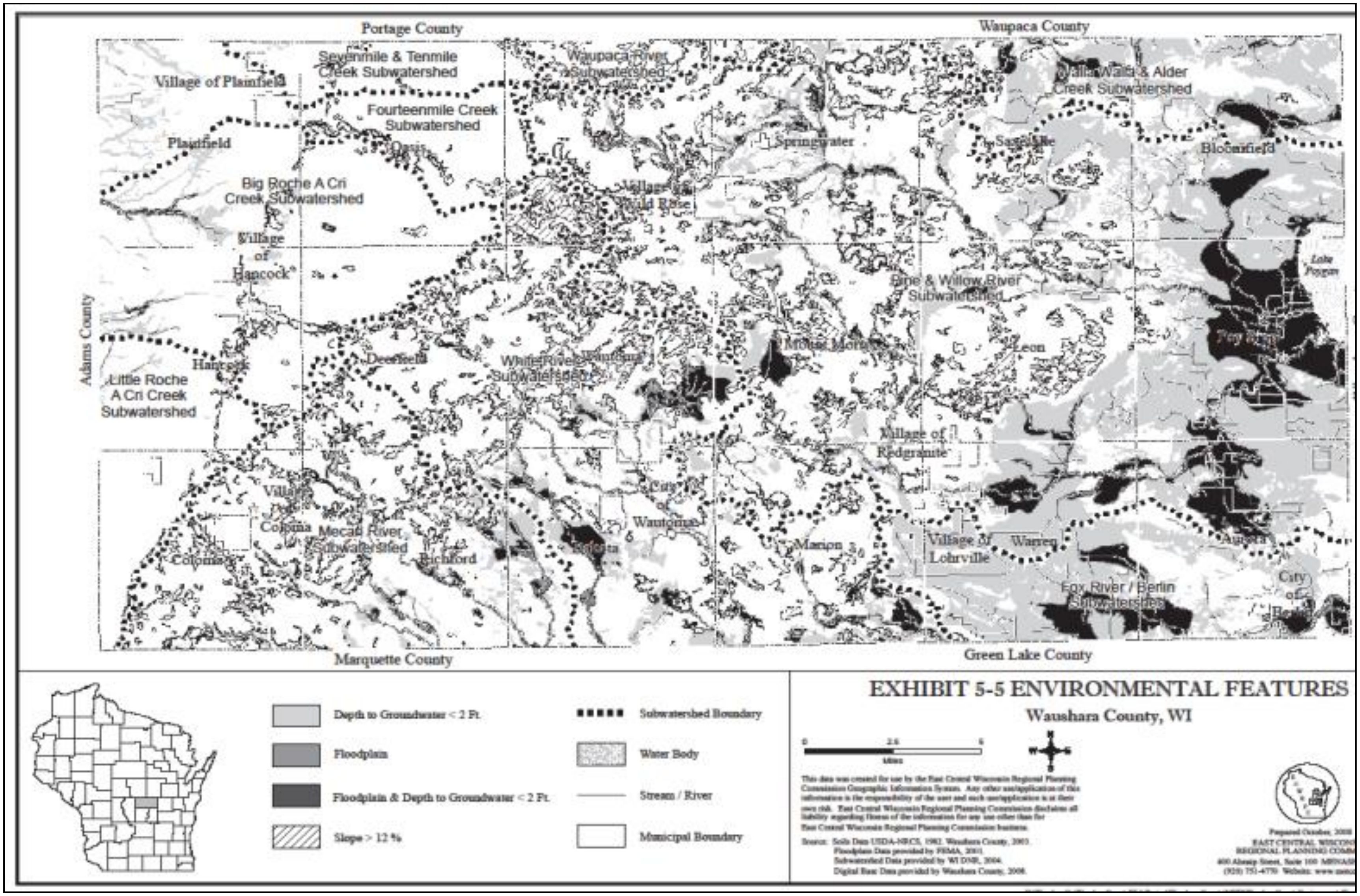


Figure 2. Environmental features of Waushara County.

Surface Water and Groundwater

Surface water and groundwater are closely linked in Waushara County. When fluctuations in precipitation, recharge, evapotranspiration, discharge, drainage and storage occur, changes in both groundwater levels and surface water runoff 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).

Many community water systems, private residences and farms in Waushara 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.

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.

Understanding the direction of groundwater flow through the region allows for a greater understanding of groundwater quality and how the aquifer responds to pumping. In the case of impacts to a lake from water withdrawal, knowing the source of the groundwater that is removed through pumping can be helpful.

Lake and Water Characteristics

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

Lake Types

Waushara 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 790 feet to 1096 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).

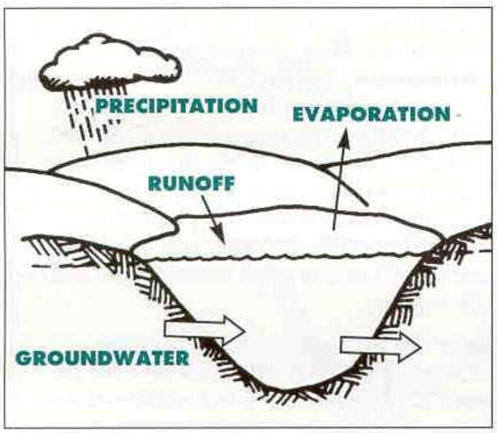
Land use practices often influence water quality for many years. In sandy soils, the flow rate of groundwater ranges at 1to 3 feet per day. Therefore, it can take years or decades to flush contaminants out of the lake. Contaminants in lakes are often loosely held in lake sediments and released over time, 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. Some of the lakes in this study are showing slow improvements in water quality. The land use data suggested this is the result of decreased agricultural activity in the area near the lakeshore. Preventing contamination is critical for maintaining the quality of our lakes and groundwater.

Water movement is a common way to classify lakes and it provides important information on how lakes function. In Waushara County, the lakes can be divided into four general categories based on water flow: 1) seepage lakes, 2) groundwater drainage lakes, 3) drainage lakes, and, 4) impoundments. Figure 3 illustrates the differences between the four lake types. Waushara County lakes are listed by lake type and mixing/stratification in Table 2.

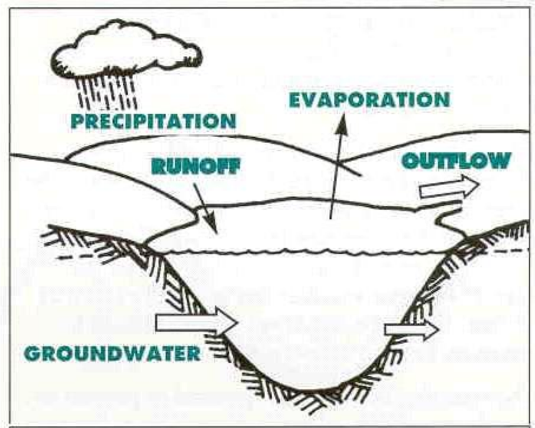
Impoundments are the ponds/lakes created when stream flow is restricted. Impoundments are common in Wisconsin, often created by dams that were installed for other purposes. The primary water source for these lakes is a river. Characteristics of impoundments include relatively large rates of water entry 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.

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.

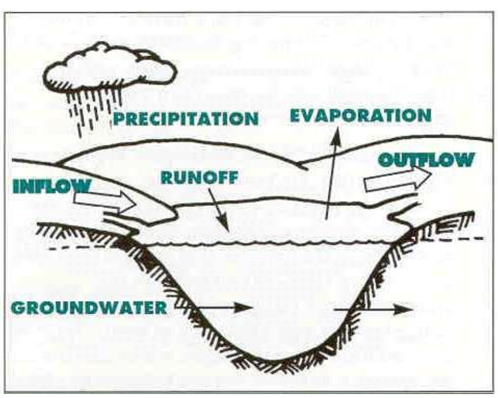
Many of the lakes in Waushara County are seepage lakes mostly fed by groundwater and have no stream inlets or outlets. Water still leaves these lakes, but it does so as groundwater. Melting ice blocks left behind by the last glacier formed these lakes. Most groundwater usually enters at one end of the lake and leaves at the other end; however, areas of groundwater inflow can also occur sporadically around the lake. Water quality in these 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 fairly 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 minimizes the amounts of runoff, sediment and nutrients reaching the lake.



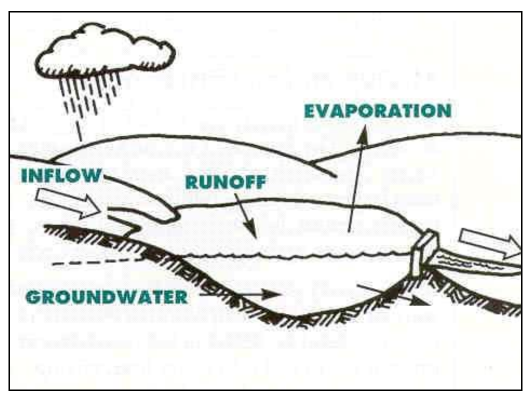
1. SEEPAGE LAKE – a natural lake fed by precipitation, limited runoff and groundwater. It does not have a stream outlet.



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 3. 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 (Table 1). Their greater depth and relatively small watersheds result in better water quality

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
	Beans White River Flowage	Alpine Deer Long-Oasis Marl Morris	Bughs Irogami Napowan Pine-Hancock West Branch Mill Wilson Witters	Curtis Huron Kusel Spring Twin	Fish Little Hills Little Silver-Springwater Pine-Springwater Pleasant Porters	Big Hills Big Silver Gilbert Johns Long-Saxeville Lucerne Pearl Round

*Summer values; µg/l = micrograms per liter or parts per billion
**DB:LA = Drainage basin/lake area

Lake Water Levels

Lake levels fluctuate naturally due to precipitation, which varies season to season and year to year. While some lakes with stream inflows show the effect of rainfall almost immediately, others take months or years. For example, water levels in seepage lakes rise in the winter when heavy autumn rainfall finally reaches the lakes as groundwater.

Many of the seepage lakes in Waushara County have fluctuating water levels, with lower levels observed for a number of years following a period of drought or significant groundwater withdrawal. Lakes near to a groundwater divide tend to have the slowest response to recharge events. One such divide in Waushara County can be seen in Figure 4, trending northeast-southwest in the far western portion of the county. Water to the west drains to the Wisconsin River watershed and ultimately to the Gulf of Mexico, and water to the east drains to the Fox River watershed and ultimately to the Great Lakes and the Atlantic Ocean. Large withdrawals of groundwater in the Central Sands region in near proximity to the groundwater divide have resulted in notable water level changes, particularly in lakes closest to the divide, such as Long Lake – Oasis (Kraft et al., 2010).

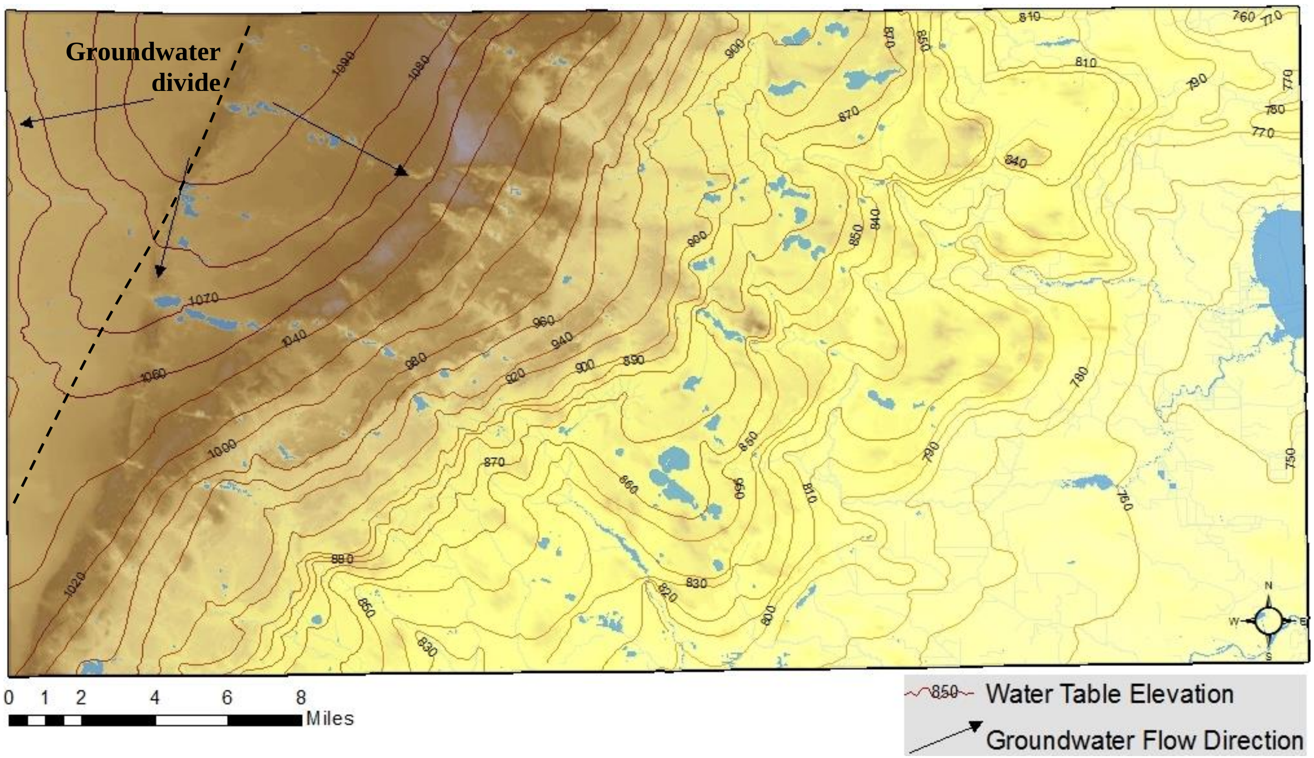


Figure 4. Waushara County groundwater contour map. The groundwater flow direction is perpendicular to contour lines.

Figure 5 illustrates the calculated change in water levels due to groundwater pumping in the Central Sands region. Water level fluctuations significantly affect lake water quality. Low levels may cause stressful conditions for fish and increase the number of nuisance aquatic plants. High water levels can boost the amount of nutrients from runoff and flooded lakeshore soils. Older septic systems located near lakes may flood when groundwater levels are high. Another consequence of fluctuating water levels is shoreline erosion.

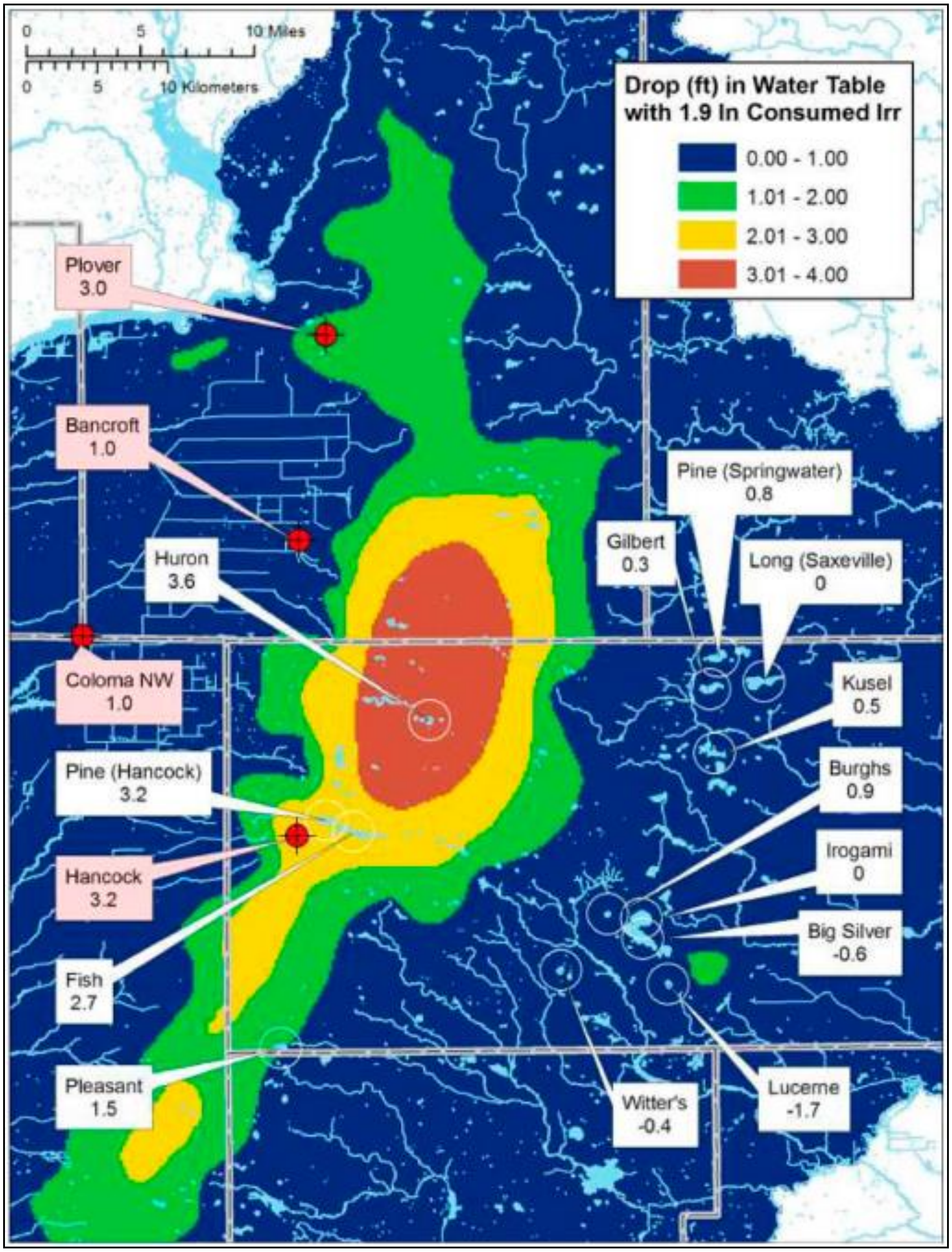


Figure 5. Statistically estimated water level declines beyond weather influences at monitoring wells (pink) and lakes (white), with 1.9 inch reduction in recharge on irrigated lands (Kraft et al., 2010).

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.

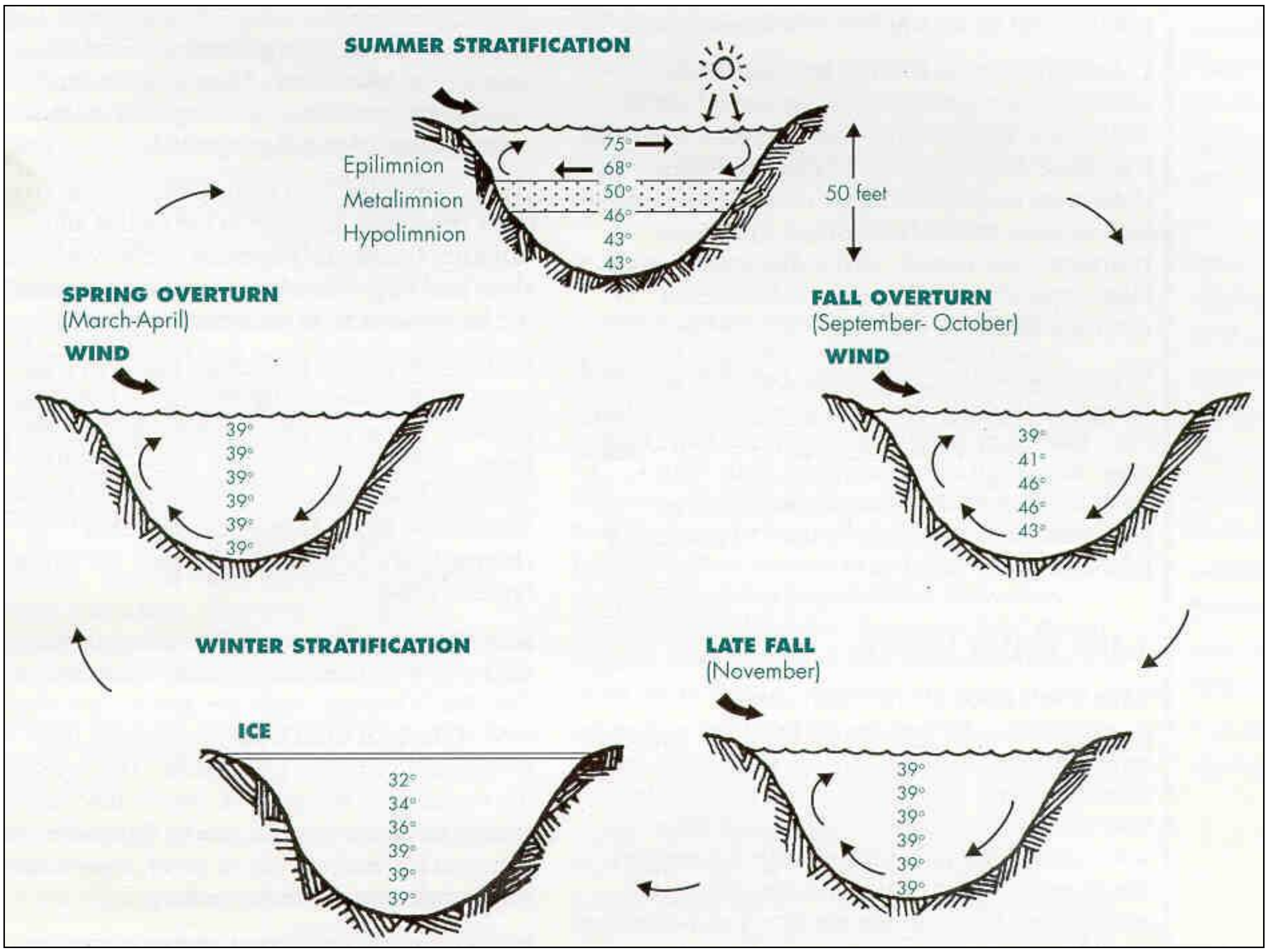


Figure 6. Schematic showing lake mixing and layering by season in a typical Wisconsin year (Shaw et. al. 2000).

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. Figure 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. 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). These categories relate to the state phosphorus standards.

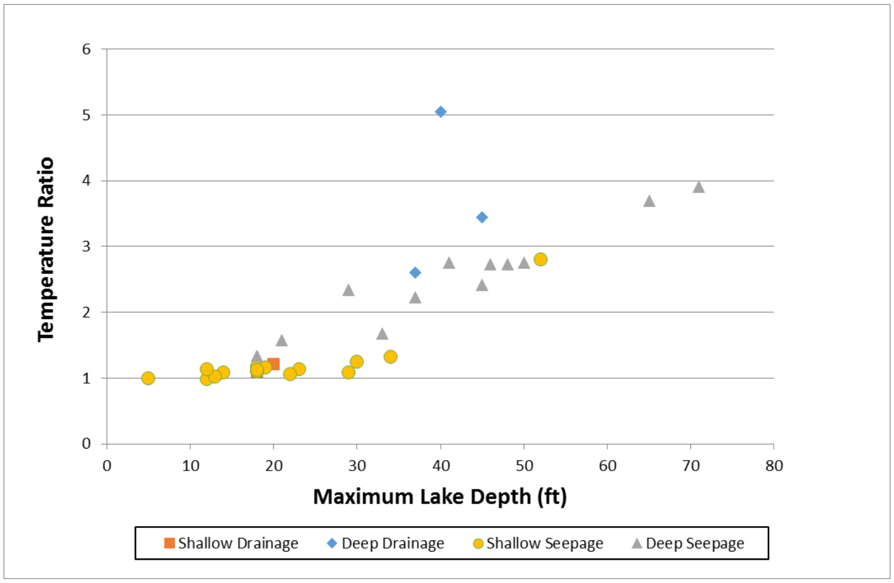


Figure 7. **Top to bottom mean temperature ratios and maximum depth for differing lake types in Waushara Co.**

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

Shallow Seepage (Mixed)	Deep Seepage (Stratified)	Shallow Drainage (Mixed)	Deep Drainage (Stratified)
Beans	Fish	Alpine	Curtis
Bughs	Gilbert	White River Flowage	Morris
Deer	Johns		Spring
Little Hills	Kusel		
Big Hills	Huron		
Irogami	Lucerne		
Long-Oasis	Napowan		
Marl	Long-Saxeville		
Pleasant	Pearl		
Porters	Pine-Springwater		
Round	Pine-Hancock		
Twin	Big Silver		
West Branch Millpond	Little Silver		
Wilson			
Witters			

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 3.

Table 3. Minimum depth of lake water with dissolved oxygen concentrations less than 5 mg/L during the Waushara County lake study (2010-12).

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
Witters	0	Curtis	12
Beans	1	Kusel	12
Deer	2	Pleasant	12
Irogami	2	Big Hills	16
Napowan	2	Marl	16
West Branch Mill	2	Round	16
Spring	3	Fish	18
Bughs	4	Little Hills	18
Porters	4	Huron	20
Johns	5	Silver (Springwater)	20
Morris	5	Lucerne	27
Pearl	5	Pine (Springwater)	30
Twin	5	Silver (Wautoma)	30
Alpine	6	Long (Saxeville)	35
Pine (Hancock)	6	Gilbert	40
White River Flowage	7	Long (Oasis)	N/A
Wilson	8		

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. Average water clarity data for lakes in the Waushara 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 Waushara 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 many lakes in Waushara County; the data were collected by citizens, consultants, and WDNR staff.

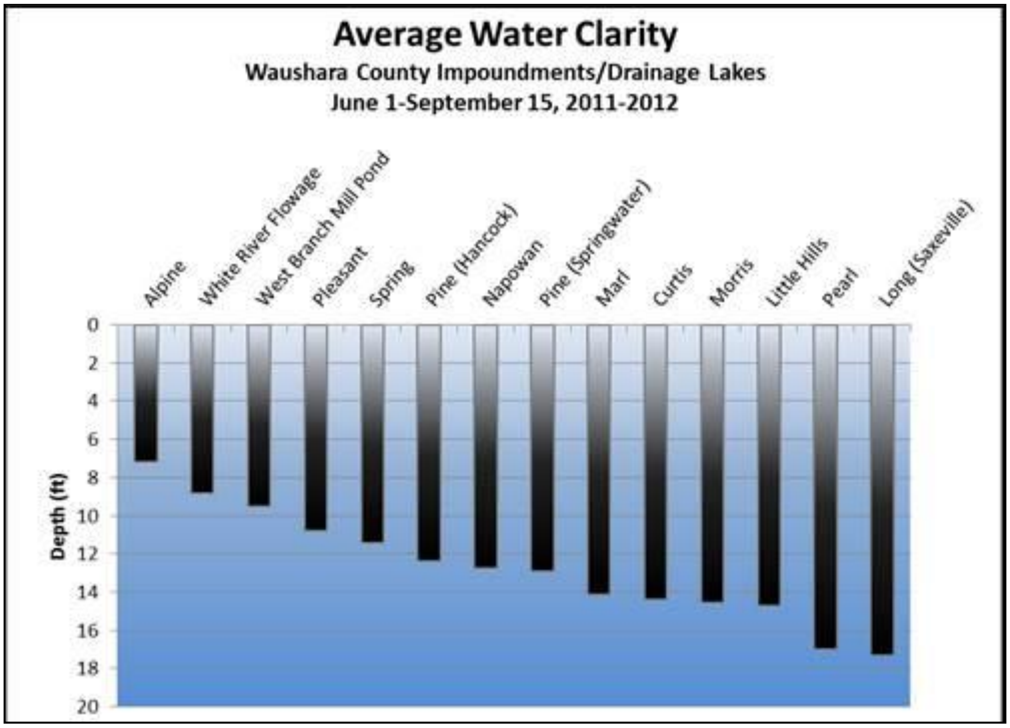


Figure 8. Average water clarity in Waushara County impoundments and drainage lake types, 2011-2012.

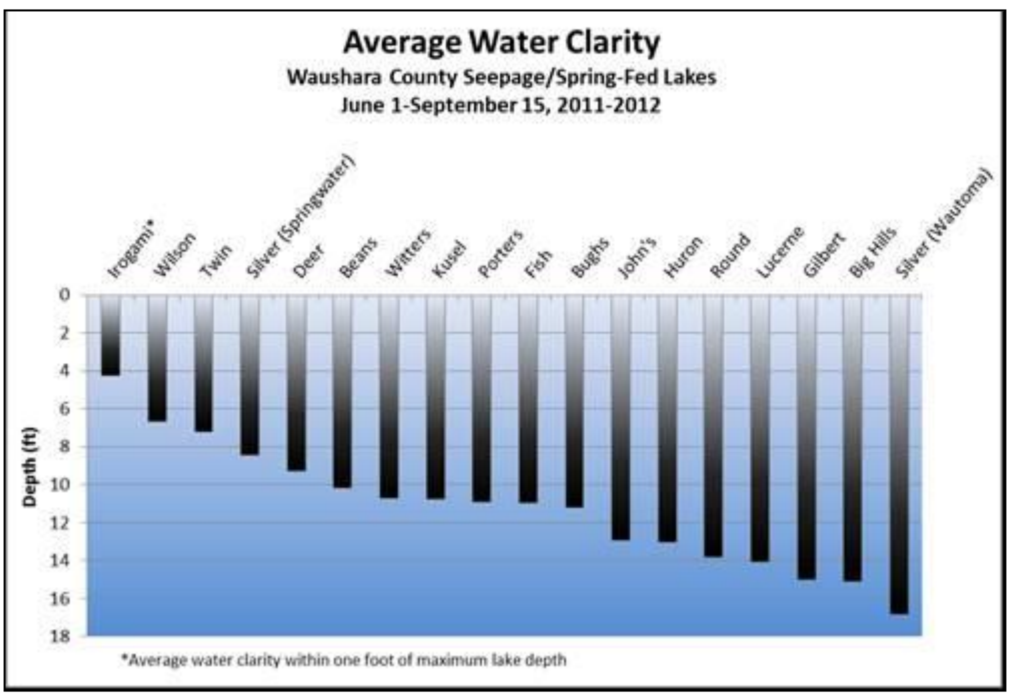


Figure 9. Average water clarity in Waushara County seepage and spring-fed lake types, 2011-2012.

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 4. Color is measured and reported as standard color units (CU). The average color unit measured in spring and fall overturn samples during the Waushara 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

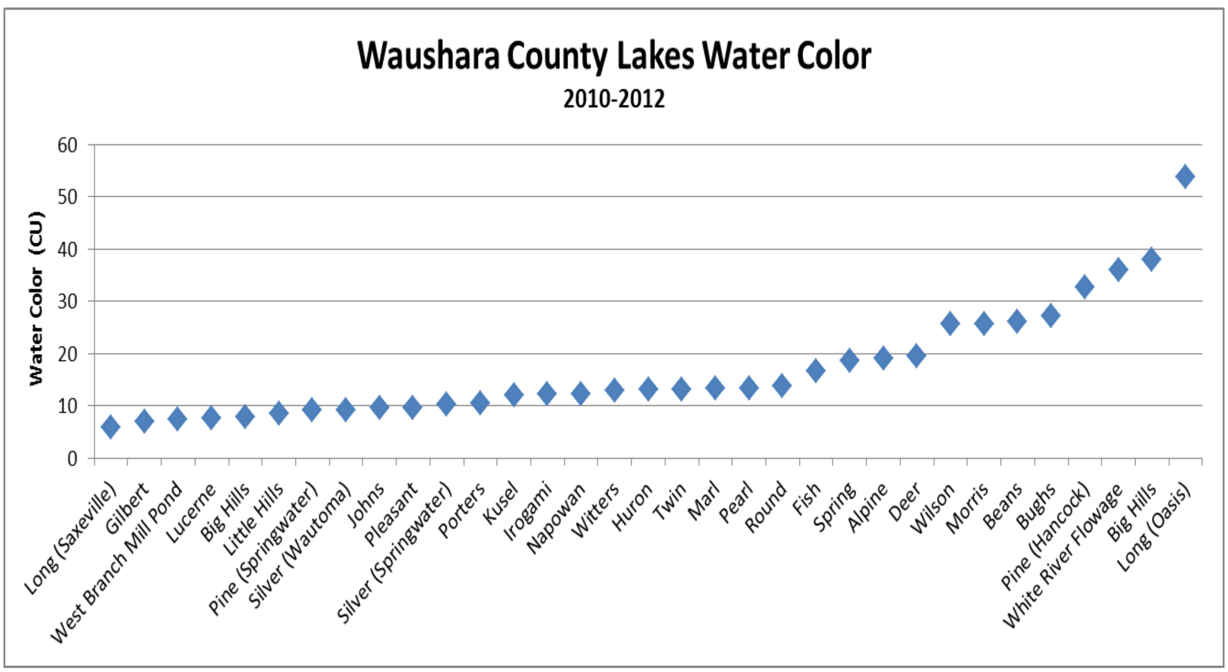


Figure 10. Average color (CU) of the lake water in the Waushara County Lakes Study during overturn, 2010-2012.

Turbidity

Another measure of water clarity**,** turbidity**,** is caused by particulates rather than dissolved compounds. Suspended sediment and algae often comprise the particles suspended in lake water. Lakes receiving runoff from silt or clay soils often exhibit high turbidities as do lakes undergoing marl production. Turbidity values can vary greatly with the nature of the seasonal runoff, or with the Stirring of bottom sediments by winds and/or motor boating.

Suspended plants (algae) and animals (zooplankton) are also measured in turbidity readings. Small organisms in higher numbers have a greater effect than large organisms in lower numbers. The abundance of organisms in open lake water can change with season and weather. The average turbidity measured in samples collected from the Waushara County lakes during spring/fall overturn ranged from 1.5 to 4.6 (Figure 11). These values are considered low.

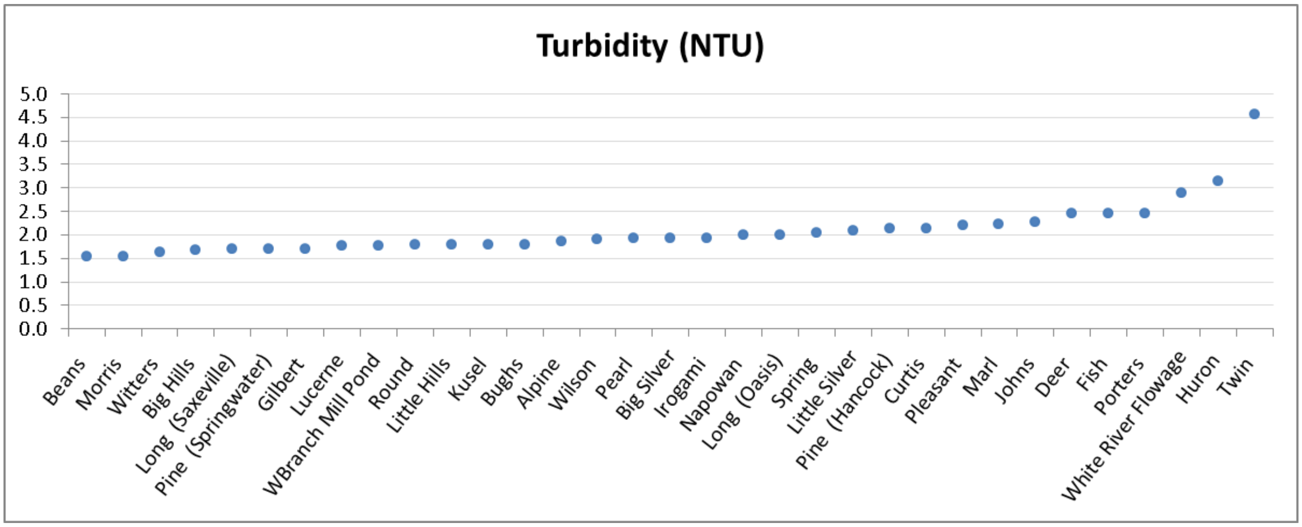


Figure 11. Average turbidity (NTU) in the Waushara County lakes during overturn, 2010-2012

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 (eg. 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. Median concentrations of chlorophyll *a* in samples collected from the study lakes ranged from 0.5 – 8.2 µg/L (Figure 12). 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 Waushara County Lakes Study. 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.

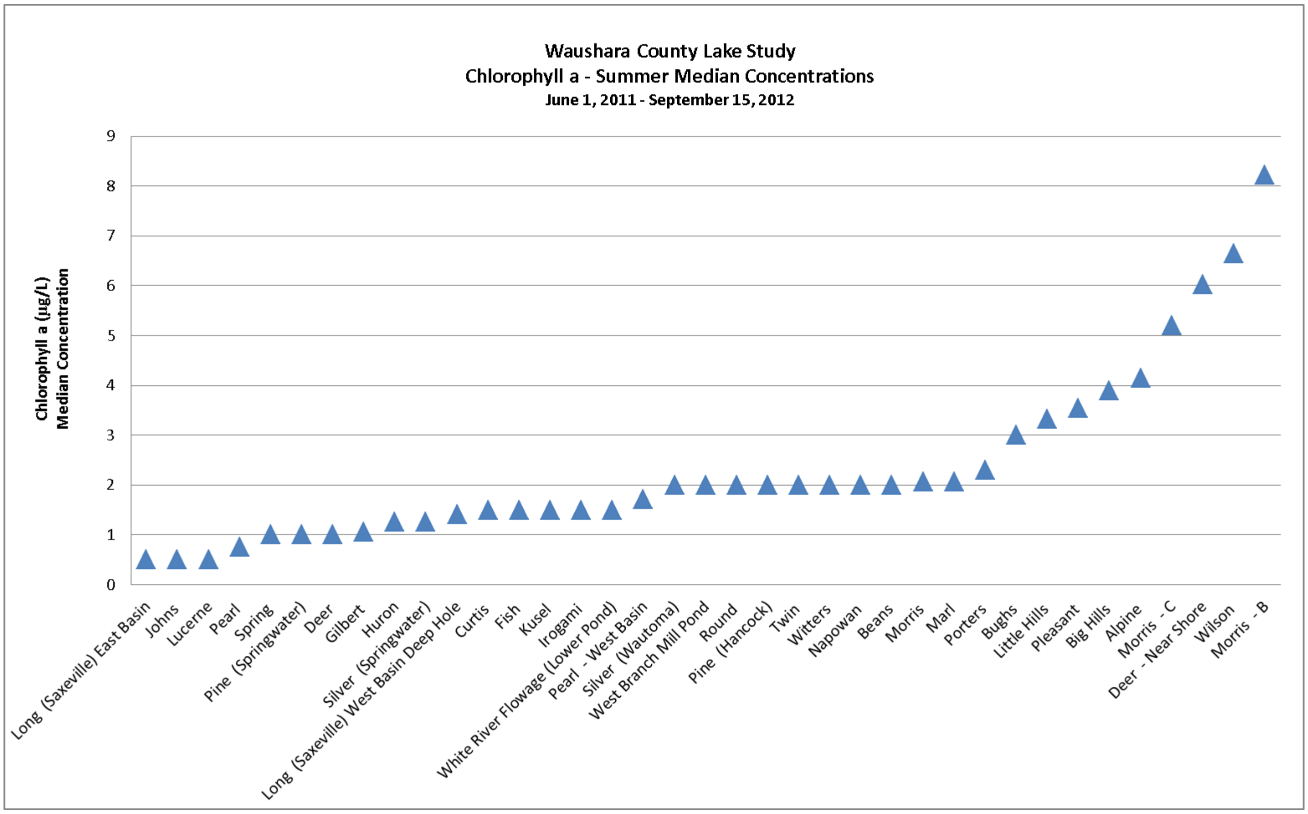


Figure 12. Median summer concentrations of chlorophyll *a* (µg/L) in Waushara County lakes (2011-2012).

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 13). 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 14).

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.

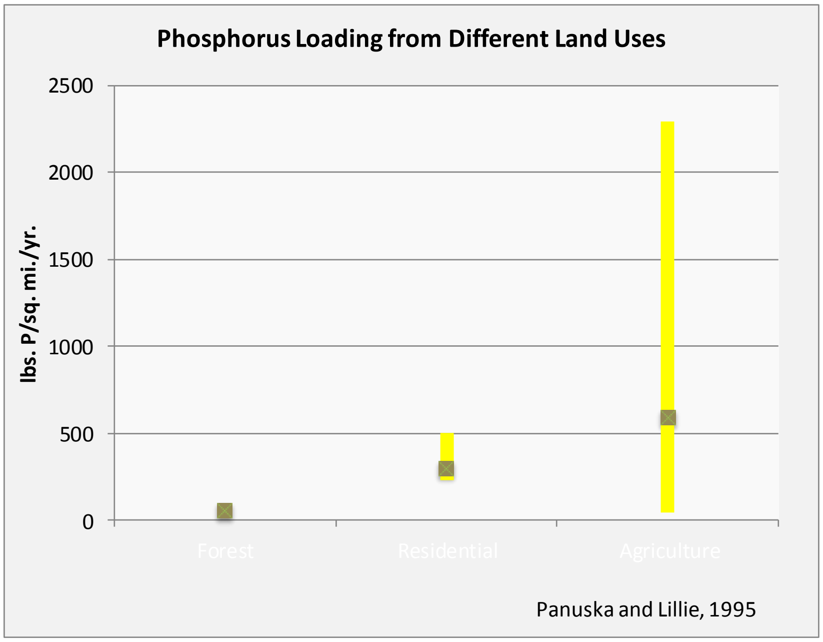


Figure 13. Range of measured phosphorus loading from different land uses in Wisconsin. Median loads are represented by the brown markers (Panuska and Lillie, 1995).

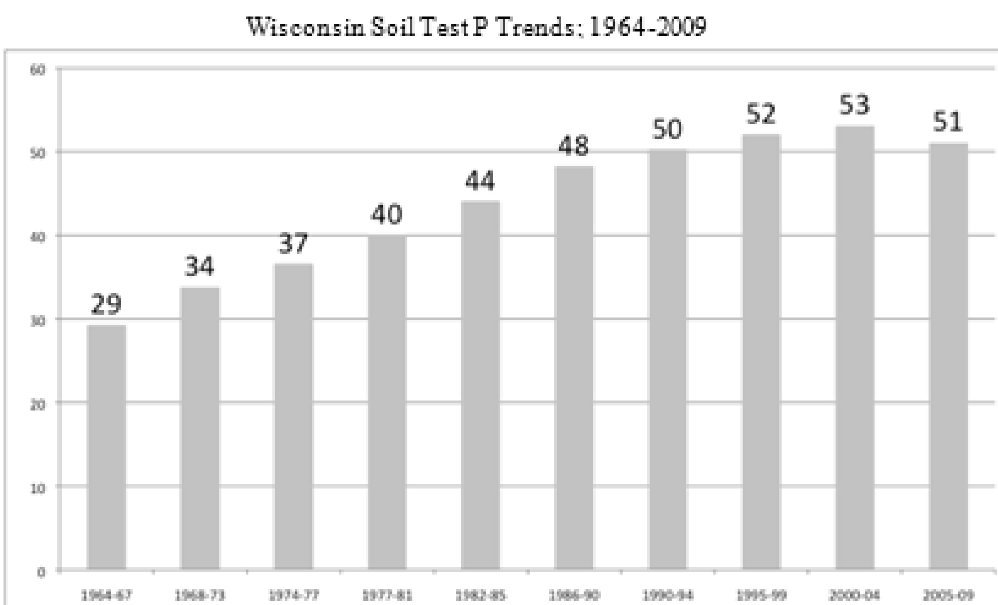


Figure 14. Soil test phosphorus results (ppm) from Wisconsin soils 1964-2009 (Peters, 2011).

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 15).

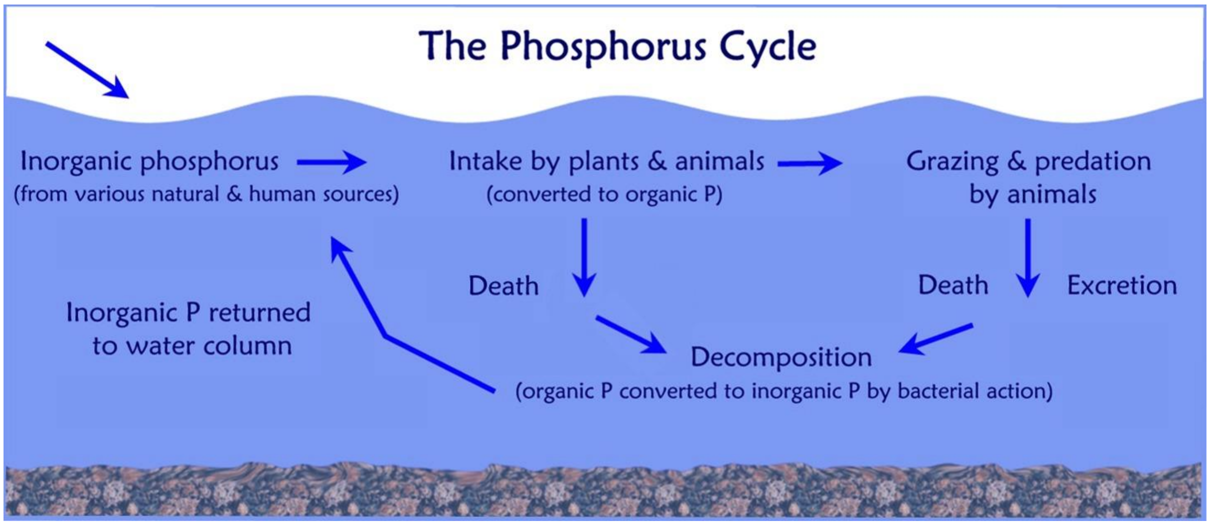


Figure 15. Schematic demonstrating phosphorus cycling within a lake.

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 **Error! Reference source not found.** 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 Waushara County lakes eight times/year between fall 2010 and fall 2012; 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 16 - Figure 19. While individual samples had concentrations above the phosphorus criteria, based on median concentrations for each year, none of the lakes exceeded the phosphorus criteria. However, 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.

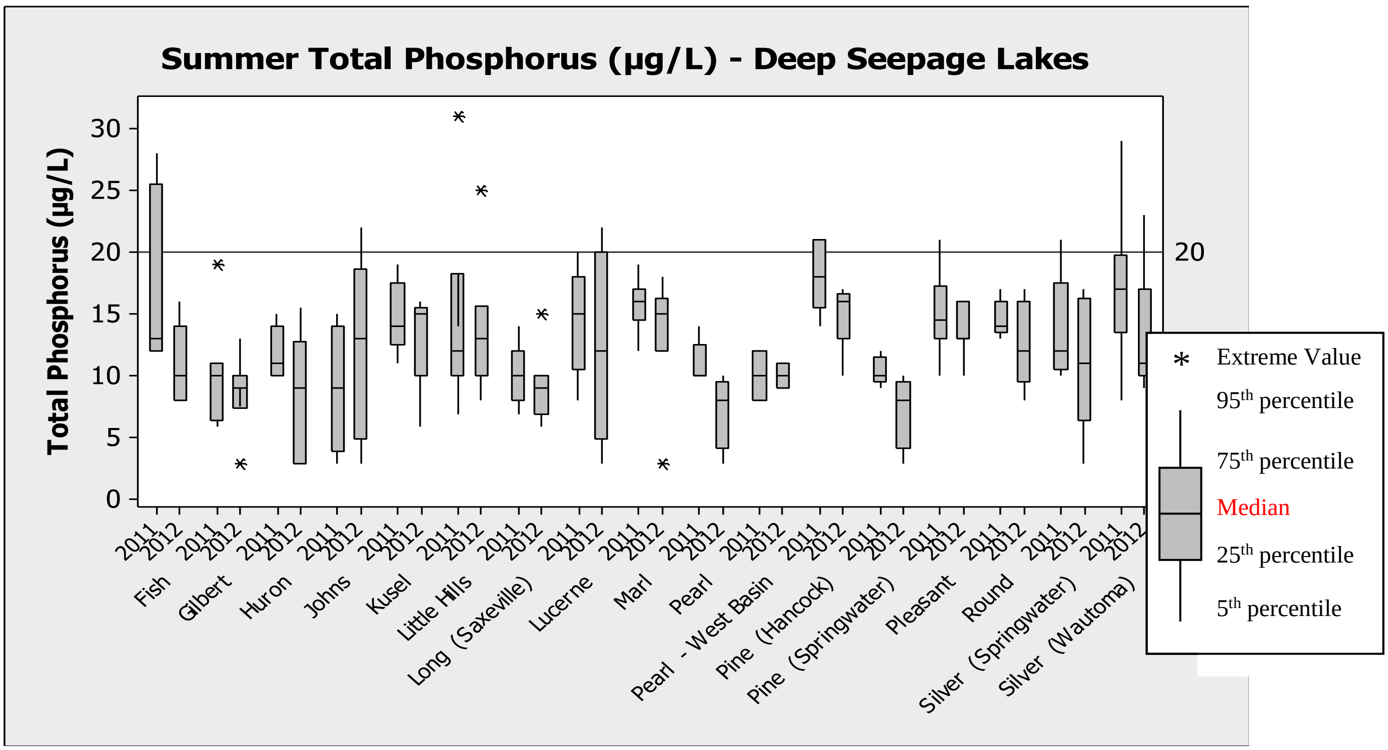


Figure 16. Summer total phosphorus concentrations in deep seepage lakes in Waushara County Lakes Study, 2011-2012.

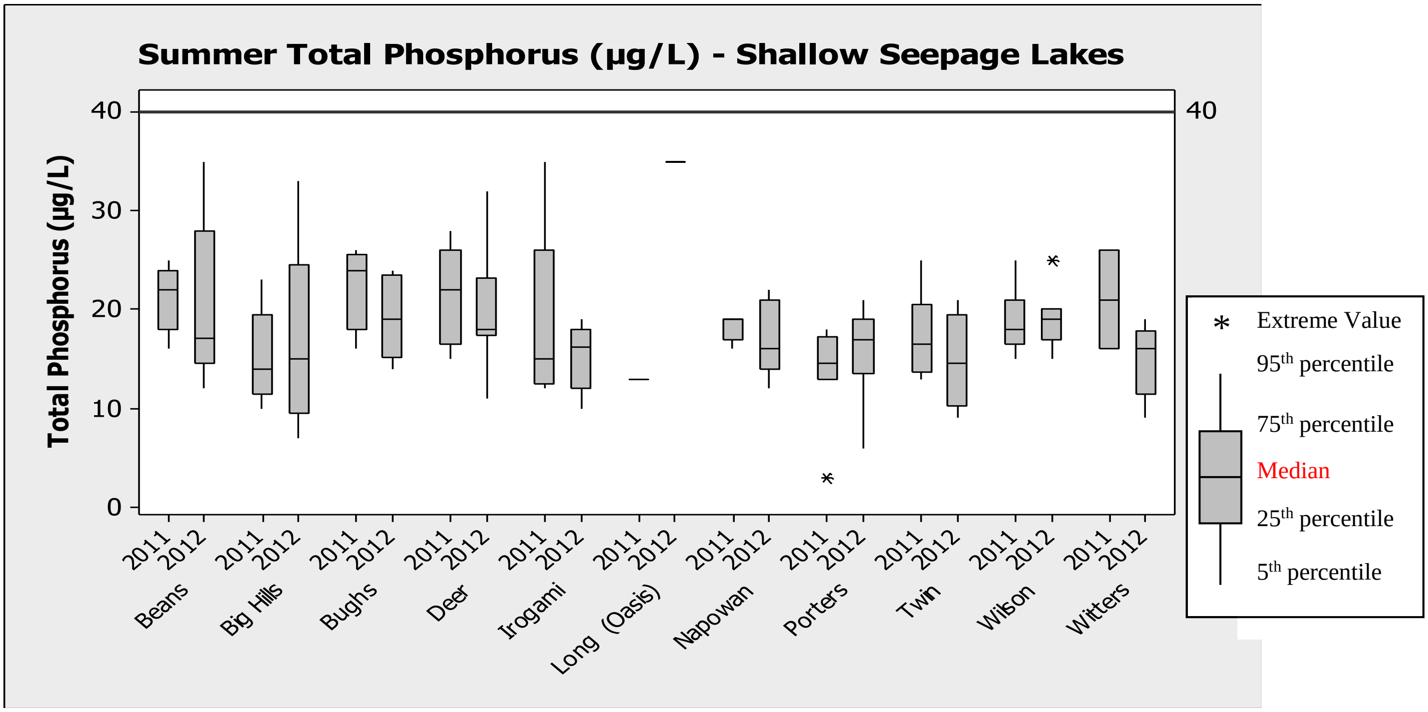


Figure 17. Summer total phosphorus concentrations in shallow seepage lakes in Waushara County Lakes Study, 2011-2012.

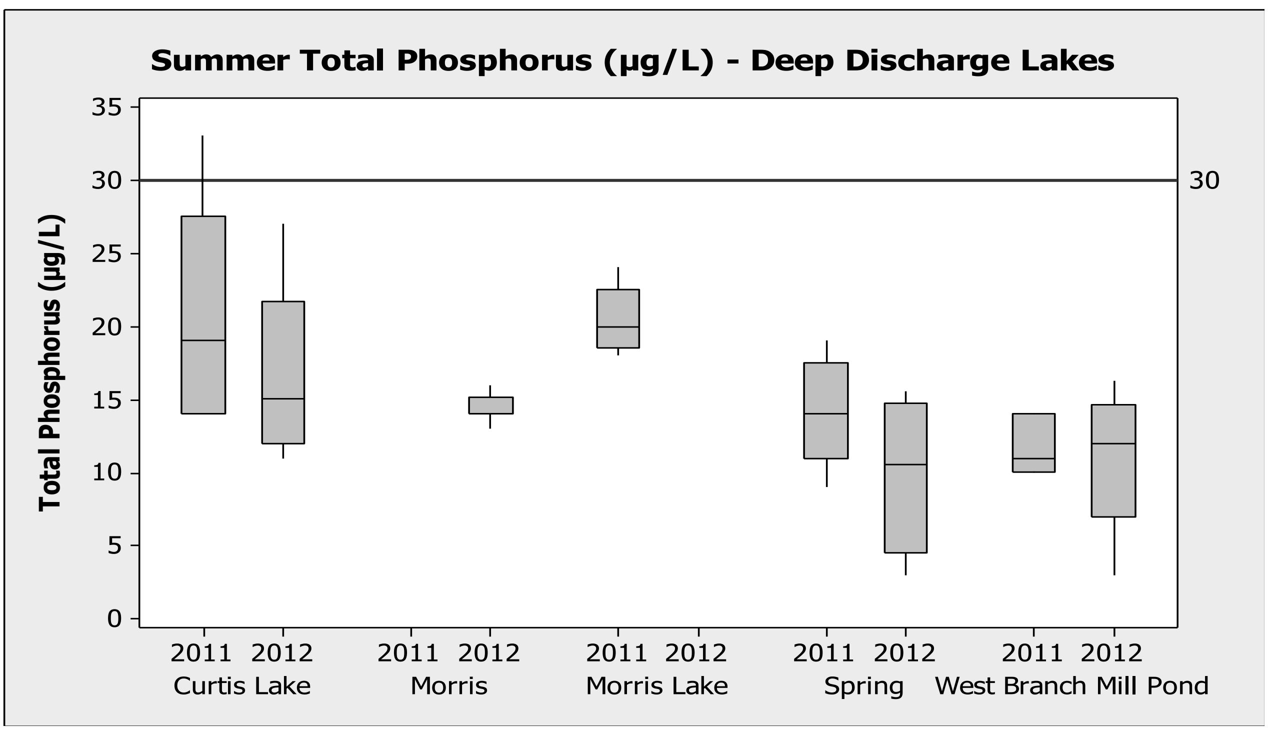


Figure 18. Summer total phosphorus concentrations in deep drainage lakes in the Waushara County Lakes Study, 2011-2012.

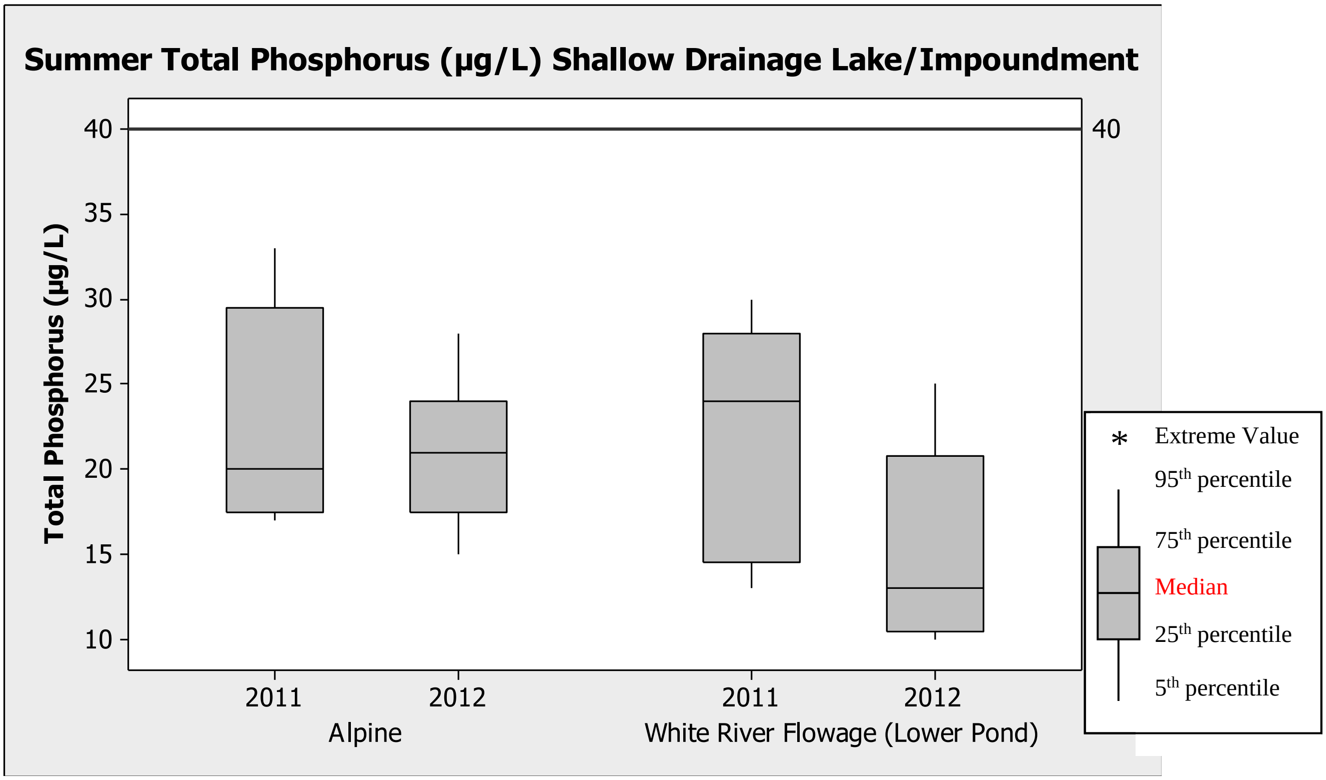


Figure 19. Summer total phosphorus concentrations in shallow drainage lakes and impoundments in the Waushara County Lakes Study, 2011-2012.

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 20.

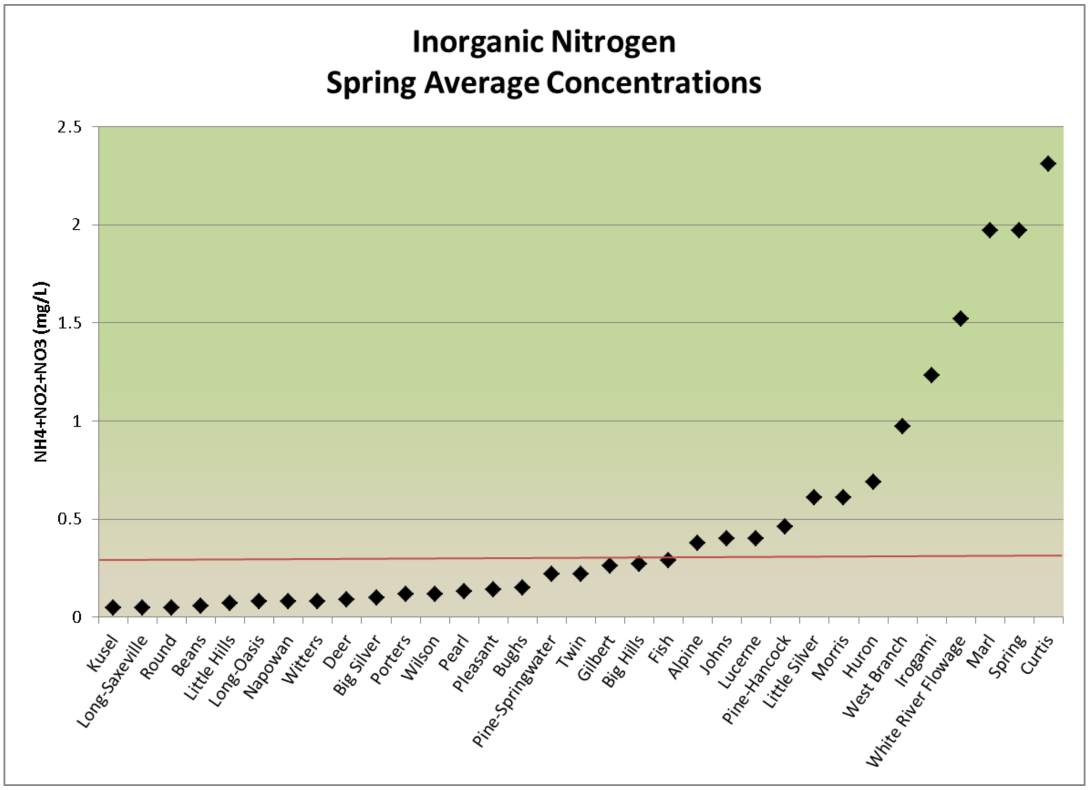


Figure 20. Average concentrations of inorganic nitrogen (mg/L) during the spring. Waushara County Lakes Study, 2010-2012.

Phosphorus and Chorophyll *a* (algae)

Chlorophyll-*a* is a measure of algae in water samples. Overall, the chlorophyll- *a* measured in the Waushara 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 can chlorophyll *a* by lake type are shown in Figure 21- Figure 23. 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. The Secchi disk (water clarity) results from many of the Waushara County lakes suggested that at certain times of year, the algal blooms were occurring at depths greater than 6 feet; therefore, the sample results for chlorophyll *a* may be skewed to be lower than what is actually occurring in the lake.

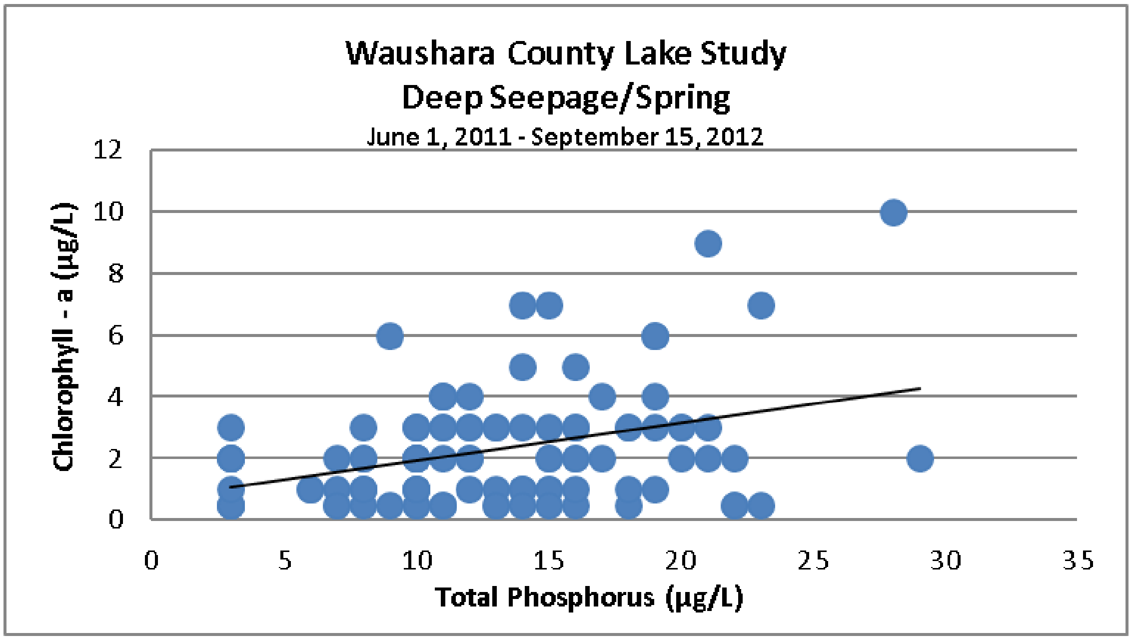


Figure 21. Chlorophyll-a and phosphorus concentrations (µg/L) in samples collected from deep seepage and spring lake types in Waushara County. Summer 2011 and 2012.

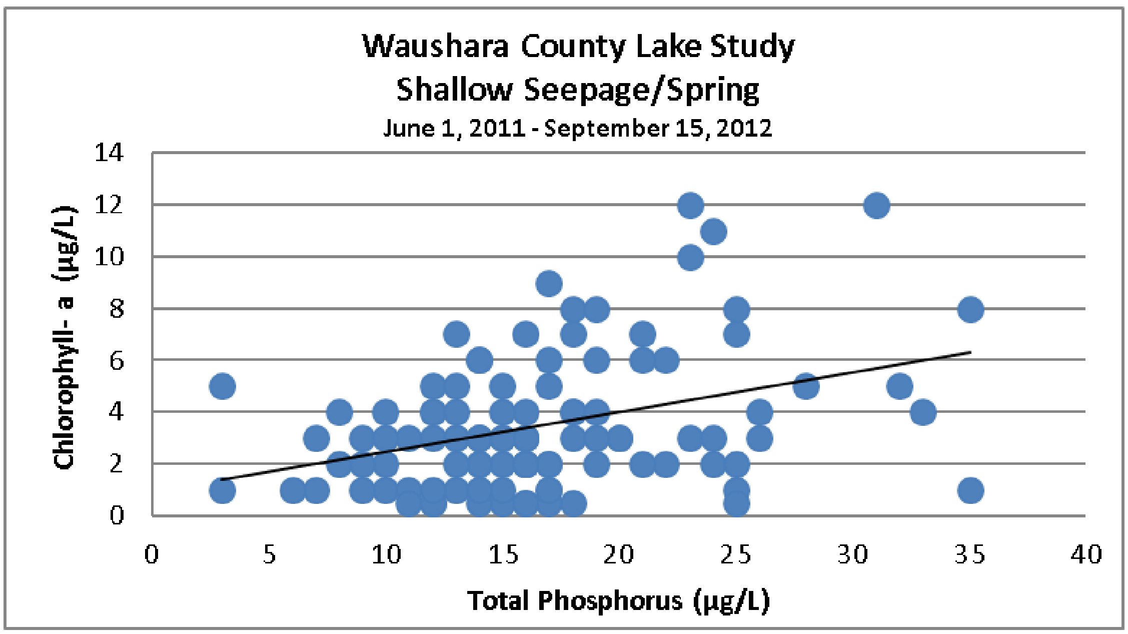


Figure 22. Chlorophyll-a and phosphorus concentrations (µg/L) in samples collected from shallow seepage and spring lake types in Waushara County. Summer 2011 and 2012.

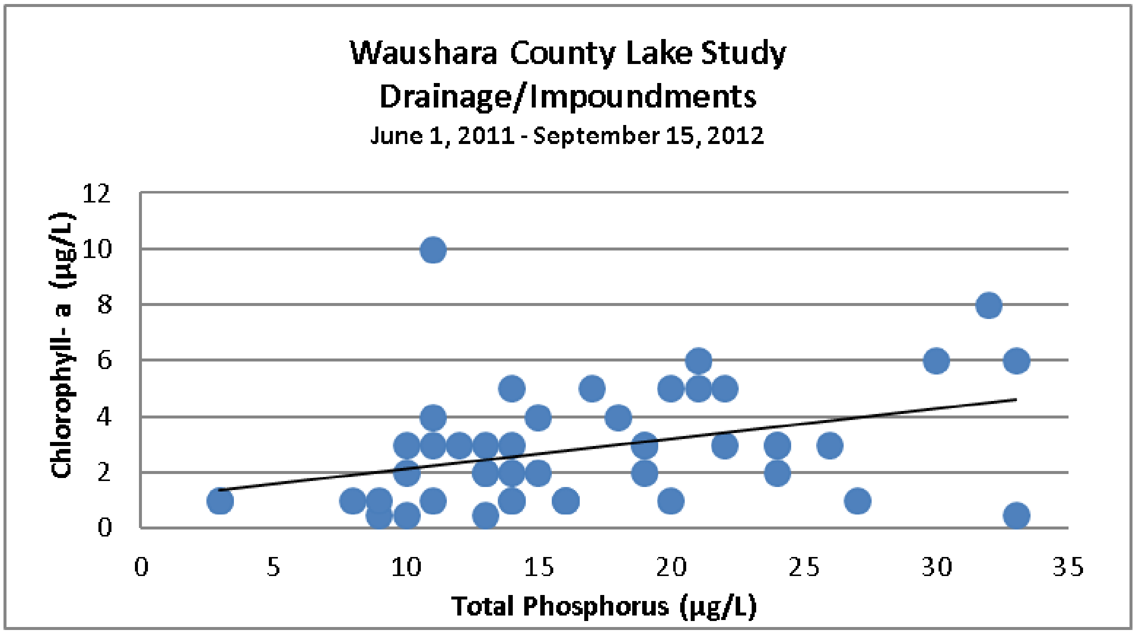


Figure 23. Chlorophyll-*a* and phosphorus concentrations (µg/L) in samples collected from drainage and impoundment lake types in Waushara County. Summer 2011 and 2012.

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 Waushara County study lakes, the average concentrations of total hardness ranged from 52 to 240 mg/L (Figure 24). In general, lakes with hardness concentrations less than 90 mg/L show a greater response by algae to inputs of phosphorus.

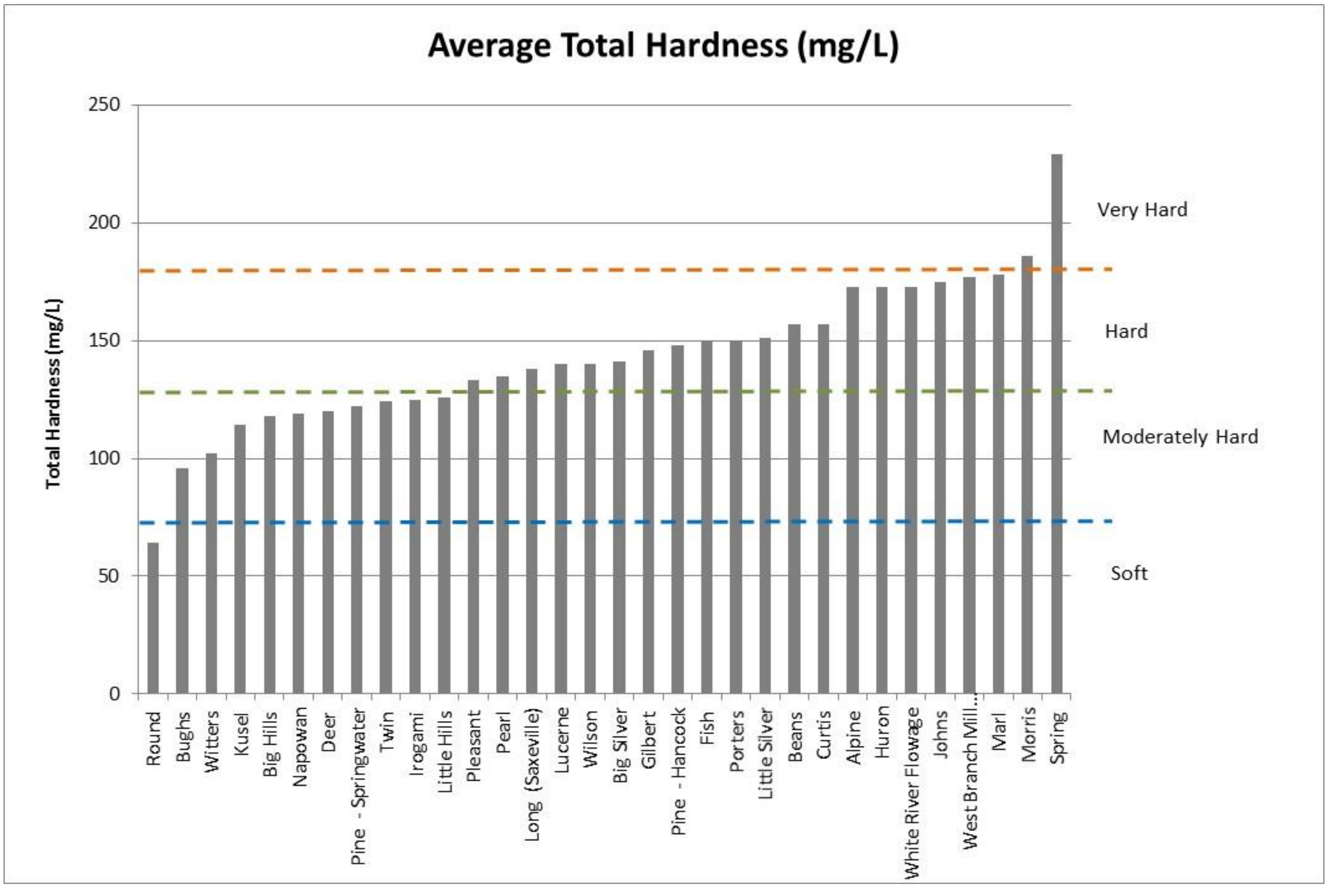


Figure 24. Average total hardness concentrations (mg/L) measured in Waushara County lakes in spring and fall overturn samples (2010-2012).

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 Waushara County lakes, ranging from natural concentrations, less than 1 mg/L in Twin Lake, to elevated concentrations of 11mg/L in Bughs Lake (Figure 25). Sodium concentrations also had a wide range of 1 - 7.5 mg/L in the Waushara County lakes, (Figure 26). Concentrations of potassium in the Waushara County lakes averaged less than 2 mg/L, which is considered natural background concentrations for this part of the state (Figure 27).

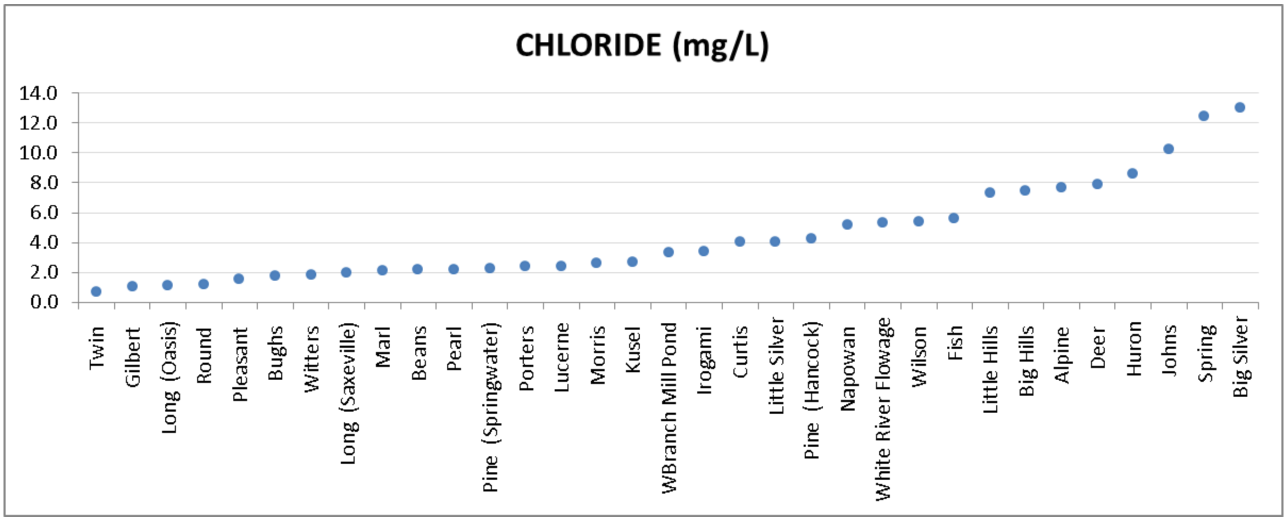


Figure 25. Average spring and fall overturn chloride concentrations (mg/L) in Waushara County lakes, (2010-12).

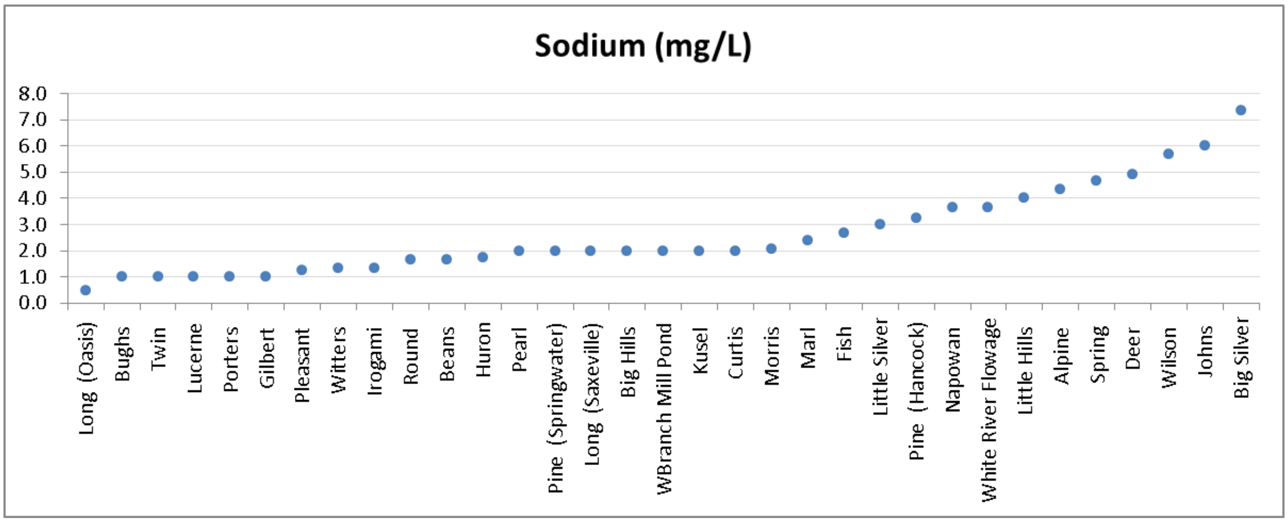


Figure 26. Average spring and fall overturn sodium concentrations (mg/L) in Waushara County lakes (2010-2012).

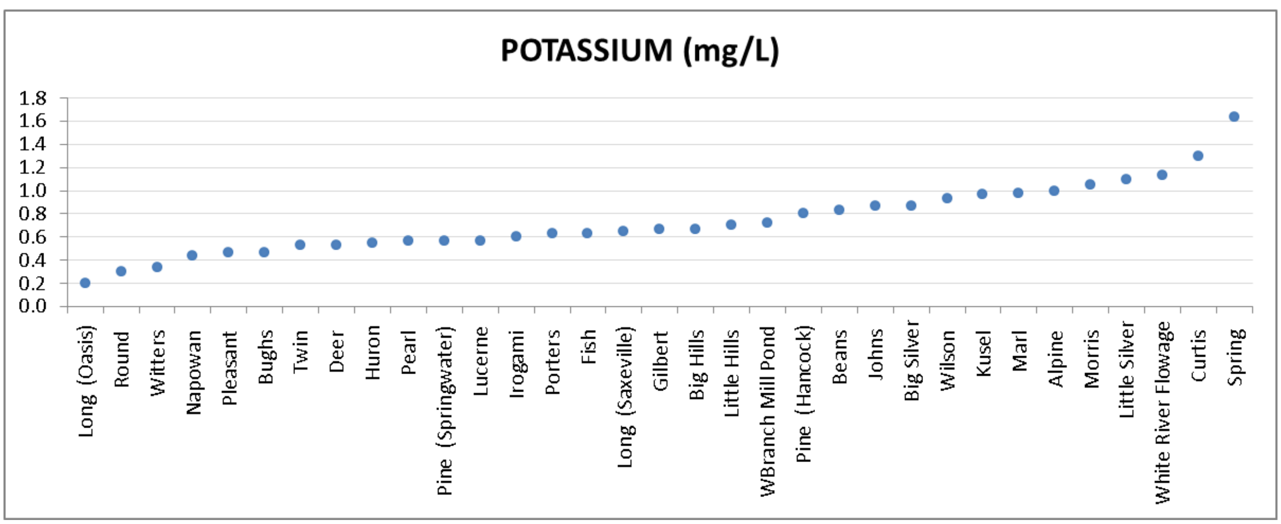


Figure 27. Average spring and fall overturn potassium concentrations (mg/L) in Waushara County lakes (2010-2012).

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 effect the diversity of plants in a lake. The aquatic plant community was surveyed in all of the Waushara County study lakes. The number of aquatic plant species identified in each Waushara County lake is shown in Figure 28; lakes with "species of special concern" in Wisconsin are identified in red.

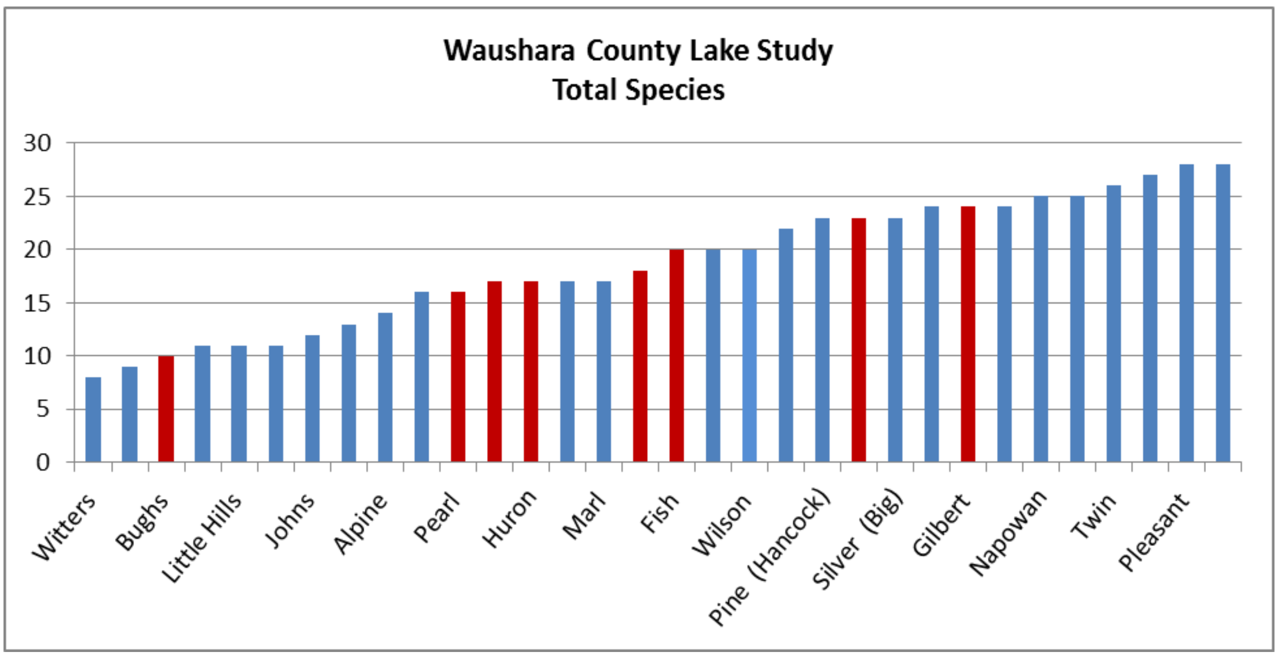


Figure 28. Total number of species of aquatic plants found in Waushara County Lakes based on 2011-2013 field surveys. Red bars indicate lakes with species of special concern.

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 Waushara County lakes are shown in Figure 30. 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.

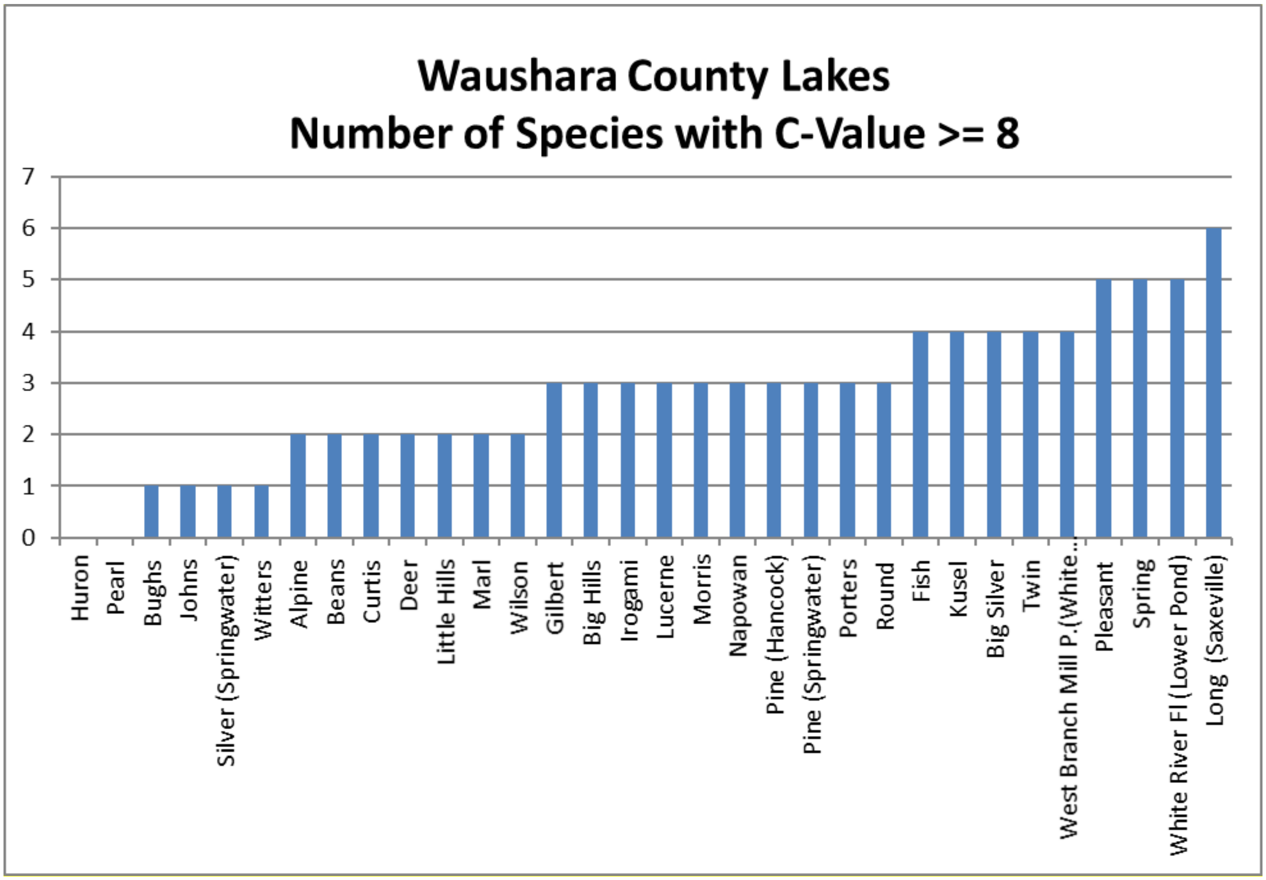


Figure 29. The number of species with a C-value greater than 8 in Waushara County lakes, based on 2011-2013 field surveys.

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 depths, and the removal of aquatic plants. The range of FQI values for the Waushara County study lakes are shown in Figure 30.

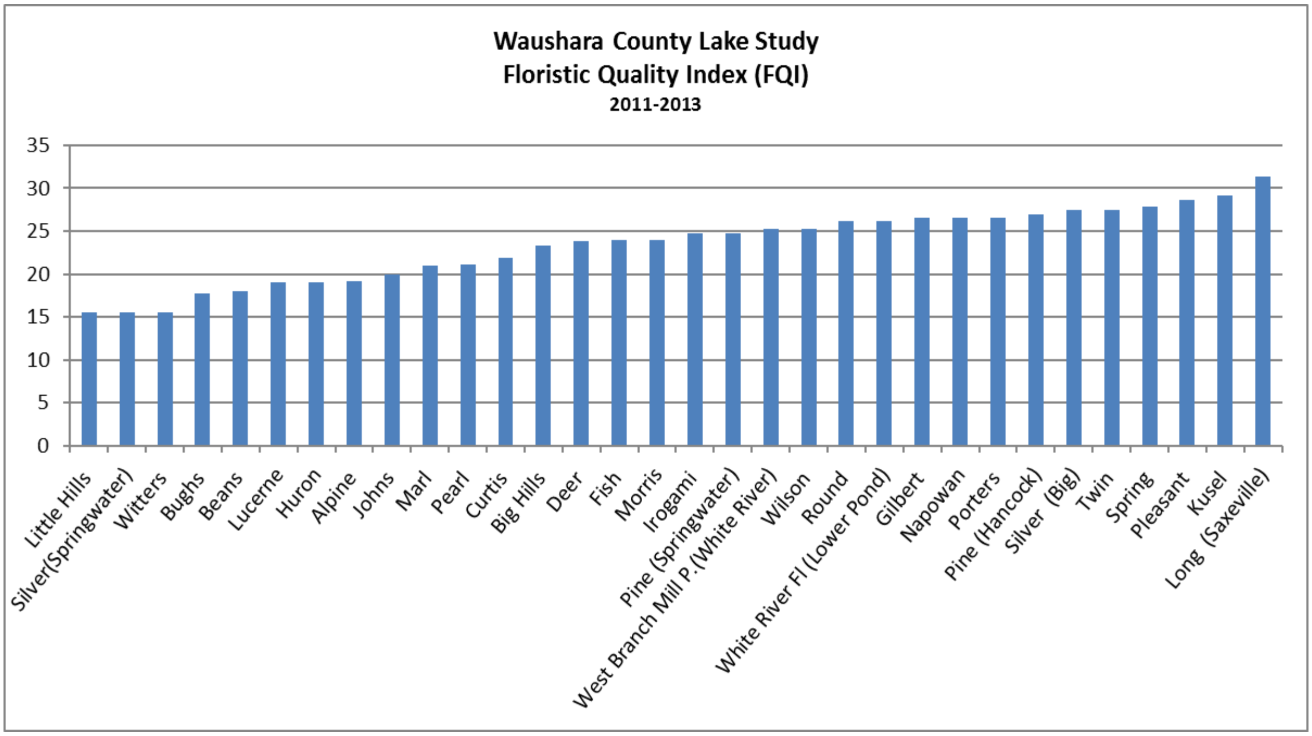


Figure 30. Floristic Quality Index (FQI) based on aquatic plant surveys conducted in the Waushara County study lakes. Summer 2011-2013.

Aquatic Invasive Species

Aquatic invasive species (AIS) are spreading throughout Wisconsin, including Waushara 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 in 2016 can be found in Table 6.

Table 6. Aquatic invasive species in Waushara County Lakes, based on 2016 Wisconsin Department of Natural Resources records.

Lake Name	Invasive Aquatic Plant Species
Alpine	Curly-Leaf Pondweed, Eurasian Water-Milfoil, Hybrid Eurasian / Northern Water-Milfoil, Japanese Knotweed, Ornamental water lilies (non-native Nymphaea sp.) , Purple Loosestrife
Bughs	Curly-Leaf Pondweed, Eurasian Water-Milfoil, Hybrid Eurasian / Northern Water-Milfoil
Deer	Eurasian Water-Milfoil
Fish	Curly-Leaf Pondweed, Eurasian Water-Milfoil
Gilbert	Eurasian Water-Milfoil, Zebra Mussel
Little Hills	Eurasian Water-Milfoil, Hybrid Eurasian / Northern Water-Milfoil, Phragmites (non-native)
Big Hills	Eurasian Water-Milfoil, Hybrid Eurasian / Northern Water-Milfoil, Phragmites (non-native)*, Zebra Mussel
Irogami	Curly-Leaf Pondweed, Eurasian Water-Milfoil
Johns	Eurasian Water-Milfoil
Kusel	Curly-Leaf Pondweed, Hybrid Eurasian / Northern Water-Milfoil
Huron	Chinese Mystery Snail, Eurasian Water-Milfoil
Lucerne	Curly-Leaf Pondweed, Eurasian Water-Milfoil
Morris	Curly-Leaf Pondweed, Eurasian Water-Milfoil, Hybrid Eurasian / Northern Water-Milfoil, Phragmites (non-native)*, Purple Loosestrife*, Yellow Iris, Zebra Mussel
Napowan	Curly-Leaf Pondweed, Eurasian Water-Milfoil, Hybrid Eurasian / Northern Water-Milfoil
Long (Saxeville)	Purple Loosestrife
Marl	Curly-Leaf Pondweed, Eurasian Water-Milfoil, Hybrid Eurasian / Northern Water-Milfoil
Pearl	Curly-Leaf Pondweed, Eurasian Water-Milfoil
Pine (Springwater)	Eurasian Water-Milfoil
Pine (Hancock)	Eurasian Water-Milfoil, Hybrid Eurasian / Northern Water-Milfoil
Pleasant	Chinese Mystery Snail, Eurasian Water-Milfoil, Hybrid Eurasian / Northern Water-Milfoil, Phragmites (non-native)*
Porters	Eurasian Water-Milfoil, Purple Loosestrife
Round	Eurasian Water-Milfoil
Silver	Curly-Leaf Pondweed, Eurasian Water-Milfoil*, Flowering Rush, Zebra Mussel*
Silver	Curly-Leaf Pondweed, Eurasian Water-Milfoil, Hybrid Eurasian / Northern Water-Milfoil, Zebra Mussel
Spring	Curly-Leaf Pondweed, Eurasian Water-Milfoil
Twin	Eurasian Water-Milfoil, Phragmites (non-native), Phragmites (non-native)*, Purple Loosestrife
West Branch Mill P.(White River)	Curly-Leaf Pondweed, Eurasian Water-Milfoil
White River Fl (Lower Pond)	Curly-Leaf Pondweed, Eurasian Water-Milfoil, Flowering Rush*, Ornamental water lilies (non-native Nymphaea sp.)
Wilson	Curly-Leaf Pondweed, Eurasian Water-Milfoil, Hybrid Eurasian / Northern Water-Milfoil, Purple Loosestrife
Witters	Phragmites (non-native)

Shorelands

From: Shoreland Survey of Waushara County Lakes, Dan McFarlane, 2011.

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 Waushara County lakes, shorelands were evaluated by the Center for Land Use Education and Waushara County as a part of the Waushara County Lakes Study. 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.

In summary, the Waushara County shoreland assessment found:

- 32 lakes with shoreline assessments encompassing 74 miles of shore and 3,275 acres of water (Long Lake – Plainfield and Lake Poygan only have photo inventories).
- 89 miles of shoreline photographed with GPS referenced photos
- 70 miles (95%) of the inventoried shoreline is vegetated
- 55 miles (74%) of the inventoried shoreline has some kind of human influence (dock, structure, beach, seawall, rip-rap).

The shoreline scoring system is based on the presence/absence and abundance of shoreline features as well as their proximity to the water's edge. From these scores, the lakes were ranked on the basis of shoreland vegetation, human influence, erosion, and structures or buildings; these scores were summed to produce a total cumulative score for each lake. Lakes with lower cumulative scores represent shorelines that are more degraded, and lakes with healthy overall shorelines have higher cumulative scores.

Vegetation Scores by Lake

Higher vegetation scores indicate lakes with more natural shoreline vegetation within 35 feet of the water. Vegetation indices include: canopy cover, understory, shrubs, tall grasses, leaf pack, woody structure, and wetlands.

Lake *	Vegetation Score
Lake Lucerne	15
White River Flowage	14
Beans Lake	14
Curtis Lake	12.4
Twin Lake	12.1
Spring Lake	11.9
Deer Lake	11.6
Pine Lake Hancock	11
Lake Napowan	10.9
Mill Pond	10.9
Little Hills Lake	10.1
Porters Lake	9.9
Kusel Lake	9.6
Gilbert Lake	9.5
Fish Lake	9.4
Round Lake	9.3
Pearl Lake	9.1
Big Hills Lake	8.6
Lake Huron	8.1
Pine Lake Springwater	8
Wilson Lake	7.3
Lake Morris	7.2
Marl Lake	7.1
Johns Lake	7.1
Irogami Lake	6.7
Long Lake Saxville	6.7
Lake Alpine	6.5
Witters Lake	6.2
Pleasant Lake	6.2
Bughs Lake	5.2
Little Silver Lake	4.6
Big Silver Lake	4

High vegetation score

Medium vegetation score

Human Influence Scores by Lake

Human influences represent the development status of the shoreline such as the presence/absence of beaches, docks, seawall, and rip-rap. Lakes with a larger absolute value are considered to have more degraded shorelines.

Lake *	Human Influence Scores
Lake Lucerne	-0.4
Beans Lake	-0.7
Deer Lake	-0.9
White River Flowage	-1
Pine Lake Hancock	-1
Twin Lake	-1
Porters Lake	-1.8
Spring Lake	-2
Kusel Lake	-2
Marl Lake	-2
Lake Napowan	-2.1
Mill Pond	-2.2
Little Hills Lake	-2.2
Curtis Lake	-2.2
Johns Lake	-2.7
Fish Lake	-2.7
Gilbert Lake	-2.8
Round Lake	-3.3
Lake Huron	-3.3
Irogami Lake	-3.3
Lake Morris	-3.4
Lake Alpine	-3.7
Long Lake Saxville	-3.9
Pine Lake Springwater	-3.9
Big Hills Lake	-4.1
Little Silver Lake	-4.1
Witters Lake	-4.4
Wilson Lake	-4.4
Pearl Lake	-4.5
Bughs Lake	-4.8
Pleasant Lake	-4.8
Big Silver Lake	-5.1

Low human influence score

Medium human influence score

Erosion Scores by Lake

These scores indicate the presence/absence of erosion at the water's edge. Larger scores represent lakes with erosion problems. Examples include lakes with exposed ground with steep slopes, undercut banks, and gully erosion. These lakes may experience increased runoff because water cannot enter the ground and will be washed quickly to the lake.

Lake *	Erosion Scores
Bughs Lake	8
Curtis Lake	8
Wilson Lake	8
White River Flowage	8
Lake Alpine	8
Spring Lake	7.9
Johns Lake	7.6
Irogami Lake	7.5
Porters Lake	7.4
Lake Huron	7.4
Pine Lake Hancock	7.3
Mill Pond	7.2
Kusel Lake	7.2
Lake Morris	7.1
Little Silver Lake	7.1
Witters Lake	7
Pine Lake Springwater	6.4
Lake Napowan	6.4
Little Hills Lake	6.3
Beans Lake	6.2
Pleasant Lake	6.1
Marl Lake	6.1
Big Silver Lake	6
Big Hills Lake	6
Deer Lake	6
Twin Lake	5.9
Fish Lake	5.7
Long Lake Saxville	5.7
Gilbert Lake	5.3
Pearl Lake	4.9
Round Lake	4.2
Lake Lucerne	4.2

High erosion score

Medium erosion score

Structure Scores by Lake

This table is sorted by each lake's structure score. Lakes with a larger absolute value (near the bottom) have more developed shorelines. Examples include main structures, boathouses, docks, and patios within close proximity to the water's edge.

Lake *	Structure Score
Lake Lucerne	-0.1
Beans Lake	-0.4
Deer Lake	-0.4
Twin Lake	-0.4
White River Flowage	-0.6
Lake Alpine	-0.6
Porters Lake	-0.8
Curtis Lake	-0.8
Pine Lake Hancock	-1
Kusel Lake	-1.1
Marl Lake	-1.1
Little Hills Lake	-1.4
Lake Napowan	-1.6
Spring Lake	-1.6
Gilbert Lake	-1.8
Mill Pond	-1.8
Fish Lake	-2
Lake Huron	-2.3
Irogami Lake	-2.3
Wilson Lake	-2.3
Lake Morris	-2.5
Johns Lake	-2.6
Little Silver Lake	-2.7
Round Lake	-2.7
Pearl Lake	-2.9
Bughs Lake	-2.9
Long Lake Saxville	-2.9
Big Hills Lake	-3.1
Pleasant Lake	-3.2
Pine Lake Springwater	-3.5
Witters Lake	-3.9
Big Silver Lake	-4.3

High structure score

Medium structure score

Total Score by Lake

This category represents the cumulative scores for vegetation, human influence, erosion, and structures scores for each lake. Lakes with lower scores represent shorelines that are more degraded. Examples include limited natural vegetation, developed shorelines, and exposed ground that increases surface water runoff to the lake. Lakes with healthy overall shorelines have higher total scores.

Lake *	Total Score
White River Flowage	20.4
Beans Lake	19
Lake Lucerne	18.7
Curtis Lake	17.4
Twin Lake	16.5
Pine Lake Hancock	16.3
Deer Lake	16.3
Spring Lake	16.2
Porters Lake	14.8
Mill Pond	14.1
Kusel Lake	13.6
Lake Napowan	13.6
Little Hills Lake	12.7
Fish Lake	10.4
Gilbert Lake	10.2
Lake Alpine	10.2
Marl Lake	10.1
Lake Huron	9.9
Johns Lake	9.4
Wilson Lake	8.6
Irogami Lake	8.6
Lake Morris	8.5
Round Lake	7.5
Big Hills Lake	7.4
Pine Lake Springwater	7
Pearl Lake	6.7
Bughs Lake	5.5
Long Lake Saxville	5.5
Witters Lake	5
Little Silver Lake	4.9
Pleasant Lake	4.4
Big Silver Lake	0.6

High total score

Medium total score

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 CaCO3. 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 (CaCO3) 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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