GUIDE FOR BACKGROUND INFORMATION AND INTERPRETATION OF PORTAGE COUNTY LAKE STUDY RESULTS AND RECOMMENDATIONS

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And excerpts from *Understanding Water Quality Data*

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Portage County

Location

Portage County is in the central part of Wisconsin, bordered on the north by Marathon County, on the east by Waupaca County, on the south by Waushara and Adams Counties, and on the west by Wood County. The total land area is 806 square miles, or 518,400 acres (Portage County Land and Water Plan)

Geology and Soil

Portage County is underlain by crystalline rocks of Precambrian age, and sandstone of Cambrian age, which are mantled by glacial deposits of Pleistocene Age. The crystalline rock is exposed and weathered in the northwest part of the county. These are generally our poorly drained soils. However, in the southern part of the county, sandstone overlies this crystalline rock.

The eastern half and south part of the county is covered with sand, gravel, and rock deposited by retreating glaciers (glacial drift). Deposits range from a few feet in the north to more than 350 feet in the southeast. Some of this material is also deposited in moraine and intermoraine drift, primarily from the Green Bay lobe of the glacier (i.e. Arnott Moraine). This glacial topography of irregular hills, which are sometimes quite steep, can create problems from soil erosion when the soil is exposed due to different types of land use practices. Because of the irregular hills, conservation practices are sometimes difficult to apply to correct soil erosion problems. (Portage County Land and Water Plan, 2004) (Figure 1)

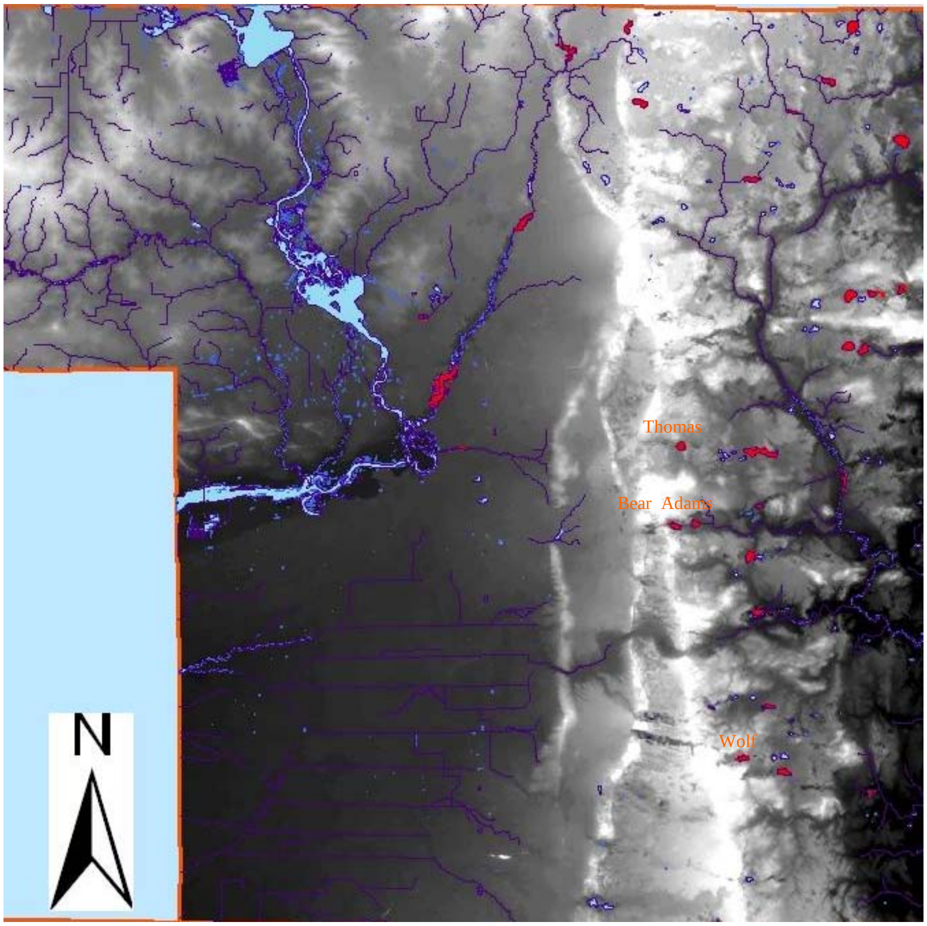
During relatively recent geologic times, the Central Wisconsin Sand Plain was home to glacial Lake Wisconsin. That lake, extending from what is now Portage County south to Sauk and Columbia counties, was fed by melting glaciers and streams. Water entering glacial Lake Wisconsin carried large quantities of sediment, some of which remains as the sand and gravel covering much of the Central Wisconsin Sand Plain up to several hundred feet deep. After the glaciers' final retreat, glacial Lake Wisconsin drained. The deposited sands and gravel which remain are a productive groundwater aquifer.

The Wisconsin River generally divides major soil types. Tight, clay soil dominates the northwest, and light, sandy soils are found in the east and south. This obviously creates differences in land uses, and significantly different techniques to solve local problems which may arise.

The primary land uses that impact soil resources in Portage County are agricultural, surface mining, and residential/urban development. The northwest and eastern townships in the moraine are primarily dairy production, while the central sand plain has developed into an irrigated cash crop region. Although these regions have generally been identified as having annual soil loss rates of 5 tons/acre or less, certain relationships of specific land use methods, soil type, percent of slope, and length of slope result in some sub-watersheds having eight or more tons/acre of soil loss/year. Center pivot irrigation techniques have also created an opportunity for wind erosion in the Central Wisconsin Sand Plain region. If not managed properly, some specific techniques can result in areas generally having a soil loss of 5 tons/acre/year, and with windstorm events in the range of 10-20 tons/acre/year.

Residential development in the moraine region has also resulted in some areas with high erosion rates. This is primarily due to poor site layout and improper methods of soil protection during construction. (Portage County Land and Water Plan, 2004) Eroded soil (which contains nutrients) can make its way to lower regions that include wetlands, lakes, and streams potentially filling in depressions and fertilizing waterbodies.

Figure 1. Topography of Portage County (higher elevation are lighter) and location of study lakes.



Surface and Groundwater

Surface and groundwater interact closely in Portage County. Fluctuations in precipitation, recharge, evapo-transpiration, discharge, drainage and storage are reflected by changes in groundwater levels and surface water runoff whether they are seasonal or part of long-term drought and flood cycles. Neither groundwater nor surface water can be considered as a separate source of supply (Holt, 1965).

In Portage County surface water drains to two distinct river basins: The Wisconsin River Basin and the Wolf River Basin. The Wisconsin River passes through western Portage County with numerous streams feeding into it. The lakes in this study are predominantly located in the Wolf River Basin, in the eastern half of the County where the hilly topography, internally drained kettle lakes and sandy soils are a result of glacial drift depositions. The lakes and streams in this area are primarily groundwater fed with surface runoff inputs often originating less than 1/4 mile from surface water.

Many community water systems and private residences and farms in Portage County use wells developed in the glacial deposits. As a result, the wells are often less than 100 feet deep, in geologic formations with high hydraulic conductivity (dissolved minerals) and with areas that have relatively high groundwater recharge through permeable surface soils.

Changes to the groundwater quality continue to occur from the time water enters the groundwater to the time it is discharged to streams or extracted through pumping. Many of these changes are naturally occurring. For example, as water enters the aquifer, it dissolves naturally occurring minerals increasing its total dissolved solids content. If those dissolved substances include calcium and magnesium, the hardness of the water increases. If the water passes through areas where its oxygen content is sufficiently depleted, dissolved iron and manganese may be acquired by the water. Other changes are reflections of the land use along the groundwater flow path. These include recharge of water percolating from septic drainfields or leaching of land applied fertilizers and pesticides. Understanding the nature and direction of the groundwater flow through the regional aquifer system allows for a greater understanding of groundwater quality and how the aquifer responds to pumping. The source of the water which is removed through pumping is important to protecting the quality and quantity of water.

Lake and Water Characteristics

Lake Types

Many of the following figures and general content come from *Understanding Lake Data* by Shaw et al, 2000. We have modified text and added tables, and figures to adapt this information to Portage County lakes.

The lakes in Portage County today are the result of thousands of years of rainfall onto the geologic terrain remaining after the last glaciers receded approximately 10,000 years ago. Although the definition of a lake may include reference to “standing water,” lakes in Portage County are surface waters through which water continues to move. These inland lakes have surface elevations ranging from 1120 to 1052 ft above sea level, and through connection with streams either directly in surface outflows or through groundwater flow, these lakes continue to lose water downstream and gain water from upstream.

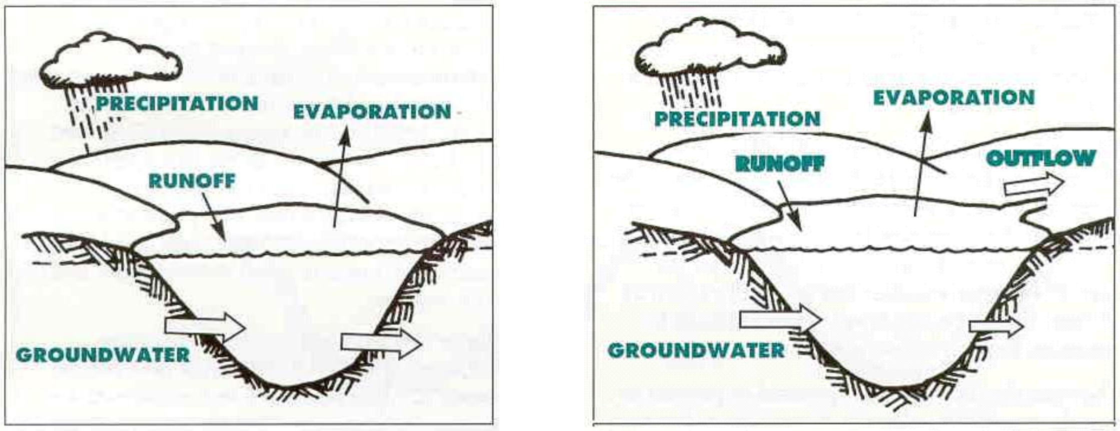
Water present in Portage County lakes originates from either, groundwater inflow, runoff from surrounding land, direct precipitation or inflow from streams and rivers. Different processes influence water quality in each of these sources.

Precipitation is most affected by air quality and may contain some beneficial natural gases and some contaminants from air pollution. It is usually relatively pure and low in phosphorus but does often contain enough nitrogen to support aquatic plants and algae. Lakes dominated by precipitation tend to be acidic and low in hardness and susceptible to acid rain damage.

Unwise land use practices often influence water quality for many years after they end. Groundwater only flows at 1-3 feet per day and once contaminated will take many years/decades to flush out of the flow system. Contaminants present in lakes will also cause problems for many years as they are often loosely held in the lake sediments, which release some of these contaminants annually and therefore influence water quality for many years. They are only very slowly flushed out of the lake via groundwater or stream flow or gradually buried deeper into lake sediments. Some of the lakes in this study are showing a slow improvement in water quality. The land use data suggests this is the result of decreased agricultural activity in the area near the lakeshore. Prevention of contamination is therefore critical for maintaining the quality of our lakes and groundwater.

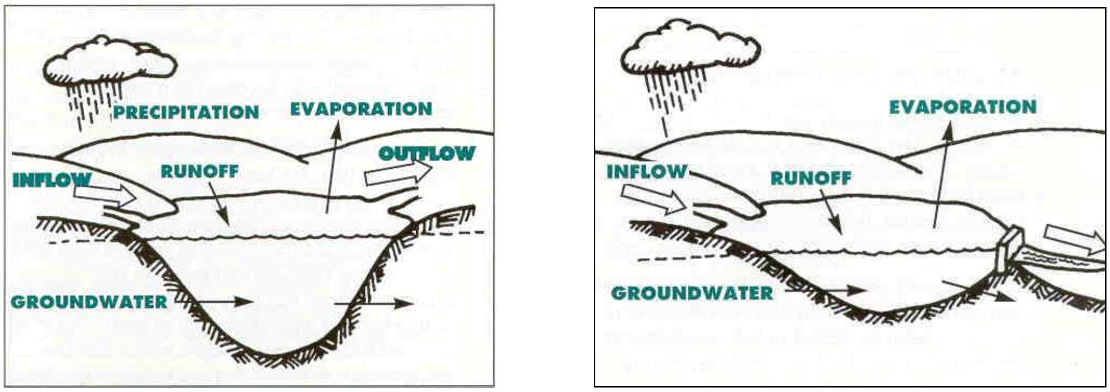
The movement of water is a common way to classify lakes and it provides important information on how lakes function. In Portage County, lakes can be divided into four general categories based on water flow: 1) seepage lakes; 2) groundwater drainage lakes; 3) drainage lakes; and, 4) impoundments. Figure 2 shows a flow chart for determining the lake type, and lists the lakes in the County that were examined as part of this study.

Figure 2. Lake types. Major water inputs and outflows of different lake types. (Large arrows indicate heavy water flow.) (from Shaw, et al, 2000)



1. SEEPAGE LAKE - a natural lake fed by precipitaion, 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 damning a stream. An impoundment is drained by a stream.

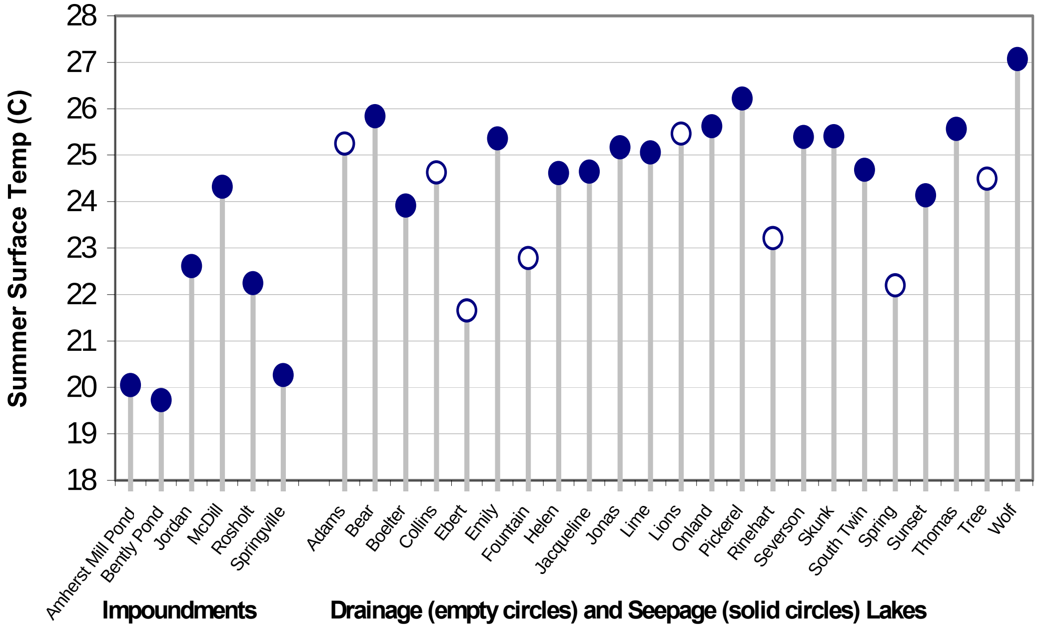
Impoundments are the ponds/lakes that are created when stream flow is restricted. Such impoundments are common lakes in Wisconsin and were often the result of dams used to make energy. The major water source for these lakes is the river. Characteristics of impoundment lakes include relatively large rates of water entry compared to lake size and correspondingly, a short water residence time in the lake. Summer water temperature for the surface layer of these lakes is generally cooler than the seepage lakes because of this high rate of inflow, although often the increased surface area of an impoundment results in warmer water temperatures than in the upstream river. Figure 3 shows the average summer temperature for the lakes in this study. The smaller impoundments have the coolest water temperature. That reflects the relatively large amount of streamflow from predominately groundwater-fed streams that enter these impoundments. The largest impoundment, McDill Pond, has the highest summer temperature reflecting its large size relative to the amount of water that enters and long residence time that allows warming. Major water quality is also largely influenced by land-use practices upstream of the impoundment that influence river water quality. Lakeshore practices are still important to near shore water quality.

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 an impoundment, these were lakes prior to dam installation. A drainage lake receives much of its water from an inlet stream. Surface watersheds for these lakes are larger and are the most important area likely to impact water quality, along with near lake shore activities. The inlet streams may be impacted by both surface runoff and groundwater inflow. **Groundwater drainage lakes** also have a stream outlet that may include a dam, but differ from drainage lakes in that the main source of their water is groundwater, The groundwater watersheds for these lakes are large, and the amount of groundwater entering a groundwater drainage lake is high compared to a seepage lake, so land use in the groundwater watershed is an important influence on lake water quality. Land uses in the surface watershed and activities near the lake shore are also important influences. In terms of summer surface temperature, several of these lakes are similar to the impoundments (Ebert, Rinehart, Fountain and Spring) suggesting these lakes have relatively high inputs of groundwater relative to their size, and several have relatively warm summer water temperatures (Adams, Collins, Lions and Tree) suggesting these lakes have relatively low rates of water flow in comparison to their lake size.

Many of the lakes in the county are **seepage lakes**; that means they are largely fed by groundwater and have no stream inlets or outlets. Water still leaves these lakes, but it does so as groundwater. Melting of ice blocks left behind by the last glacier formed these lakes. Most groundwater usually enters one end of the lake and leaves at the other end of the lake, however, areas of groundwater inflow can also occur sporadically around the lake. Water quality in these lakes is influenced by land use in the ground 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 is particularly important to lake water quality as it can influence both the groundwater quality and runoff water quality. Use of fertilizers in these areas can be particularly damaging as can use of septic systems that result in nutrient leaching and movement to the lake via groundwater. Natural vegetation in the entire near-shore area of lakes is known to minimize the amount of runoff, sediment and nutrients reaching the lake.

Comparing the summer water temperature in Figure 3 with the impoundments and drainage lakes shows that these lakes have relatively warm summer temperatures. This reflects the lower rate of water entry in comparison to lake size and in some cases, increased stratification of the lake.

Figure 3. The mean summer temperature in the top layer of the different lakes demonstrates general differences between the impoundments, drainage lakes, and seepage lakes.



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 recycled annually with spring and fall mixing. Reserve nutrients in lake sediments can continue to recirculate, even after the source of nutrients in the watershed has been controlled. Thus, the effects of watershed protection may not be apparent for a number of years. Nevertheless, lakes with long retention times tend to have the best water quality as shown by the lower levels of the plant nutrient phosphorus in Table 1. Better water quality results from both their greater depth and relatively smaller watersheds.

Table 1. Several characteristics of lakes with different retention times. (Adopted 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 (ug/l)*	94	85	56	48	33	25
Mean DB:LA ratio**	1166	142	42	15	8	6

*Summer values; ug/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 widely from season to season and year to year. While some lakes with stream inflows show the effect of rainfall almost immediately, others, such as seepage lakes, do not reflect changes in precipitation for months or years. For example, heavy autumn rains often cause water levels to rise in the winter when rain enters the lake as groundwater.

Many of the seepage lakes in Portage County have fluctuating water levels, with reduced levels occurring for a number of years following a period of draught or significant groundwater withdrawal. The lakes located closest to the groundwater divide (Arnott moraine) have the slowest response to addition of precipitation. These lakes include Bear, Boelter, Emily, Pickerel, Thomas, and Wolf. Pumping of groundwater can significantly affect the quantity of water in these lakes.

Water level fluctuations significantly affect lake water's 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. Yet another consequence of fluctuating water levels is shoreline erosion.

Mixing and Layering

Another important characteristic of lakes is the degree of mixing that occurs within the lake. 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 lack dissolved oxygen and therefore are inhospitable to many aquatic organisms. Many factors determine if lake water mixes including the season, amount and direction of wind, height of land and vegetation around a lake and the lakes 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 (Figure 4). 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 as depth and wind interaction with the water can vary.

To evaluate how mixing varies within the Portage County lakes, the temperature variation between the top and bottom of the lake was calculated. Lakes that are frequently and thoroughly mixed would not exhibit strong temperature differences between top and bottom. Lakes that do not mix during the summer would be expected to stratify with cooler, denser water on the bottom of the lake and warmer, less dense water on the surface. Figure 5 compares the ratio of top and bottom temperatures for July and August 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 ratio shows mixing differences between the lakes. Some of the lakes exhibit little difference between top and bottom water during the summer. These are the relatively shallow lakes with maximum depths less than 25 ft. As the maximum depth increases, so does the temperature ratio. Mixing provides another way to characterize lakes. Using the temperature ratio and water movement, the lakes can be divided into five different categories as shown in Table 2.

Figure 4. Schematic showing lake mixing and layering by season in a typical Wisconsin year.

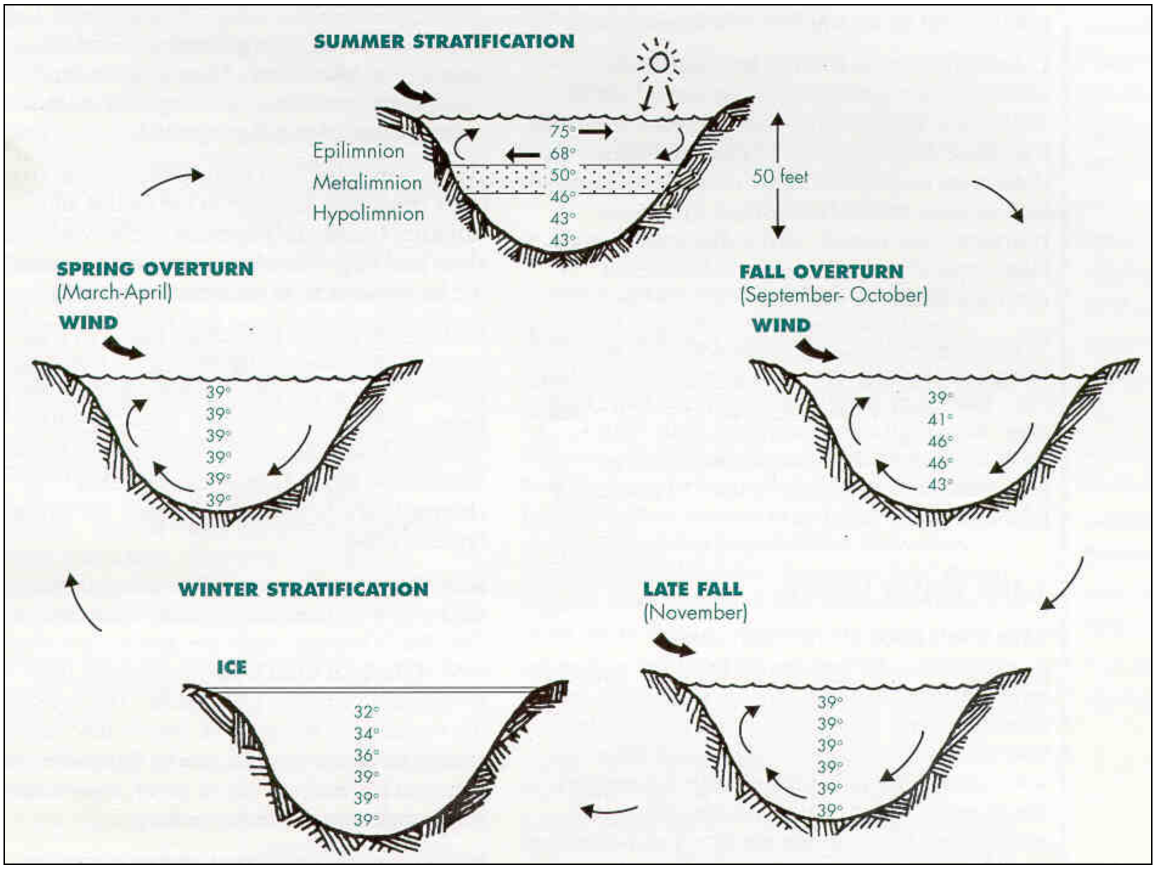


Figure 5. Top to bottom mean temperature ratios and maximum depth in Portage County drainage and seepage lakes**.**

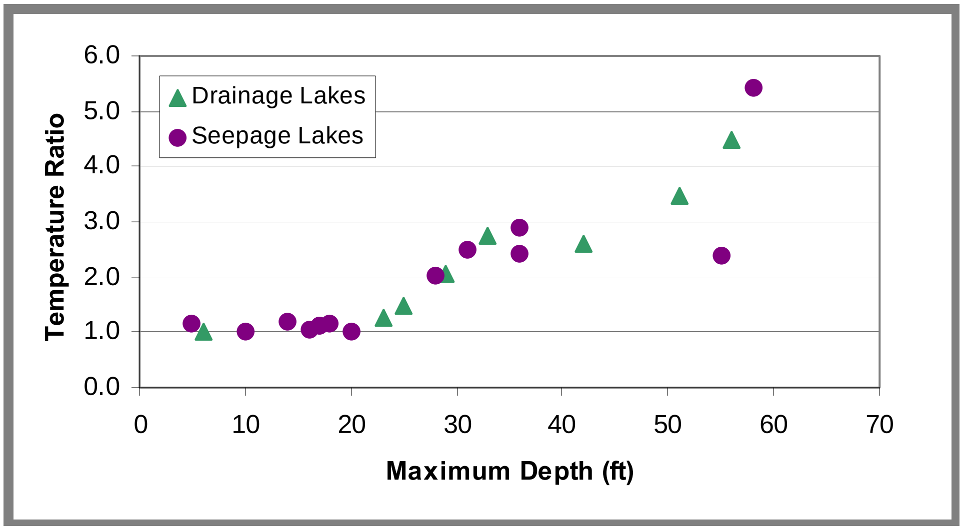


Table 2. **Portage County Lakes based on lake type and mixing/layering.**

Mixed Seepage	Stratified Seepage	Mixed Drainage	Stratified Drainage	Impoundments
Boelter	Bear	Fountain	Adams	Amherst
Helen	Emily	Lions	Collins	Bentley
Jacqueline	Lime	Rinehart	Ebert	Jordan
Joanis	Severson		Spring	McDill
Onland	Sunset		Tree	Rosholt
Pickeral	Thomas			Springville
Skunk				
South Twin				
Wolf				

Water Clarity

Strictly speaking, clarity is not a chemical property of lake water. More accurately, it is an indicator or *measure* of water quality related to 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 algae population is usually the largest and most variable component.

Water clarity often indicates a lake's overall water quality, especially the amount of algae present. Algae are natural and essential, but too much of the wrong kind can cause problems. Table 3 shows the inverse relationship between **Secchi disc depth** (a measure of clarity) and **water clarity**.

Table 3. Water clarity index.

Water clarity	Secchi depth (ft.)
Very poor	3
Poor	5
Fair	7
Good	10
Very good	20
Excellent	32

Secchi disc values vary throughout the summer as algal populations increase and decrease. Measuring several sites may be useful in some lakes, depending upon the uniformity of the lake. Year-to-year changes result from weather, sediment, and nutrient accumulation.

The color of lake water reflects the type and amount of dissolved organic chemicals it contains. Measured and reported as standard color units on filtered samples, color's main significance is aesthetic. Color may also reduce light penetration, slowing aquatic plant and algae growth. Darker colors can also increase the water temperature. 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 even reddish color to the water.

Color can affect the Secchi disc reading. Table 4 lists color values associated with varying degrees of water color.

Table 4. Water color. (Adapted from Lillie and Mason, 1983.)

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

Another measure of water clarity, **turbidity** is caused by particles of matter rather than dissolved organic compounds. Suspended particles dissipate light, which affects the depth at which plants can grow. Turbidity affects the aesthetic quality of water. Lakes receiving runoff from silt or clay soils often possess high turbidities. Turbidity values can vary widely with the nature of the seasonal runoff.

Suspended plants and animals also produce turbidity (i.e. algae and zooplankton). Many small organisms have a greater effect than a few large ones. Turbidity caused by algae is the most common reason for low Secchi disc readings. However, in shallow zones of lakes, turbidity can be increased by boating activity as sediments are stirred up.

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 2002; Cogger 1988). Phosphorus is present naturally on the lake shore and in the watershed, found in the soil and plants. It transfers to the lake from the erosion of soil, animal waste, septic systems, fertilizers, inland recycling, and atmospheric deposition. In a study on urban lakes by the United States Geological Survey’s Waschbusch, Selbig, and Bannerman, it was determined that streets and lawns were contributing 80% of the dissolved phosphorus to the urban lakes, with lawns contributing more than streets.

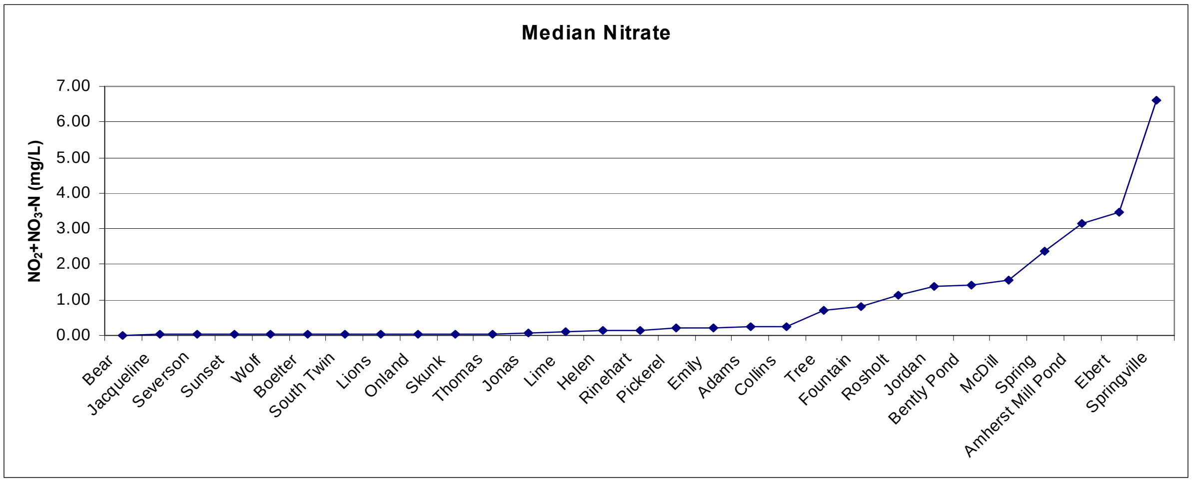
High concentrations of phosphorus are primarily transported to lakes in surface runoff. Phosphorus is reactive and adheres to soil particles. If those particles are disturbed or if water containing phosphorus from decaying vegetation and fertilizer is conveyed directly to the lake, phosphorus is transferred from land to water. Soil has a large capacity to hold phosphorus but where there are significant sources of phosphorus (i.e. barnyards, septic drainfields, over application of fertilizer) the soil holding capacity can be exceeded allowing excess phosphorus to leach to the groundwater. Wetlands that are submerged by raising water levels with dams can also be significant sources of phosphorus. Once in a lake, a portion of the phosphorus becomes part of the aquatic system in the form of plant and animal tissue or sediments. The phosphorus continues to cycle within the system, and is very difficult to remove once it enters.

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. In Wisconsin, minimal nitrogen occurs naturally in soil minerals, but it is a major component of all plant and animal tissue, and therefore organic matter. It is often found in rainfall with precipitation as the primary nitrogen source in some seepage and drainage lakes. It also travels in groundwater and surface runoff; therefore, nitrogen enters the system both as soluble and particulate forms. Sources of nitrogen are often directly related to local land uses including septic systems, sewage treatment plants, lawn and garden fertilizers, eroding soil, and agricultural sources.

Nitrogen enters and exits lakes in a variety of forms. The most common include ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), and organic nitrogen. These forms summed yield total nitrogen (TN). Aquatic plants and algae can use all inorganic forms of nitrogen (NH_4^+, NO_2^-, and NO_3^-); if these inorganic forms of nitrogen exceed 0.3 mg/L in spring, there is sufficient nitrogen to support summer algae blooms (Shaw et al., 2000). Ammonium is the most available form of nitrogen to aquatic plants. Median nitrate concentrations for study lakes are shown in Figure 6.

In Wisconsin lakes, either nitrogen or phosphorus concentrations control the amount of algae and aquatic plant growth. In lakes that are limited by nitrogen the ratio of total nitrogen to total phosphorus is 10:1. (For every 10 nitrogen molecules there is 1 phosphorus molecule.) If limitation varies from year to year there is a ratio between 10:1 and 15:1. When lakes are limited by phosphorus ratios are above 15:1 (Wetzel, 2002).

Figure 6. Median concentrations of nitrate (mg/L) in Portage County study lakes.



Trophic State

Trophic state is another indicator of water quality. Lakes can be divided into three categories based on trophic state-oligotrophic, mesotrophic, and eutrophic. These categories reflect a lake's nutrient and clarity levels.

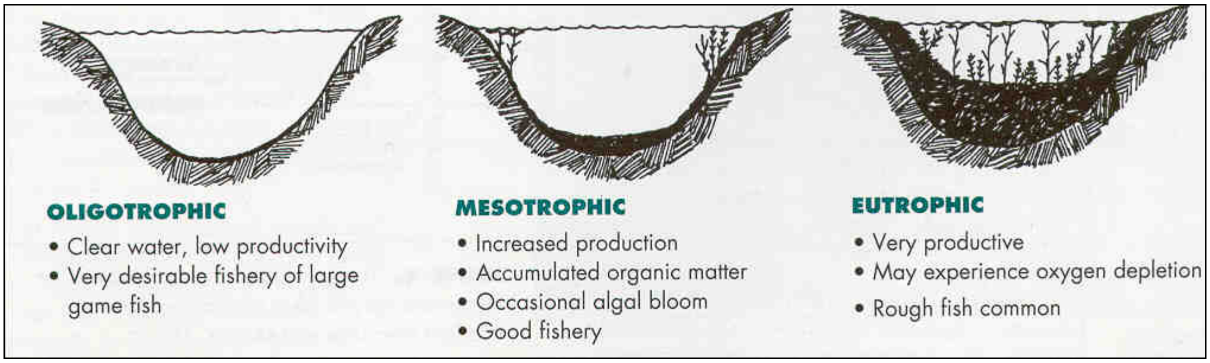
Oligotrophic lakes are generally clear, deep and free of weeds or large algae blooms. Though beautiful, they are low in nutrients and do not support large fish populations. However, oligotrophic lakes often develop a food chain capable of sustaining a very desirable fishery of large game fish.

Eutrophic lakes are high in nutrients and support a large biomass (all the plants and animals living in a lake). They are usually either weedy or subject to frequent algae blooms, or both. Eutrophic lakes often support large fish populations, but are also susceptible to oxygen depletion. Small, shallow, eutrophic lakes are especially vulnerable to winterkill which can reduce the number and variety of fish. Rough fish are commonly found in eutrophic lakes.

Mesotrophic lakes lie between the oligotrophic and eutrophic stages. Devoid of oxygen in late summer, their hypolimnions (bottom layer) limit cold water fish and cause phosphorus cycling from sediments.

A natural aging process occurs in all lakes, causing them to change from oligotrophic to eutrophic over time, and eventually to fill in (Figure 7). People can accelerate the eutrophication process by allowing nutrients and sediments from agriculture, lawn fertilizers, streets, septic systems, street runoff, bare soils, and urban storm drains to enter lakes.

Figure 7. Lake aging process. (Shaw et al, 2000)



In nutrient-poor areas, the aging process may lead instead to **dystrophic** and bog lakes which are highly colored, acid, and not as productive as eutrophic lakes.

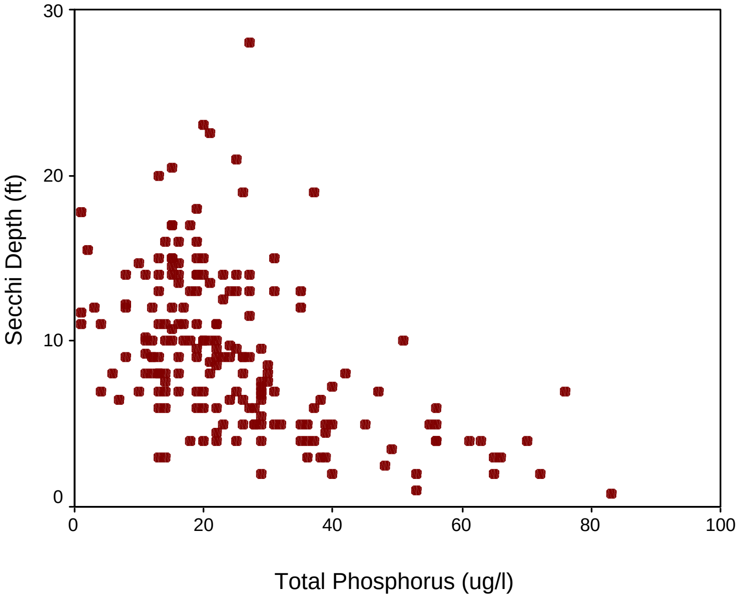
Researchers use various methods to calculate the trophic state of lakes. Common characteristics used to make the determination are:

- total phosphorus concentration (important for algae growth)
- chlorophyll *a* concentration (a measure of the amount of algae present)
- Secchi disc readings (an indicator of water clarity).

Phosphorus (P) and Clarity Relationships

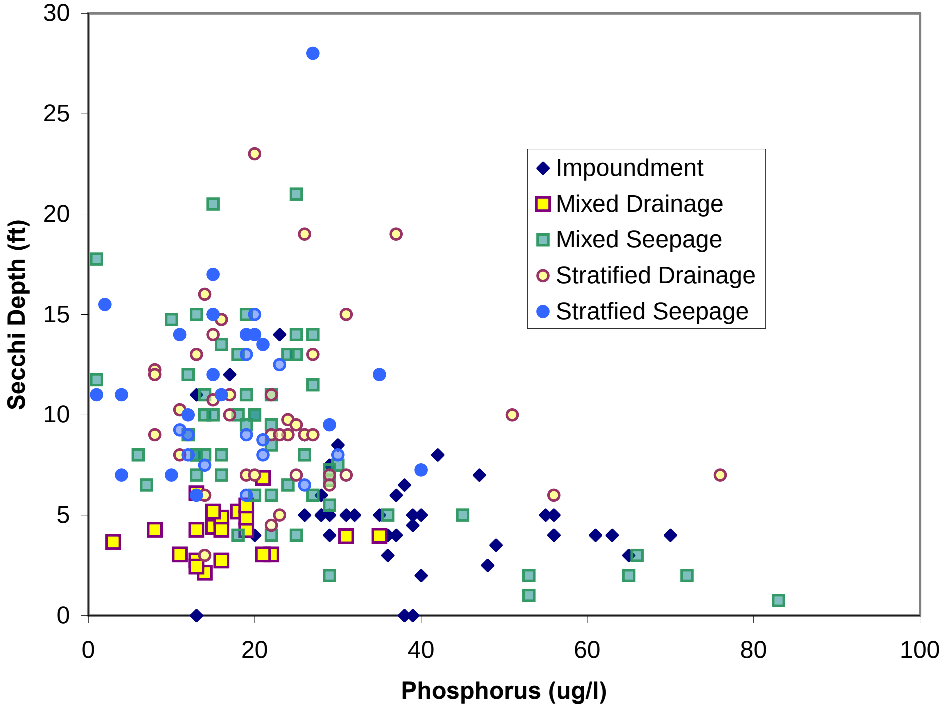
There is a relationship between P and Secchi disk measurements. Taking the entire Portage County Lake data set together, the following figures were developed.

Figure 8. Secchi depth corresponding to phosphorus concentrations measured in June/July/August/September in all study lakes in the recent Portage County Lake study.



Comparison by lake type shows considerable scatter, but some general trends: 1) mixed drainage lakes and impoundments have the lowest Secchi depths; 2) stratified lakes have better Secchi depths for the same phosphorus concentrations. These observations are consistent with increased mixing leading to reductions in water clarity through higher levels of turbidity and/or reduced settling (Figure 9).

Figure 9. Secchi depth corresponding to phosphorus concentrations measured in June/July/August/September by lake type in the recent Portage County Lake study.



Chlorophyll a (a measure of algae) measured in the Portage County Lakes had a strong relationship to phosphorus concentrations as shown in Figure 10. Median concentrations of phosphorus and chlorophyll a by lake type are shown in Figure 11 and Figure 12.

Figure 10. Chlorophyll *a* concentrations shown at different total phosphorus concentrations.

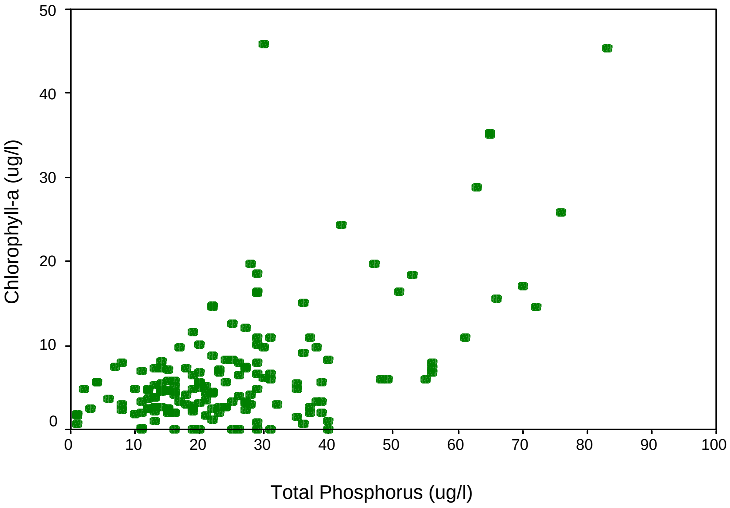


Figure 11. Median concentrations of chlorophyll a (mg/L) for Portage County lakes.

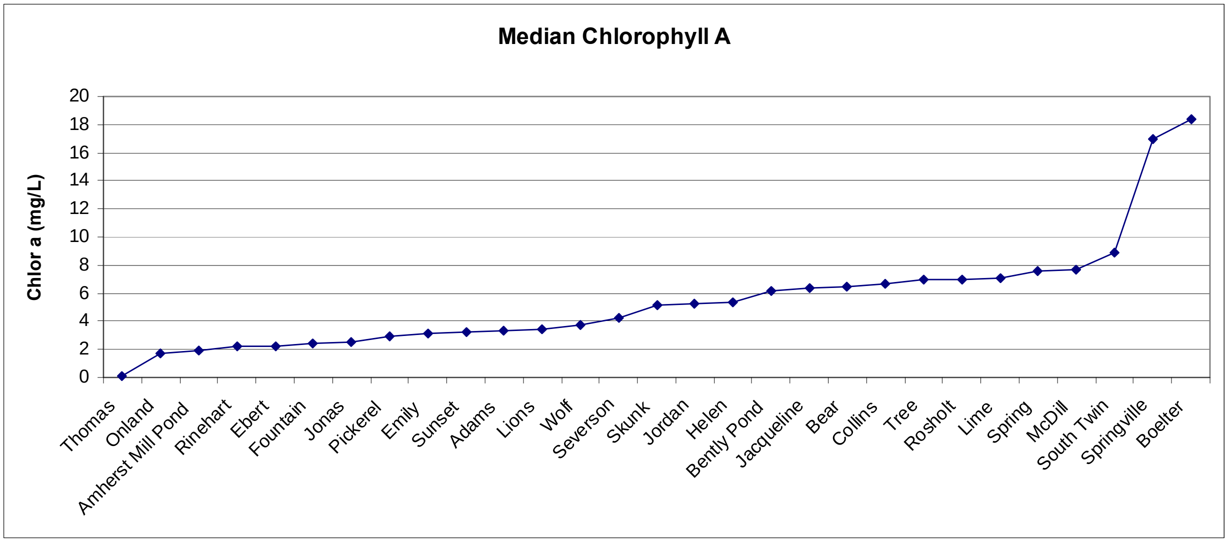
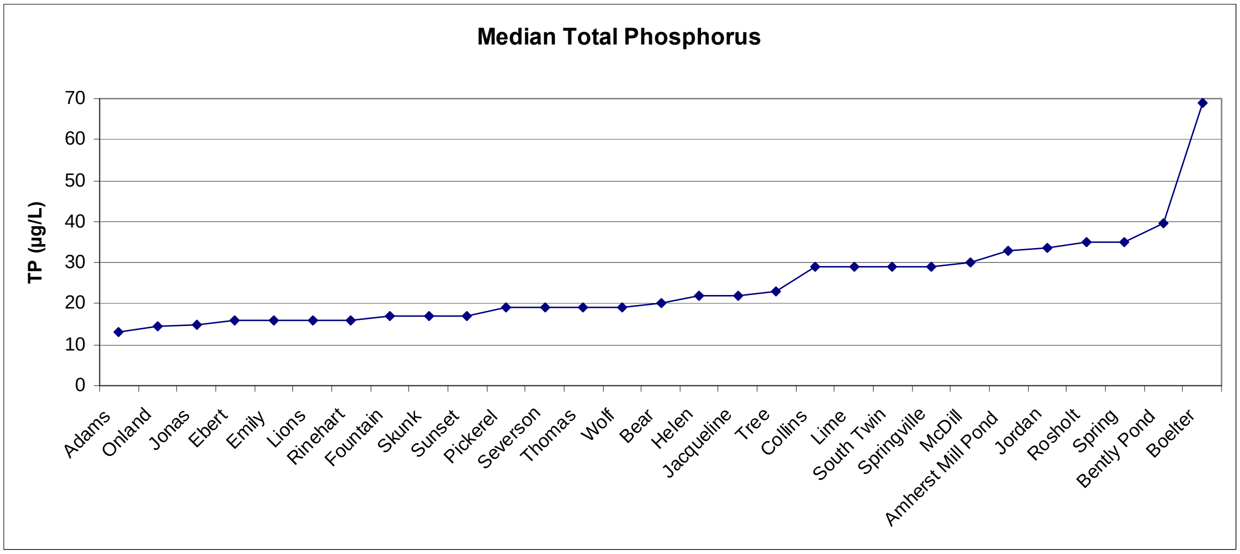


Figure 12 Median concentrations of total phosphorus (ug/L) for Portage County lakes.

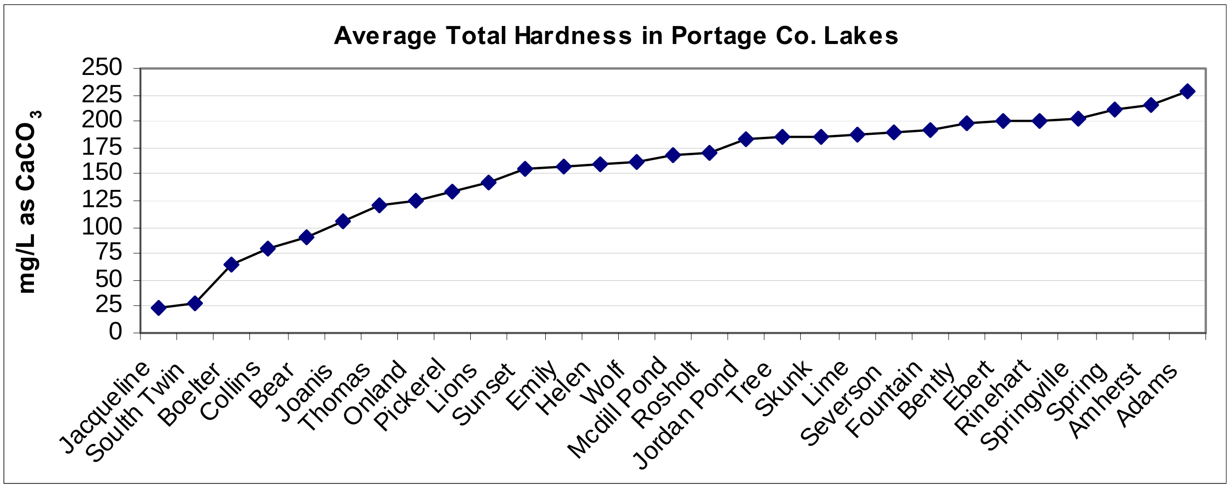


Hardness

The amount and type of minerals in a lake depends upon the geology of the lake's watershed and how the water travels to the lake. In Portage County the lakes many of the lakes have strong connections with groundwater. The groundwater travels through the sandy aquifer which often contains large amounts of calcium and magnesium. These minerals are easily dissolved and are carried with the groundwater to the lakes and streams. Lakes with high levels of calcium and magnesium are called hard water lakes; lakes with low levels are called soft water lakes. When there is an abundance of calcium entering a lake, the calcium precipitates out of the water and forms a soft (often light colored) sediment called marl. The marl can help to protect the lake from phosphorus inputs by making the phosphorus less available for use by algae and aquatic plants.

In the Portage County study lakes, average concentrations of hardness ranged from 25 to 225 mg/L (Figure 13). Lakes with hardness less than 90 mg/L generally show a greater response by algae to inputs of phosphorus. Concentrations in Bear Lake have actually changed from an average harness of 91 mg/L in the 1970s/80s to an average of 46 mg/L in more recent years. This is unusual and may be due to changes in the amount of groundwater feeding Bear Lake.

Figure 13. Average total hardness (mg/L) measured in Portage County lakes.



Aquatic Plants (Macrophytes):

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 plant community in a lake is sensitive to changes in nutrient levels (nitrogen and phosphorus), sedimentation, water clarity, temperature, and bottom disturbance from boats and construction of docks and piers. Plant communities that are out of balance often exhibit over abundance of some species. Preventing destruction of plant communities by good planning and education of riparian land owners is a great investment because attempts to correct or control this condition can be costly in both time and money and in many situations can not be reversed.

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 establishment of these hardier species result in nuisance levels of growth. Barren sediment can also provide ideal habitat for invasive aquatic plant species such as Eurasian milfoil (EWM), curly leaf pond weed, etc. Another effect of aquatic plant removal can be increasing the growth and abundance of algae in a lake.

Aquatic exotic plants are spreading through Wisconsin at an alarming rate. This study identified the presence of the exotic invasive species EWM in Portage County including Bear, Emily, Jonas, Pacawa, and Thomas Lakes and Jordan, McDill, and Springville Ponds. Follow up surveys of these lakes were conducted by Golden Sands RC&D and specific management recommendations were made by Wisconsin DNR, UW-Stevens Point, Portage County, and Golden Sands RC&D. The results of this survey can be found in two documents “Portage County Eurasian Milfoil Assessment” (Golden Sands RC&D Dec 2003 and Dec 2004).

Curly Leaf Pondweed (*P. crispis*) is another invasive plant species that was observed in Amherst Mill Pond and Spring Lake. To date no follow up efforts have been pursued.

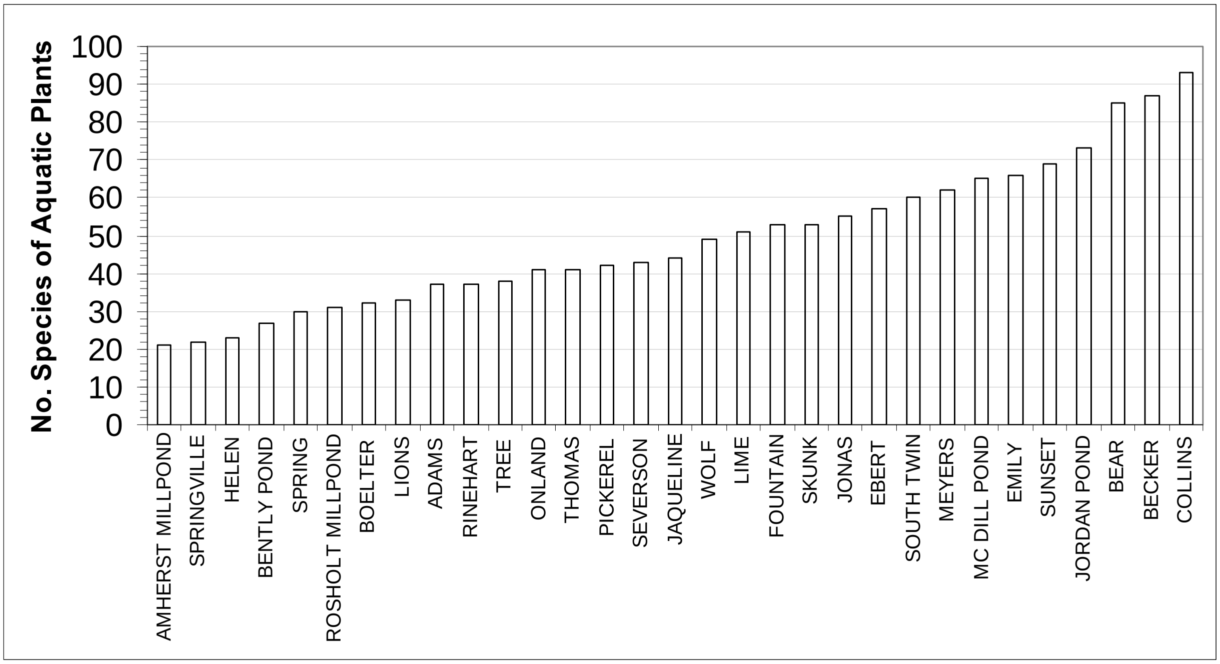
Aquatic invasive species are spread from lake to lake via contaminated boats, trailers, and equipment, and live well water. In the case of EWM, just a few small fragments can settle in the sediment and produce adult plants. Typically, new colonies of aquatic invasives are found near boat landings and as boat motors move through these colonies, plants are chopped into fragments, drift or blow to other areas of the lake, and can then settle and form new colonies. Aggressive action must be taken early on in the infestation to “rid” a lake of these nuisance species of plants. Once they are fully established the elimination of these species has not been successful.

Prevention and early detection of aquatic invasive species is the best and cheapest method of insuring they do not spread to a lake. Boaters, fishers, and recreational lake users should remove plant parts from anything they are bringing into a lake. Citizens should learn to identify invasive species and report them to WDNR Lake Specialists if they locate an invasive plant in Portage County Lakes. The WDNR has educational programs and materials to help citizens learn to identify invasive species and patrol boat landings to help lake users learn about removing plant parts from trailers, boats, live wells before entering the water. This WDNR program is called “Clean Boats, Clean Waters”. The Portage County Land Conservation Dept. has a Clean Boats, Clean Water kit with videos, educational materials, and bumper sticker that can be checked out by citizens that have attended a Clean Boats, Clean Waters training session.

The composition of the plant community indicates the overall health of the aquatic ecosystem. As a general rule of thumb, a greater number of species and presence of sensitive species indicate a healthier aquatic ecosystem. All of the Portage County Lakes in this study had the aquatic plant community evaluated along with review of 30 years of historic records from the UWSP Freckmann Herbarium. The number of aquatic plant species for each Portage County lake is shown in Figure 14.

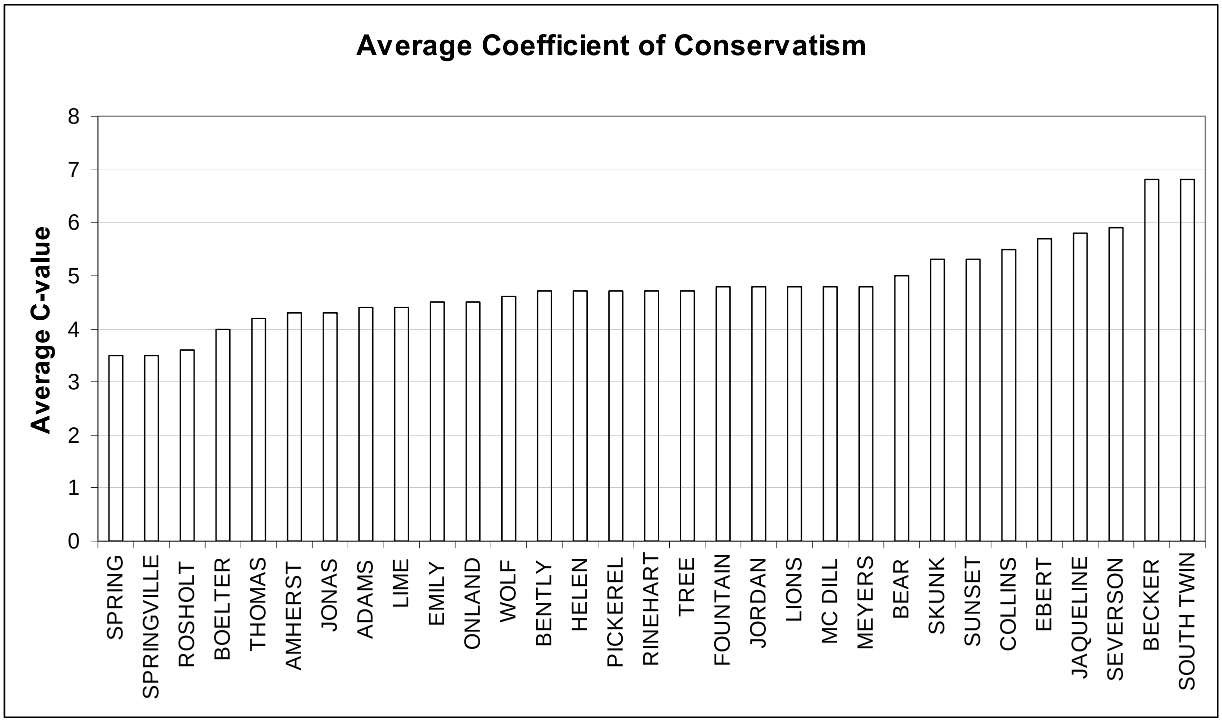
Measures and interpretation of the relative health of the aquatic plant community are described below. Checklists of aquatic plant species by lake can be found in the appendix of this report. If threatened or endangered species were found in a lake, a map with the relative location of these plant communities is presented by lake in the results section of this document.

Figure 14. A comparison of the total number of species of aquatic plants found in Portage County Lakes based on aquatic and wetland vascular plants noted in the 2002-2003 field surveys, and the UWSP herbarium collections, beginning in 1958.



The **coefficient of conservatism** ("c value") indicates on a scale of 0 to 10 the degree to which a species can tolerate disturbance to a native plant community; a species with a c value of 10 is found only in relatively undisturbed areas of native plant community, whereas a species with a c value of 0 never grows in undisturbed areas of native plant communities. Plants with low numbers tend to occur in a wide range of more-or-less disturbed plant communities. Alien species are also assigned a c value of 0. The c values are used in this report in calculating the Floristic Quality Index for each lake. The c values for the Portage County lakes are shown in Figure 15.

Figure 15. A comparison of the average coefficient of conservatism (c-value) of Portage County lakes based on aquatic and wetland vascular plants noted in the 2002-2003 field surveys, and the UWSP herbarium collections, beginning in 1958.

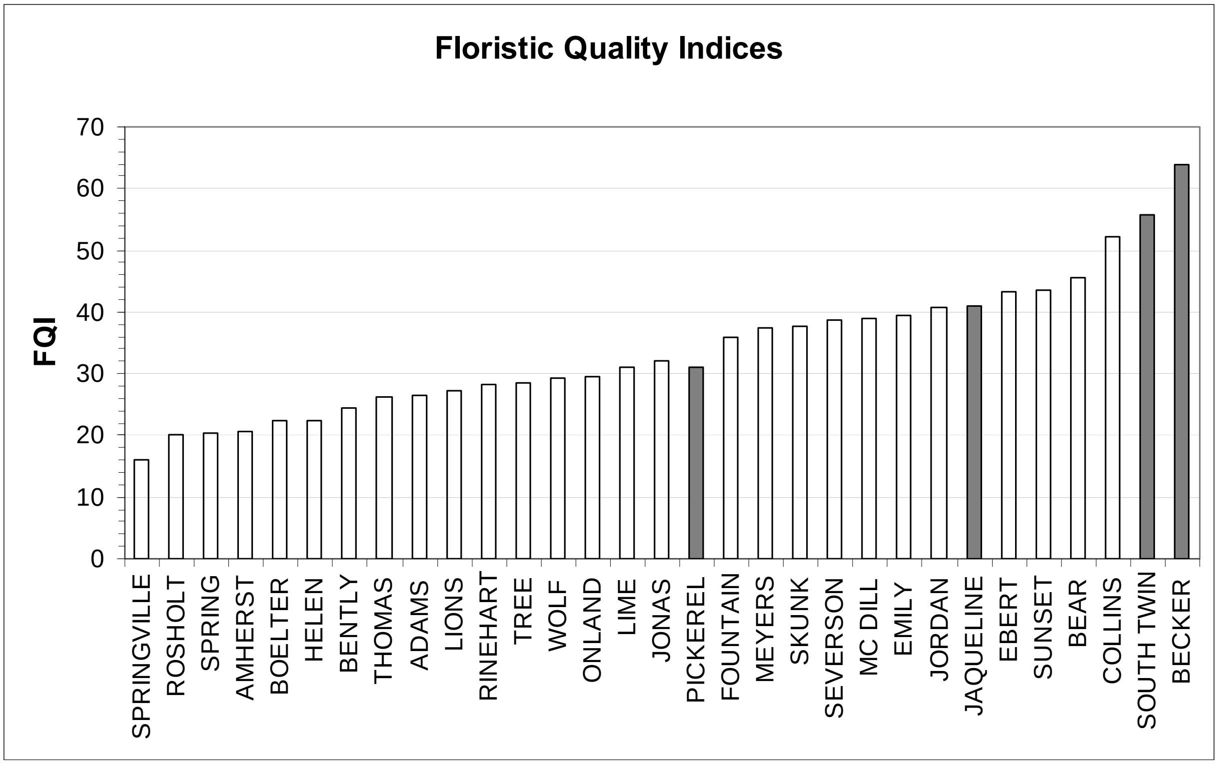


Following the c values on the Checklist in the Appendix is the indicator category for wetland plants, consisting of the following designations:

obl = a plant which always grows in wetland
facw+ = a plants which almost always grows in wetlands
facw= a plants which grows in wetland over 67% of its occurrences
fac = a plant which grows in wetland 33% to 67% of its occurrences
facu= a plant which rarely grows in wetland
upl = a plant which always grows in uplands.

The **floristic quality index** 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; 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.

Figure 16. A comparison of the Floristic Quality Index of Portage County lakes based on aquatic and wetland vascular plants noted in the 2002-2003 field surveys, and the UWSP herbarium collections, beginning in 1958. Endangered, threatened, or plants of special concern were located in lakes with darkened bars.



Herpetological Survey

This summary provides information on the amphibian and reptile species observed and their distribution at the twenty-nine Portage County lakes included in the Portage County Lakes Grant.

The objectives of this component of the Portage County Lakes Grant project were to: 1) Determine the presence and abundance of species of reptiles and amphibians at 29 Portage County Lakes; 2) Identify habitat quality relative to each species of reptile and amphibian at each lake; 3) Identify sensitive areas for each species at each lake.

Herpetological surveys followed standard protocols, which differ for the various species. Because of limits determined by time and resources, not all reptiles and amphibians were as thoroughly surveyed. In anticipation of this limit we focused on anurans (frogs and toads) and turtles. We emphasized anurans because with their permeable skin and biphasic lifecycle (having two life phases: tadpole and adult) they are considered excellent indicators of overall ecosystem health. Furthermore, both turtles and anurans utilize both aquatic and terrestrial habitats and especially the shoreline interface between these two habitats, and thus are of particular relevance.

Large sections of continuous natural shoreline on lakes are ideal habitats for many frog species. Natural areas with large amounts of submergent, emergent, and floating-leaf vegetation provide protection and for attachment of eggs during the breeding season. The upland areas surrounding these lakes also provide important habitat as many frog species migrate to lakes and other bodies of water in the spring or fall to breed and spend the summer months foraging in the uplands. Several species also use the surrounding uplands for overwintering. The turtle species found associated with lakes are predominantly aquatic, usually departing from the water only to deposit eggs in a nest. Nests are usually on south facing slopes above the shoreline where there is open vegetation and sandy soil. The newly hatched young then find their way to the water. Thus, both turtles and anurans are intimately associated with lakes and the associated habitats of a watershed.

Table 5. Summary of herpetological surveys of Portage County Lakes during 2002–2003 (A = Amphibians

	Survey Efforts					
Lake	**Frog Call Surveys**	**Frog Transect Surveys**	**Turtle Trapping**	**Shoreline Vegetation**	**Sensitive Areas**	**Salamander Surveys**
Adams	X	X	X	X	A	X
Amherst Millpond	X		X		A	X
Bear	X		X	X	A	X
Bently Pond	X				A	X
Boelter	X				A	X
Collins	X		X	X	A	X
Ebert	X		X	X	A	X
Emily	X		X		A	X
Fountain	X		X	X	A	X
Helen	X			X	A	X
Jaqueline	X	X		X	A	X
Jonas	X		X	X	A	X
Jordan Pond	X		X		A	X
Lime	X		X	X	A	X
Lions	X		X	X	A	X
McDill Pond	X		X		A	X
Onland	X		?	X	A	X
Pickeral	X		X	X	A	X
Rinehart	X	X		X	A	X
Rosholt Millpond	X				A	X
Severson	X			X	A	X
Skunk	X				A	X
South Twin	X			X	A	X
Spring	X		X		A	X
Springville	X			X	A	X
Sunset	X		X	X	A	X
Thomas	X		X	X	A	X
Tree	X		X	X	A	X
Wolf	X		?	X	A	X

Results

Twelve frog species have been documented in Wisconsin, nine of which currently inhabit Portage County: American toad (*Bufo americanus*), chorus frog (*Pseudacris triseriata*), spring peeper (*Pseudacris crucifer*), eastern gray treefrog (*Hyla versicolor*), Cope's gray treefrog (*Hyla chrysoscelis*), green frog (*Rana clamitans*), pickerel frog (*Rana palustris*), northern leopard frog (*Rana pipiens*), and wood frog (*Rana sylvatica*). Historically, Blanchard's cricket frog inhabited Portage County but is believed to now exist only in southwestern Wisconsin. Of the nine species that currently inhabit Portage County, the pickerel frog was not located through fieldwork for this project. The pickerel frog has been listed as a species of Special Concern in Wisconsin.

Seven salamander species have been documented in Wisconsin, all of which currently inhabit Portage County: blue-spotted salamander, spotted salamander, tiger salamander, central newt, mudpuppy, northern redback salamander, and four-toed salamander. The blue-spotted salamander and the northern redback salamander were located during fieldwork for this project. Other research has documented the mudpuppy in one lake.

Table 6. Species of frogs and toads documented for Portage County Lakes during 2002–2003.

	Species							
Lake	**American Toad** *(Bufo americanus)*	Gray Treefrog *(Hyla versicolor)*	**Cope's Treefrog** *(Hyla chrysoscelis)*	**Spring Peeper** *(Pseudacris crucifer)*	**Western Chorus Frog** *(Pseudacris triseriata)*	**Wood Frog** *(Rana sylvatica)*	**Green Frog** *(Rana clamitans)*	**Leopard Frog** *(Rana pipiens)*
Adams				X	X	X	X	X
Amherst Millpond				X	X			
Bear				X	X		X	
Bently Pond				X			X	X
Boelter	X			X				
Collins	X			X		X	X	X
Ebert				X				
Emily	X			X	X			X
Fountain	X			X		X	X	
Helen				X	X	X		X
Jaqueline	X			X	X		X	X
Jonas	X	X	X	X	X		X	
Jordan Pond				X	X		X	
Lime				X				
Lions				X		X		
McDill Pond	X	X		X			X	X
Onland				X				
Pickeral	X			X				
Rinehart	X	X		X	X	X	X	X
Rosholt Millpond				X		X		
Severson	X			X				
Skunk							X	
South Twin	X			X	X		X	
Spring	X			X				
Springville	X							
Sunset	X	X	X	X	X	X		
Thomas				X			X	
Tree				X				
Wolf				X				

Table 7. Species of salamanders documented for Portage County Lakes during 2002–2003.

	Species		
Lake	**Blue Spotted Salamander** *(Ambystoma laterale)*	**Red Backed Salamander** *(Plethodon cinereus))*	**Mudpuppy** *(Necturus maculosus)*
Adams			X
Amherst Millpond			
Bear			
Bently Pond			
Boelter			
Collins			
Ebert			
Emily			
Fountain			
Helen			
Jaqueline			
Jonas			
Jordan Pond			
Lime			
Lions			
McDill Pond			
Onland			
Pickeral			
Rinehart	X		
Rosholt Millpond			
Severson			
Skunk			
South Twin			
Spring			
Springville			
Sunset	X	X	
Thomas			
Tree			
Wolf			

Table 8. Species of turtles documented for select Portage County Lakes during 2002–2004. (Numbers indicate trapped and marked turtles; obs = observations; hist = historical record or observation.)

	Species				
Lake	**Painted Turtle** *Chrysemys picta)*	*Snapping Turtle (Chelydra serpentina)*	*Spiny Softshell Turtle* **(Apalone spinifera)**	*Wood Turtle* **(Clemmys insculpta***)*	*Blanding's Turtle* **(Emydoidea blandingii)**
Adams	6	4			
Amherst Millpond	0	2			
Bear	13	0			
Bently Pond					
Boelter					
Collins	11	1			
Ebert	1	1			
Emily	9	6			
Fountain	0	2			
Helen					
Jaqueline					
Jonas	2	0			
Jordan Pond	12	3		obs	
Lime	13	4			
Lions	9	1			
McDill Pond	obs	obs	hist obs	hist obs	
Onland					
Pickeral	obs	obs			
Rinehart					
Rosholt Millpond					
Severson					
Skunk					
South Twin					
Spring	obs	1			
Springville					
Sunset	5	0			
Thomas	6	3			
Tree	0	1			
Wolf	obs		hist		

Birds

Lakeshore development can negatively or positively affect habitat quality of birds depending on the ecological requirements of each species. Development can play a important role in providing resources unavailable to certain species in a more natural environment, yet eliminate other species' needs altogether, especially at the most extreme levels of development.

At the species level, bird species are known to respond differently to resource changes resulting from urbanization. As expected, some species in this study selected developed areas over undeveloped areas whereas other species showed little or no preference. Of the 28 most common species, Eastern Phoebe (*Sayornus phoebe*), American Goldfinch, American Robin, Morning Dove (*Zenaida macroura*), and Downy Woodpecker (*Picoides pubescens*) showed the greatest tendency to be found in developed areas. These species may be taking advantage of different resources available in the urban environment, such as birdfeeders (as in the case of the American Goldfinch and Downy Woodpecker), open foraging areas (American Robin and Mourning Dove), or nest sites (Eastern Phoebe). At undeveloped sites, Least Flycatcher (*Empidonax minimus*), Great Crested Flycatcher (*Myiarchus crinitus*), Red-eyed Vireo (*Vireo olivaceus*), Black-capped Chickadee, Blue Jay (*Cyaanocitta cristata*), Red-bellied Woodpecker (*Melanerpes carolinus*), Eastern Wood-pewee (*Contopus virens*), Indigo Bunting (*Passerina cyanea*), and Common Yellowthroat (*Geothylypis trichas*) were the most common. A majority of these species are insectivores and are likely to feed in more forested environments. A northern Wisconsin study found similar lakeshore development effects on the composition of the avian community.

If food resources are a driving factor in these habitat selections, then analyses of food guild associations should show similar relationships of species to development levels. In support of this hypothesis, most of the aforementioned species fell into similar development categories in the food guild analysis as they did for the species analysis. For example, seedeaters (American Goldfinch and Morning Dove) were found to be associated with buildings. Insectivores (Least Flycatcher, Great Crested Flycatcher, Black-capped Chickadee, Red-bellied Woodpecker, Eastern Wood-pewee, Indigo Bunting, and Common Yellowthroat) were associated with thicker understory and canopy cover, both undeveloped areas. Exceptions included two insectivores, Downy Woodpeckers, and American Robins, all of which are known to be quite common in developed areas. American Robins, for example, are quite tolerant of humans and may benefit from urbanization.

Food provided by humans may play an important factor in this analysis, as seedeaters could be drawn to more developed areas where food is readily available. The number of seedeaters can dramatically increase in the urban environment and seeds provided by the urban setting's human inhabitants may be significant. Thus food guilds coupled with food availability may be important predictors of certain species' presence across my study sites.

An analysis of nest locations reveals reed nesters (Red-winged Blackbirds) were found in open areas. Snag and deciduous tree nesters were most common in wooded developed areas, along with bank nesters. Of the bank nesters, Belted Kingfisher (*Ceryle alcyon*) is known to use snags for perches. Ground nesters selected undeveloped areas and shrub nesters prefer areas of heavy understory. Previous studies have shown similar results, indicating that corresponding levels of development may provide more adequate nest locations for these guilds. This study appears to provide further support for this resource-based habitat selection.

Cavity nesters, burrow nesters, and species that make pendant-shaped and saucer-shaped nests were associated with developed areas. Oven-shaped nest builders (Ovenbirds, *Seiurus aurocapilla*) were found in wooded undeveloped areas and parasite nesters (Brown-headed Cowbirds, *Molothrus ater*) were present in mostly wooded developed areas. Predicting bird presence based upon nest type may seem less intuitive than using food or nest site availability, but perhaps species requiring uncommon nesting strata or substrates may select certain locations because of limited resource availability. Like nest locations, developed areas are hypothesized to provide more opportunities for some nest types by increasing holes for cavity nests, crevices for burrows, and ledges for saucer-shaped nests. Results from this study support for this concept, as cavity, burrow, and saucer-shaped nest builders were associated with developed areas. Cup-shaped nesters showed no preference. Arguably, cup nests can be built on man-made structures such as buildings or in more natural locations like trees and shrubs, making such nest builders less likely to select one level of development over another.

Although we found that bird communities appeared to respond strongly to the variables we measured, other variables known to affect avian assemblages could not be examined. These include predator abundance, human density, competition, and climate, among others. Of those included here, availability of food and nesting strata and substrate seem to be important parameters in avian habitat selection, with differing levels of development sometimes enhancing or degrading bird habitat, depending upon the species. For example, greater food availability associated with human presence appears to benefit a number of avian species.

It is clear in this study that avian communities were dramatically altered as a result of urban development. However, further long-term studies addressing how bird species respond to the urban to rural gradient are necessary for managers to design and implement effective mitigation strategies.

Table 9. Mean richness (S) and diversity (H') scores per lake. Lakes are separated according to the 3 distinctly different average habitat scores (derived from PCA).

Lake Category and lake	$\bar{X}$ S	$\bar{X}$ H'
Developed		
Springville	11	2.2
Helen	16	2.6
Rhinehart	23	2.3
Jacqueline	18	2.7
Group Average	**17.0**	**2.5**
Moderately Developed		
South Twin	11	2.1
Emily	21	2.6
Sunset	18	2.8
Adams	23	2.7
Jordan	21	2.9
Rosholt	20	2.8
Bear	14	1.8
Thomas	17	2.6
Group Average	**18.1**	**2.5**
Undeveloped		
Joanis	12	2.1
Wolf	16	2.6
Severson	13	2.4
Skunk	18	2.7
Fountain	14	2.5
Group Average	**14.6**	**2.5**

Table 10. Means of habitat variables for each of the three development groups as defined by an analysis of habitat scores.

	Developmental Group			
Habitat Variables	**Developed**	**Moderately Developed**	**Undeveloped**	**Total**
canopy cover (%)	45.2	49.6	67.1	54.0
buildings (#)	5.0	0.9	0.1	2.0
birdfeeders (#)	3.9	0.5	0.0	1.5
birdhouses (#)	1.4	0.4	0.0	0.6
open developed (%)	61.5	37.0	10.8	36.4
wooded developed (%)	12.3	20.6	6.3	13.1
open undeveloped (%)	1.7	6.1	20.3	9.4
wooded undeveloped (%)	7.5	27.3	60.2	31.7
paved (%)	16.5	9.1	2.3	9.3
cover pole-ground (%)	43.3	53.8	64.3	53.8
cover pole-upper (%)	28.8	31.1	35.5	31.8

Table 11. Means per lake of the most abundant species for each of the three development groups as defined by an analysis of habitat scores.

	Developmental Group			
Species	**Developed**	**Moderately Developed**	**Undeveloped**	**Total Detected**
Red-winged Blackbird	9.3	9.0	2.2	120
American Goldfinch	4.0	3.8	2.8	60
American Robin	4.5	2.9	2.0	51
Black-capped Chickadee	0.8	2.5	4.8	47
Common Grackle	5.8	2.3	0.0	41
Song Sparrow	1.8	2.6	2.6	41
Chipping Sparrow	2.8	2.5	0.8	35
Blue Jay	1.8	1.4	2.6	31
Catbird	0.8	1.6	1.4	23
House Wren	2.5	0.9	1.0	22
Red-eyed Vireo	1.0	0.8	2.4	22
American Crow	0.3	2.3	0.0	19
Common Yellowthroat	0.8	1.0	1.4	18
House Finch	1.8	0.8	0.0	13
Mourning Dove	1.8	0.6	0.2	13
Baltimore Oriole	0.8	1.1	0.2	13
White-breasted Nuthatch	0.5	1.0	0.6	13
Eastern Wood-Pewee	0.0	0.6	1.4	12
Brown-headed Cowbird	0.0	1.1	0.4	11
Least Flycatcher	0.5	0.0	1.8	11
Northern Cardinal	1.0	0.8	0.2	11
Rose-breased Grosbeak	0.5	0.3	1.4	11
Ovenbird	0.0	0.4	1.4	10

Land Use and the Aquatic Ecosystem

The following section is adapated for Portage County lakes from “Shoreland Development Density and Impervious Surfaces How do they affect water resources? How much is too much for our lakes and streams?” by L. Markham, UWSP Center for Land Use Education

Introduction

When a landowner develops a waterfront lot, many changes may take place including the addition of driveways, houses, decks, garages, sheds, piers, rafts and other structures, wells, septic systems, lawns, sandy beaches and more. Many of these changes result in the compaction of soil and the removal of trees and native plants, as well as the addition of impervious (hard) surfaces, all of which alter the path that precipitation takes to the water.

Each of these alterations decreases the ability of the shoreland area to serve its natural functions: removal of trees and native plants eliminates the food and shelter on which wildlife depends, natural beauty is replaced with manmade materials, water cannot soak into the ground thereby increasing stormwater runoff that carries fertilizers, pesticides and other pollutants to the lakes and streams. If 50% of a lot is converted to impervious surfaces, half of this lot is no longer capable of filtering rainwater or providing the food and shelter on which wildlife depends.

Changing one waterfront lot in this fashion may not result in a measurable change in the quality of the lake or stream. The cumulative effects, however, can be enormous. These changes are framed by issues such as stewardship of the resource, the rights of the public, and land owners’ rights – both of those developing land and those whose land is being affected by this development.[i]

Shoreland development has increased dramatically.

The influence that such changes have on water quality might appear relatively insignificant when it occurs on one lot on a large lake, but an examination of recent trends suggests that shoreline development is increasing both in numbers and intensity. From 1960 to 1995, the number of dwellings along 235 northern Wisconsin lakes increased an average of 216 percent.[ii] At the same time, people are building bigger homes but lot sizes are not increased proportionally. If present development rates persist, all undeveloped lakes not in public ownership could be developed by 2020.[iii]

Shoreland impacts are cumulative.

In the past, we could stress our aquatic systems without seeing a noticeable change in the quality of the water resource. But “cumulative” effects, such as the same stress applied later in time to an already stressed system can have a much larger impact. This is like a boxer who can take a punch in round 1 and still be standing, but when hit with the same punch in round 15 is knocked out. The cumulative effect of all the previous punches reduces the resiliency of the boxer. In one Wisconsin study, a 10% reduction in the area covered with lakes and wetlands resulted in about 10% greater flood flows and erosion when the watershed started out with 40% lake and wetland area. When the same 10% reduction was applied to a watershed that started out with only 10% of its area containing lake and wetlands, flood flows and erosion increased by 250 to 500%.[iv] Thus, a system’s response to stress depends on what condition the system is in to begin with. These effects are cumulative, and how systems responded to the stresses of our ancestors may not give us a good indication of how they will respond as we and our descendants stress them.[v]

Will the cumulative impact of many homeowners making such changes to their shorelands degrade water quality, eliminate, fragment or degrade habitat for fish and wildlife, and increase erosion and the potential for flooding? Likewise, could the cumulative impact of many buildings close together, near the water with minimal screening degrade the natural scenic beauty of the shoreline? To explore these questions, a review of the hydrology, water quality, fish and wildlife habitat and shoreline aesthetic studies relevant to shoreland development are summarized here.

State shoreland management standards

In the mid 1960's when the current minimum standards for county shoreland zoning ordinances were first adopted in Chapter NR 115, there was clear recognition that development density (lot size requirements) had a significant effect on the shoreland management objectives. Specifically, Chapter NR 115 requires lots served by public sanitary sewers to have a minimum average width of 65 feet and a minimum area of 10,000 square feet. Lots with a septic system must have a minimum average width of 100 feet and a minimum area of 20,000 square feet. The current rule does not include a minimum statewide standard for impervious surfaces to address the increased runoff and pollutant transport. This is not surprising because at the time this rule was adopted regulations focused on controlling point sources of pollution. Since the mid-1990s many Wisconsin counties have significantly revised their shoreland ordinances, choosing larger lot sizes and impervious surface caps.

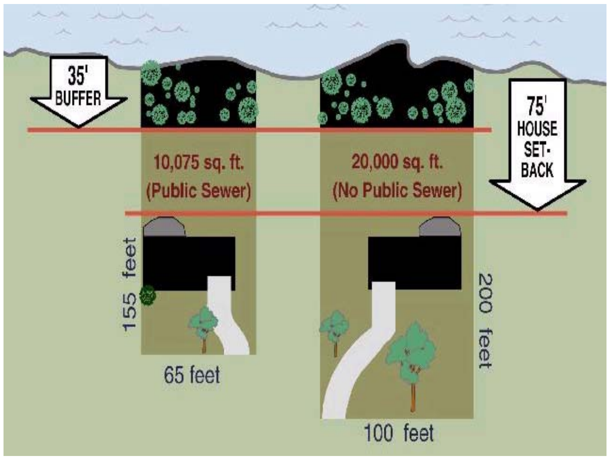


Figure 17. Current NR 115 standards.

Limiting the density and intensity of shoreland development can safeguard our lakes and streams. Specifically the statute authorizing shoreland zoning [s. 281.31(1), Wis. Stats.] requires that:

"*. . . (t)he purposes of the regulations shall be to further the maintenance of safe and healthful conditions; prevent and control water pollution; protect spawning grounds, fish and aquatic life; control building sites, placement of structure and land uses and reserve shore cover and natural beauty.*"

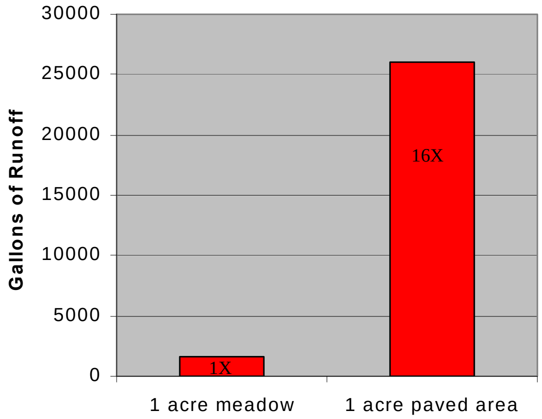
The remainder of this document will look in more detail at how development density and impervious surfaces affect the hydrology, water quality, wildlife habitat and the natural beauty of Wisconsin's shorelands.

Hydrology: Where do rain and snow go?

The simple answer is "it runs downhill." How much water is involved? On average in Wisconsin, we receive approximately 30-34 inches of precipitation a year.[vi] Of this amount, 18 to 25 inches evaporate or are transpired, and the remaining 7-13 inches either run off to surface waters or infiltrate into the ground.[vii] During a one-inch storm 27,152 gallons of water fall on one acre of land, enough to fill three and one-half rooms that are 10'x10'x10'.

An important question for the health of lakes and streams is how much of the precipitation flows over the land surface directly to lakes and streams and how much filters into the ground and is either stored as groundwater or slowly makes its way back into rivers. **An unintended result of development is that impervious surfaces cause more water to run off the landscape and less to infiltrate to groundwater.** For instance, a parking lot produces 16 times more runoff (on B soils: those with moderate infiltration rates of 0.15-0.30 in/hr when thoroughly wetted) than a meadow of the same size for the same storm event. [viii]

Figure 18.
Runoff from a 1" Rainstorm



Schueler, T. 1994. The Importance of Imperviousness. *Watershed Protection Techniques*, 1(3):100-111.

Figure 19. shows the average percentage of imperviousness for different land uses and lot sizes. Typically the percentage of impervious cover is higher for smaller lots. Additionally, industrial, commercial and retail uses have much higher percentages of impervious cover than residential development.

Natural shoreland functions are lost when impervious surfaces are added.

Figure 19.
Average Percentage of Impervious Cover by Land Use

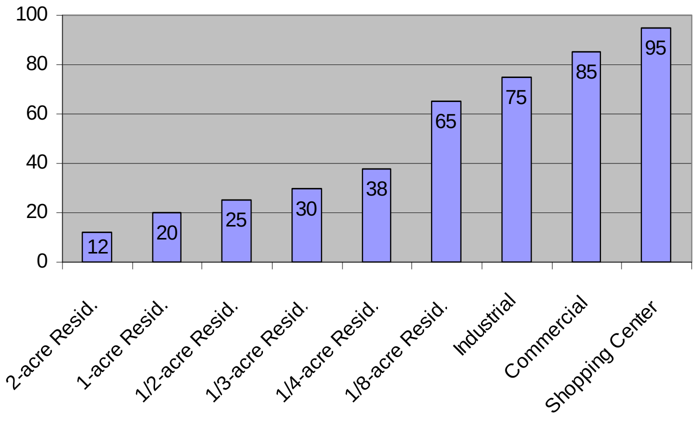


Chart adapted from Ferguson, B. K. 1998. *Introduction to Stormwater: Concept, Purpose, Design*. New York: John Wiley & Sons.

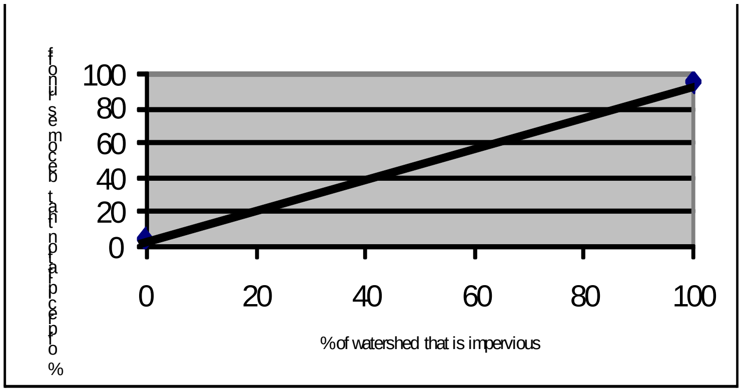
Table 12 provides a comparison of the amount of runoff from two forks of the Pheasant Branch watershed near Madison. After the South Fork was converted to commercially developed land with 31% connected impervious surface, the amount of runoff was 690% that of the North Fork that is agricultural land with little impervious surface. In this situation, the runoff increased by over seven inches a year while groundwater recharge decreased by nearly three inches per year. [ix] As a result of the high erosion rates, the City of Middleton has spent over $2.3 million in the last 25 years in an attempt to protect bridges and sewer lines from erosion. [x]

Table 12. Average annual water budget for two portions of the Pheasant Branch watershed (budget not balanced because of change in groundwater storage)[xi]

	North Fork Agricultural land with little impervious surface	South Fork Commercially developed land with 31% connected impervious surface
Precipitation	35.0 inches	35.0
Runoff (overland flow)	1.2	8.3
Groundwater recharge	8.8	6.0
Evapotranspiration	24.6	20.5

The effects of different land cover types on nutrient delivery is discussed further under the phosphorus section.

Figure 20. Percentage of precipitation as runoff v. percentage of watershed that is impervious.



Schueler, T. 1987. *Controlling Urban Runoff: A practical Manual for Planning and Designing Urban Best Management Practices*. Metropolitan Washington Council of Governments. Washington, D.C.

Figure 20 illustrates research findings that runoff increases as the percentage of the watershed that is impervious increases. This runoff data was derived from 44 small catchment areas across the country for EPA's Nationwide Urban Runoff Program.[xii]

The quantity and quality of water that infiltrates or runs off also depends on season, topography, plant cover, land use and soil type.

Intense rainstorms produce more runoff than slow, steady rains. Steep slopes have more runoff than flatter lands. Urban areas have more runoff than forests, fields and pasturelands. Rock and clay soils have more runoff than organic soils or sands.[xiii] As shown in Table 13, groundwater provides a large portion of the water in the Waupaca River that drains an area of thick sandy deposits. This is in contrast to the Big Eau Pleine River near Stratford that drains an area with thin clay over relatively impermeable rock and receives a significant portion of its flow from runoff.[xiv]

Table 13. Comparison of stream flow from different types of drainage areas

River	Waupaca River	Big Eau Pleine
Drainage area characteristics	Sandy deposits	Thin clay over relatively impermeable rock
Flow during dry periods from groundwater*	0.5-1.0	0 – 0.2
Annual flow* = groundwater + runoff	0.78	0.75

*cubic ft per second per square mile of drainage area

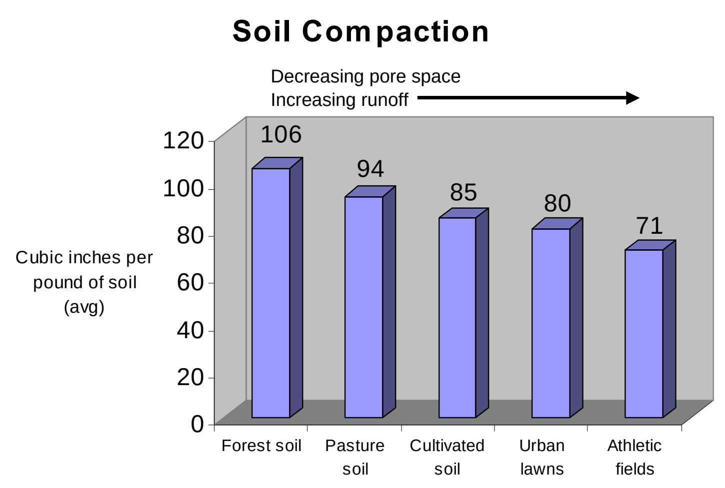
Holt, 1965. Geology and Water Resources of Portage County, Wisconsin, U.S.G.S. Water-Supply Paper 1796, p. 17

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.

Do the effects depend on where the impervious surfaces are located?

Yes! Not surprisingly impervious surfaces closer to the water have a greater impact because there is less opportunity for the runoff from these areas to soak into the ground or be filtered before reaching the lake or stream. The findings from a study of 47 watersheds in southeastern Wisconsin indicated that 1 acre of impervious surface within 100 meters (~330 feet) of the stream had a negative effect on fish populations and diversity equivalent to 10 acres of impervious surface more than 100 meters from the stream.[xv]

Figure 21. Soil compaction for various land uses.

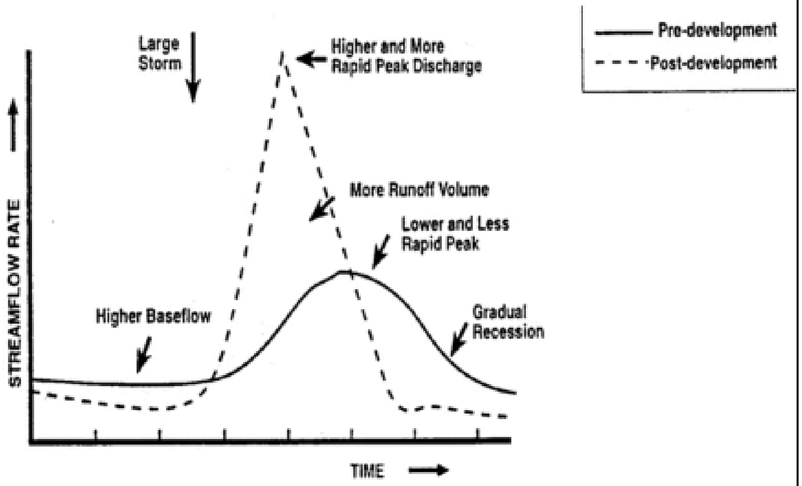


Schueler, Watershed Protection Techniques, 3(2): 661-665

Lawns have limited natural shoreland functions.

Lawns often comprise the largest fraction of land area within low-density residential development and often have similarities with impervious surfaces. Although lawns are pervious, they have sharply different properties than the forests and farmlands they replace in terms of compacted soils, greater runoff and much higher input of fertilizers and pesticides.[xvi] Figure 21 shows that a pound of soil in a lawn has 24% less volume than forest soil and 15% less volume than pasture soils. The decreased volume of the lawn soil reflects decreased pore space and ability to infiltrate water, resulting in increasing runoff. Cultivated soils and those in lawns are more similar due to disturbance and compaction.

Figure 22. Stream flow graph pre and post development.



Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban Best Management Practices*. Metropolitan Washington Council of Governments. Washington, D.C.

Blades of turf grass are flat and easily flattened during a runoff event whereas native grasses and forbs typically have round, square or triangular stems that stay upright to slow runoff velocity and filter it during a storm. The effects of lawns on water quality and wildlife habitat are discussed below.

Impervious surfaces change the flow, size and shape of streams.

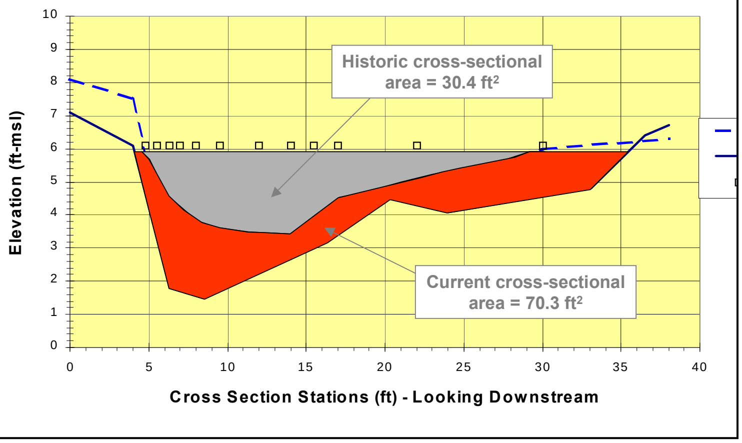
With increased areas of impervious surface and compacted soil, a greater fraction of annual rainfall is converted to surface runoff. Under these conditions, streams become ‘flashy’, meaning runoff occurs more quickly, peak flows become larger, and critical dry season flows decrease because less groundwater recharge is available,[xvii] as shown in Figure 22.

Increased runoff and stream flashiness result in physical changes to the stream including:

- wider and/or deeper stream channels,[xviii] (Figure 23)
- increasingly unstable streambanks,
- loss of large woody cover, and
- a simpler and more uniform habitat structure with reduced pool depths, loss of riffles, fewer meanders, and rocky bottoms filled in with sediment[xix]

Figure 23. Stream channel enlargement

Caraco, D. 2000. The Dynamics of Urban Stream Channel Enlargement. *Watershed Protection Techniques*. 3(3):729-734



When site conditions change to increase the amount of runoff, the velocity of flow can also increase. **Impervious surfaces, compacted soils, and reduced vegetation density all can reduce the roughness of the land surface which accelerates runoff velocity and concentrates flow.** These changes increase the energy available for erosion of sediment and transport of nutrients. For instance, the runoff velocity from a parking lot is four times greater than from a meadow during a two-year storm.[xx]

Water quality

Along with the increased erosive power of stormwater runoff that accompanies increased impervious surfaces, come more pollutants that are washed from developed waterfront properties and surrounding areas into the adjacent lakes and streams. Pollutants frequently found in stormwater runoff include: sediment, nutrients, metals, hydrocarbons, bacteria and pathogens, organic carbon, pesticides and deicers.[xxi] This summary will focus on sediment, nutrients and temperature. Table 3 provides further information about the impacts of various water pollutants.

Table 14. Surface water pollutants

Pollutant	Source in Nature	Role in Natural Ecosystem	Source in Developed Areas	Role of Excess Pollutant
Sediment	Banks of meandering channels and shorelines	Maintain stream profile and energy gradient; store nutrients	Construction sites; eroding banks	Abrade fish gills; carry excess nutrients and chemicals; block sunlight; cover gravel (spawning) & bottom habitats
Organic Compounds	Decomposing organic matter	Store nutrients	Car oil; herbicides; pesticides; fertilizers	Deprive water of oxygen by decomposition
Nutrients	Native soils & decomposing organic matter transported by natural runoff rates	Support ecosystems Sustain plant base of food chain	Organic compounds; organic litter; fertilizers; food waste; sewage	Unbalance ecosystems; produce algae blooms & aquatic plant excess; deprive water of oxygen by decomposition
Trace Metals	Mineral weathering	Support ecosystems	Cars; construction materials; coal burning power plants; anthropogenic chemicals	Reduce resistance to disease; reduce reproductive capacity; alter behavior; chronic & acute toxicity depending on concentration
Chloride	Mineral weathering	Support ecosystems	Pavement deicing salts, water softener salt	Sterilize soil and reduce biotic growth
Bacteria	Native animals	Natural decomposition & nutrient cycling	Waste handling areas; domestic & agricultural animals	Cause risk of disease to humans & wildlife
Oil	Decomposing organic matter	Store nutrients	Cars, paving	Deoxygenate water

Modified from Ferguson, B. K. 1998. *Introduction to Stormwater: Concept, Purpose, Design*, New York: John Wiley & Sons, Inc.

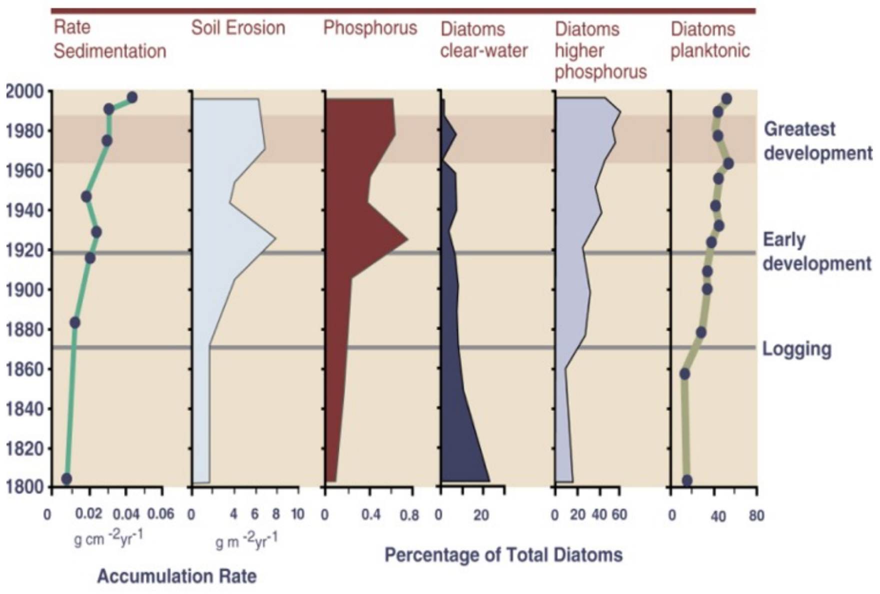
Sediment loading increases during construction and when impervious surfaces are increased.

Sediment buries plant and animal habitat critical to healthy streams, lakes and wetlands. Sediment can cover aquatic insects and mussels, warm streams, decrease flow capacity, increase flooding, transport other pollutants that bind to sediment particles, and decrease light penetration to bottom-dwelling plants.[xxii]

Sediment sources in developed watersheds include stream bank erosion; erosion from exposed soils, such as from construction sites; and sediment washed off impervious areas.[xxiii] The unit area pollutant load delivered by stormwater runoff to receiving water increases in direct proportion to the coverage of a watershed by impervious surfaces.[xxiv] Sediment loads from two small construction sites – one residential and one commercial – found sediment loads were **10 times larger** than typical loads from rural and urban land uses in Wisconsin.[xxv]

A long-term study of Wisconsin lakes found the greatest sediment and nutrient loading during construction periods.

Figure 24. Round Lake sediment core results



Garrison, Paul J. and Robert S. Wakeman. 2000. Use of Paleolimnology to Document the Effects of Lake Shoreland Development on Water Quality. *Journal of Paleolimnology*, 24(4); 369-393,

A study of lakebed sediment cores spanning the last 150 years from four Wisconsin lakes noted that initial development resulted in small but significant impacts on the lake's nutrient status. The construction period, whether during the early development phase or during later home improvement, caused the greatest increase in sediment and nutrient inputs. In the last half of the twentieth century the expansion or replacement of cottages with much larger homes has had the largest impact on all of the lakes. The sediment delivery was higher and the nutrient input was also elevated compared with the initial construction period (~1920). As cottages were converted to year-round homes or upgraded for seasonal use, more land was disturbed in order to enlarge the dwellings as well as add additional structures such as garages. In many cases, lots were suburbanized which removed much of the native vegetation and replaced it with mowed lawns.[xxvi] Figure 7 illustrates the results of this study for Round Lake in Chippewa County. Namely, during the 1920s when cottages were built, and during the 1970s and 80s when the cottages were expanded or replaced with larger homes, increases were seen in sedimentation, soil erosion, phosphorus deposition, and diatoms (algae) that survive in higher phosphorus water and float on the surface (planktonic), while algae species that survive in clear water decreased. [xxvii]

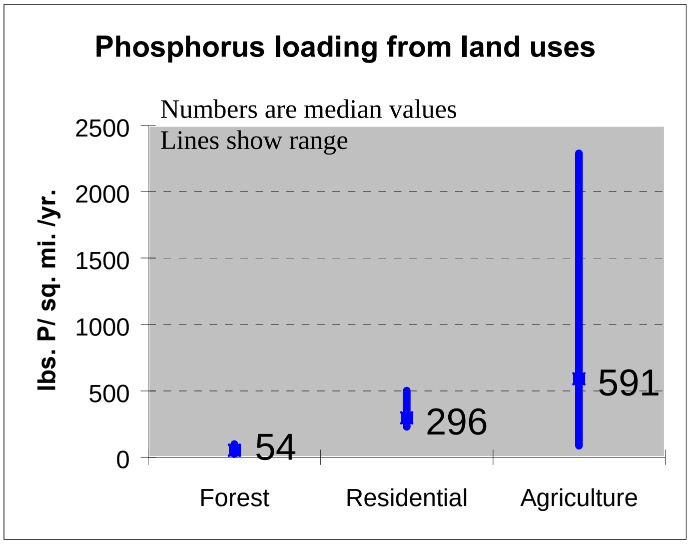
<u>Phosphorus</u> is the key nutrient for most Wisconsin lakes.

In more than 80% of Wisconsin's lakes, phosphorus is the key nutrient affecting the amount of algae and aquatic plant (weed) growth. Phosphorus originates from a variety of sources including: human and animal wastes, soil erosion, detergents, septic systems and runoff from farmland or lawns.[xxviii] The amount of in-lake phosphorus is the result of phosphorus loading to the lake as well as internal recycling from the sediment. A concentration of total phosphorus below 20 parts per billion (ug/L) for lakes and 30 parts per billion for impoundments should be maintained to prevent nuisance algal blooms. [xxix] Additional results of high phosphorus levels include excessive aquatic plant growth, decreased oxygen levels and resulting fish kills.

The amount of phosphorus delivered to lakes and stream per acre of land typically increases from forested land to residential development to cropland.

Median concentrations of pollutants in residential runoff are usually higher than in runoff from forest, pasture and open space. Cropland, on the other hand, often produces higher sediment and nutrient loading than residential development.[xxx] Thus, conversion from intensively managed crops to low density residential development may result in a slightly decreased sediment or nutrient load. On the other hand, land uses with greater than 30% impervious surface will tend to equal or exceed cropland loadings. Figure 9 shows the amount of phosphorus delivered to lakes and streams from forest, residential and agriculture based on a study of 35 watersheds in southern Wisconsin.[xxxi]

Figure 25.



Panuska, John C. and Richard A. Lillie. 1995 Phosphorus Loadings from Wisconsin Watersheds: Recommended Phosphorus Export Coefficients for Agricultural and Forested Watersheds. *Research Management Findings*, No. 38, Bureau of

These results are corroborated by a 1985 Maine study that found a 720% increase in the amount of phosphorus exported to streams when the watershed was developed with sewered lots averaging 1.2 acres in size compared with an undeveloped watershed with similar soils and slopes. The developed watershed in this study had 41% forest cover and 15% impervious surface. Additionally, preliminary results from a 2001-2002 USGS study in Forest and Vilas counties comparing waterfront forested and residential lawn sites found the lawn sites contributed seven times more phosphorus and ten times more nitrogen than the forested sites, due to significant increases in runoff volume.[xxxii]

Impervious surfaces increase water temperature.

Impervious surfaces heat the air, water and people around them – an effect obvious to anyone who has walked across a parking lot on a hot summer day. A study in Minnesota found stream temperature increases up to 10 degrees Fahrenheit after summer storm events in an urban area.[xxxiii] **Increased water temperatures eliminate trout and other fish that can only survive in cold water. Increased temperature is also important because water does not hold as much oxygen**

when warmed. Thus, increased temperatures make the aquatic system more susceptible to other stresses such as added nutrients that use up oxygen.

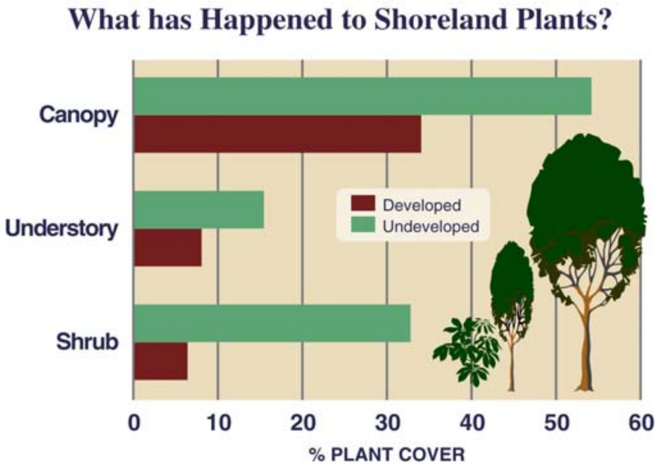
Fish and wildlife habitat

Wildlife are attracted to lakes and streams because the essentials of life for many species occur there, including food, water, shelter, and a place to raise their young. The variety of terrestrial and aquatic plants provide a mosaic of wildlife habitat. The tree canopy provides foraging and nest sites for many species of neotropical migratory birds. The understory is used by nesting birds and also provides cover, foraging sites and travel corridors for mammals such as fox, coyote, mink and fishers. Dead trees or "snags" are often used as dens, nest sites and perching and foraging sites by species such as wood ducks, hooded mergansers, owls, woodpeckers, and belted kingfishers while fallen trees are utilized by species as diverse as fish, amphibians and black bears. Birds such as thrushes and ovenbirds nest amongst the ground cover on the forest floor, while shoreline grasses provide forage and shelter for small mammals such as shrews, weasels, lemmings, voles and deer mice. Emergent and submerged aquatic vegetation near the shore provides food and shelter for a whole host of critters such as fish, frogs, toads, muskrats, mink, otter, beaver and waterfowl. Therefore, it follows that the more diverse the habitat is along lakes and streams, the more abundant and diverse wildlife will be. The attraction of wildlife to shorelines is evidenced by well-worn game trails that surround most undeveloped shorelines.[xxxiv]

The quality of fish and wildlife habitat generally decreases as the density of development increases along shorelines. Changes in water quality, bottom sediment, water levels and terrestrial and aquatic vegetation all contribute to this decline.

Aquatic and terrestrial plants are significantly reduced on developed shorelines compared to undeveloped shorelines.

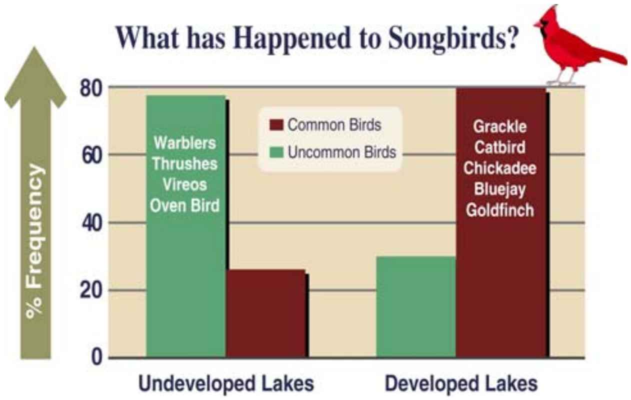
Figure 26.



Meyer, Michael, James Woodford, Sandra Gillum, Terry Daulton. 1997. Shoreland Zoning Regulations Do Not Adequately Protect Wildlife Habitat in Northern Wisconsin. Final Report – USFWS State Partnership Grant P-1-W, Segment 17. Bureau of Integrated Science Services, Wisconsin Department of Natural Resources.

Because aquatic and terrestrial plants serve many functions – from spawning habitat, shelter and foraging opportunities for a variety of fish to nesting material, cover and food for waterfowl and shorebirds - they are crucial to high quality fish and wildlife habitat.[xxxv] Emergent and floating-leaf plants are removed for boat access, docks, and piers, and by motorboat operation while submersed plants are cleared for swimming areas.[xxxvi] Researchers studying northern Wisconsin lakes found developed shorelines averaging one home per 330 feet of shoreline had 92% less floating-leaf coverage and 83% less emergent coverage than undeveloped shorelines.[xxxvii] In addition, all three stories of terrestrial vegetation (canopy, understory and shrub) were significantly reduced on developed shorelines compared to undeveloped shorelines (Figure 26).[xxxviii] Trees that have fallen in the water (coarse woody cover) constitute another important component of wildlife habitat – natural fish cribs, basking areas for reptiles and feeding sites. A study of 16 lakes in Northern Wisconsin and Upper Michigan found that cabin occupied sites contained only one-tenth as many downed trees as undeveloped sites.[xxxix]

Figure 27.



Lindsay, Alec R., Gillum, Sandra S., Meyer, Michael W. Influence of lakeshore development on breeding bird communities in a mixed northern forest. *Biological*

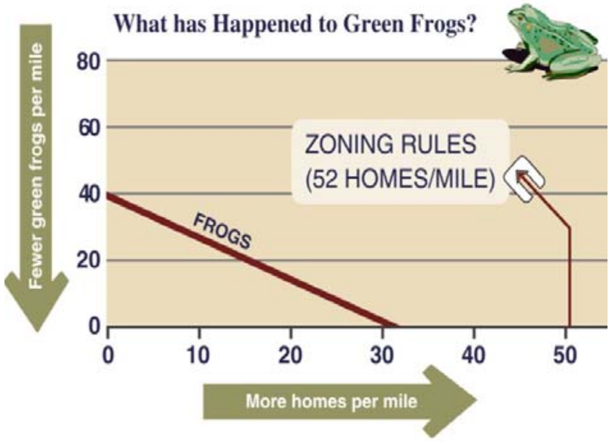
On shore…

Bird species shift and frogs are eliminated on highly developed shorelines.

As nesting cover and foraging areas are eliminated, fragmented or degraded, native wildlife declines in diversity and abundance.[xl]

As shown in Figure 27, while a northern Wisconsin study found no decrease in overall bird abundance, there were significant declines on developed shorelines in insect-eating and ground-nesting birds such as loons and warblers, contrasting with increases of seed-eating birds and deciduous-tree nesting birds such as crows and goldfinches.[xli] In short, “city birds” are favored on developed shorelines over other species.

Figure 28.



Woodford, J.E. and M. W. Meyer. 2002. Impact of lakeshore development on green frog (*Rana clamitans*)

Fewer green frogs were found on lakes in northern Wisconsin when the shorelines were developed (Figure 28). Frogs were eliminated from shorelines with 100-foot lots (52 homes per mile).[xlii] This is likely due to loss of habitat, habitat fragmentation, and increased susceptibility to predators.

In the water…

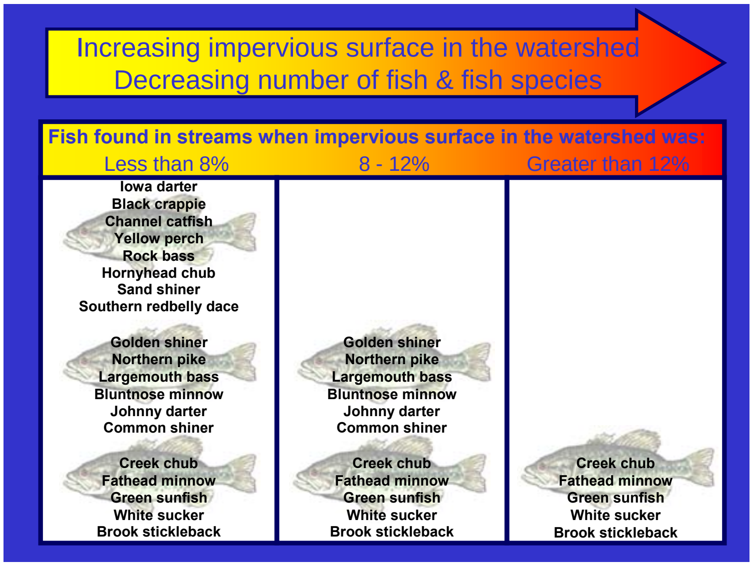
Fish and aquatic insects decrease with increasing impervious surfaces.

The aquatic insect community is an important component of the food chain in streams[xliii] and many species find shelter in the large pore spaces among cobbles and boulders. When fine sediments fill these pore spaces, it reduces the quality and quantity of habitat available to aquatic insects.

Aquatic insects are valuable stream quality indicators because they have limited ranges and short life cycles, and, unlike fish, they are abundant in most small streams. Over 20 years ago researchers found that aquatic insect diversity drops sharply in streams where watershed impervious surface exceeded 10 to 15%.[xliv]

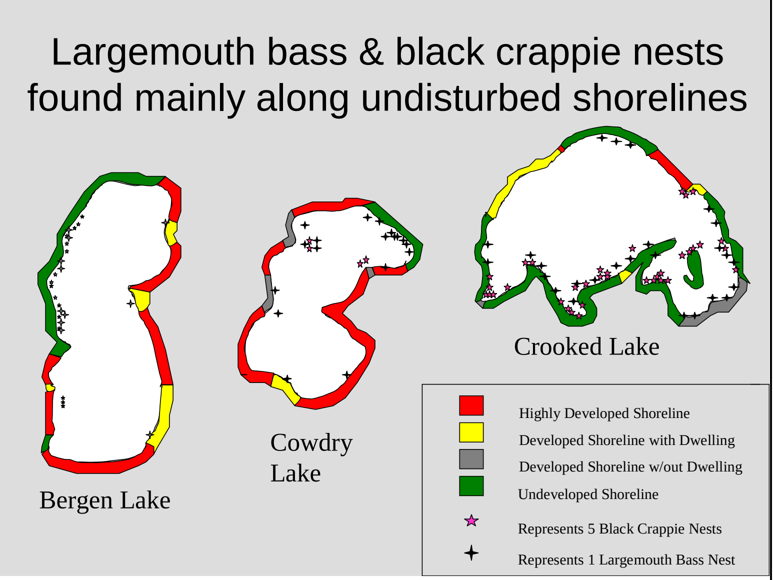
Besides the detrimental impacts on aquatic insects, fine sediments also affect fish spawning, egg incubation and fry-rearing. Figure 29 illustrates results from a study of 47 warm water streams in southeast Wisconsin that found that fish and insect populations decline dramatically when impervious surfaces exceed about 8-10% of the watershed. Streams with more than 12% imperviousness have consistently poor fish communities.[xlv]

Figure 29.



Examination of black crappie and largemouth bass nests on three Minnesota lakes found only 74 of 852 crappie nests near shorelines that had any type of dwelling on it (Figure 30). The largemouth bass were slightly more tolerant of shoreline development, but they still nested along undeveloped areas far more often that could be explained by chance. Both black crappie and largemouth bass preferred undisturbed shoreline for nest construction, indicating that as shoreline continues to be developed, both species may be crowded into fragmented habitat.[xlvi]

Figure 30.



Reed, Jeffrey. 2001. Influence of Shoreline Development on Nest Site Selection by Largemouth Bass and Black Crappie, North American Lake Management Conference Poster

Natural shoreline beauty

The aesthetics of a shoreline may be an intangible concept, but many people often recognize when it has been degraded or lost. In a Minnesota survey, waterfront property owners and lake users cited cabin and home development over 85% of the time as the cause when they perceived a decline in the scenic quality on the lake they used the most. Other activities at the top list that resulted in a decline in scenic quality included installation of docks and boat lifts, and removal of trees and shrubs in the shoreland area.[5]

These man-made elements are often seen as visual intrusions in a natural setting – they “grab” our attention and interrupt or upset the natural character of a setting. In general, landscape aesthetic assessment literature has found that more natural scenes, those in which human presence or activities are relatively less visually apparent, are consistently preferred over scenes where human development is more obvious.[6] To reduce the obvious nature of man-made elements, landowners may keep clearings and land disturbances to a minimum and retain vegetation to screen structures from view.[7]

Mitigation

Can the negative effects of shoreland development density and impervious surfaces on water quality, wildlife and natural shoreline beauty be effectively mitigated? Partially. One difficulty is that watershed practices are seldom installed consistently across an entire subwatershed and where they are installed they may be inadequately constructed or maintained.[xlvii] The remainder of this section will summarize research analyzing the following mitigation techniques:

- Low impact design
- Avoiding or reducing soil compaction
- Stormwater ponds
- Shoreline buffers
- Seeding and mulching construction sites
- Reduced application of fertilizers

Low impact design increases infiltration, thereby decreasing runoff

Traditional storm water management seeks to remove runoff as quickly as possible, gathering excess runoff in detention basins for peak reductions where necessary. In contrast, more recently developed low impact design (also known as open space subdivisions, conservation subdivisions or cluster designs) increases contiguous open spaces, reduces impervious surfaces, minimizes land disturbing activities such as road and utility installation and promotes infiltration by directing runoff from impervious areas to vegetated areas. This approach has many advantages including:

- Reducing the amount of surface runoff
- Increasing the recharge of local groundwater aquifers and streams
- Reducing erosion and stream widening
- Improving stream quality
- Avoiding additional expense and maintenance associated with traditional engineered storm water infrastructure.[xlviii]

In the open space subdivision significant cost savings were achieved by reducing impervious surfaces by 20% by:

- reducing road widths,
- reducing driveway lengths & widths, and
- using a road loop rather than a cul-de-sac.

Low impact design can do much more to reduce runoff and nutrient loads than best management practices (BMPs; in this case stormwater sewers and a sediment pond), as shown in Figure 4. Utilizing BMPs reduced nutrient loading by less than 5% in this study, whereas switching from a conventional subdivision design to an open space subdivision decreased nutrient loading by

40-50% by locating impervious surfaces farther from waterways and minimizing the amount of impervious surfaces.[xlix]

Table 15. Nutrient loading from conventional and open space subdivisions

	Nutrient Loads		
	Conventional Subdivision	Conventional Subdivision + BMPs	Open Space Subdivision
Phosphorus (lbs./yr.)	46	44	23
Nitrogen (lbs./yr.)	274	264	156

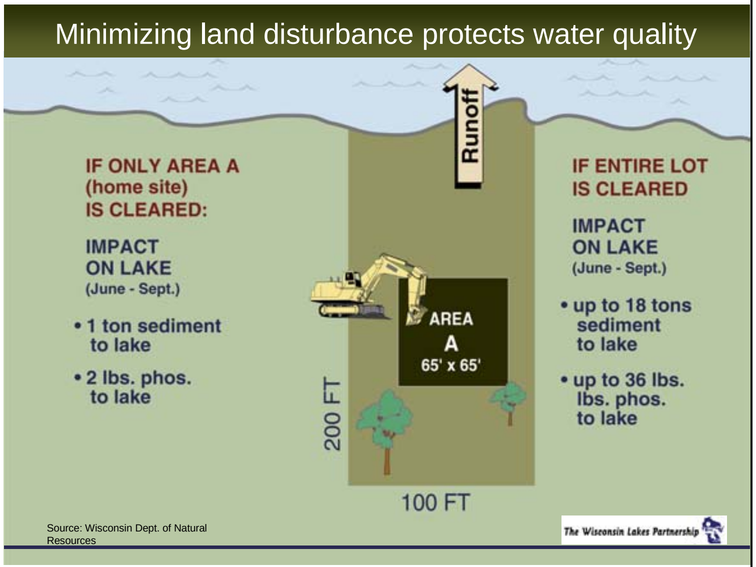
Center for Watershed Protection. Nutrient Loading from Conventional and Innovative Site Development, July 1998. pp. 26-29.

A recent modeling study found that for rainfall events less than one inch, low impact design is able to fully compensate for increased runoff from development on high infiltration capacity soils and to significantly reduce runoff for the lowest infiltration capacity soils, compared with traditional stormwater management.[l] This study also suggests that impacts of impervious surfaces can be minimized by locating them in areas with less pervious soils.[li] As shown in Table 15 below, infiltration is the most effective stormwater treatment practice for reduction of total suspended solids and phosphorus.[lii]

Minimizing land disturbance during construction reduces erosion and soil compaction.

As shown in Figure 31, this approach protects water quality by reducing the amount of sediment and phosphorus delivered to a lake by 18-fold.[liii] Fencing during construction to exclude construction activity from some areas of the site is an effective proactive measure for avoiding soil compaction.[liv]

Figure 31.



Wisconsin Department of Natural Resources memo from John Panuska 11/6/94. Graphic by Wisconsin Lakes Partnership.

Seeding and mulching construction sites reduces sediment loads

The amount of solids carried from a residential construction site can be five times greater than a developed site due to removal of vegetation and soil compaction from heavy equipment that leads to more runoff. Seeding and mulching construction sites dramatically reduced sediment loads.[lv]

Soil compaction can be reduced.

The most effective means of reducing soil compaction after construction are:

- amending the soil with compost,
- time (on the order of decades), and
- reforestation.[lvi]

Engineered stormwater treatment practices vary in effectiveness.

Stormwater ponds are commonly designed with the goal of maximizing pollutant removal, which may lead to different designs than if the goal was to protect stream habitat, prevent downstream erosion or promote aquatic diversity. The degree of pollutant removal by ponds and other stormwater treatment practices is reported in Table 1.

Table 16. Average percent removal rate of pollutants by stormwater treatment practices

Practice	Total suspended solids	Total phosphorus	Nitrogen	Oil/Grease	Bacteria
Infiltration	95%	80%	6%	NR	NR
Dry ponds	47%	19%	9%	3%	44%
Wet ponds	80%	51%	43%	78%	70%
Wetlands	76%	49%	36%	85%	78%
Water quality swales	81%	34%	9%	62%	increase
Ditches	31%	increase	9%	NR	0%

NR = Not Reported

Winer, R. 2000. *Nationanal Pollutant Removal Performance Database for Stormwater Treatment Practices, 2nd Edition*. Center for Watershed Protection. Ellicott City, MD.

Three studies found no detectable difference in aquatic insect diversity in streams with or without large stormwater ponds. Four other studies detected a small but positive effect of stormwater ponds relative to aquatic insect diversity. The positive effect of detention was typically seen only in the range of 5-20% impervious surface and was generally undetected beyond about 30% impervious cover. Although each author was hesitant about interpreting results, all generally agreed that perhaps as much as 5% impervious surface could be added to a watershed while maintaining aquatic insect diversity, given effective stormwater treatment.[lvii]

Shoreline buffers have a positive effect on fish and insect diversity.

Five studies all detected a small to moderate positive effect when forested stream buffers were present (frequently defined as at least two-thirds of the stream network with at least 100 feet of stream side forest). If excellent riparian habitats were preserved, they generally reported that fish diversity could be maintained up to 15% impervious surface, and good aquatic insect diversity could be maintained with as much as 30% impervious surface.[lviii]

Reducing application of fertilizers decreases the amount of nitrogen and phosphorus delivered to lakes.

Multiple Wisconsin communities have implemented this straightforward mitigation strategy through educational campaigns to minimize fertilizer use or convert to no-phosphorus fertilizer near water. A United States Geological Survey study found that the amount of phosphorus running off regularly fertilized lawns along Walworth County's Lauderdale Lakes was 1.6 times as great as the phosphorus coming off unfertilized sites.[lix]

Conclusion

The changes to the landscape from shoreline development increase runoff and decrease water quality, wildlife habitat and natural scenic beauty. Shorelands are especially sensitive to development activities because of their close proximity to surface waters. There is little opportunity to filter or infiltrate pollutants and nutrients from shoreland sources because they have such a short distance to travel to surface waters. Controlling lot size, width and the extent and location of impervious surfaces are important tools to decrease the *cumulative* environmental impact.

Mitigating the adverse effects after shoreland development has occurred can *reduce* the impact of impervious surfaces and compacted soils. However, it's important to realize that mitigation techniques can be expensive and difficult to consistently implement and maintain.

When trees, shrubs and grasses are replaced with impervious surfaces, especially those located close to the water, the following community benefits are threatened:

- Healthy streams with fish spawning areas, adequate flows and stable banks
- Cool, shady water for a diversity of fish
- Food and habitat for songbirds and other animals
- Natural scenery for relaxation and privacy
- Safe and sufficient groundwater for drinking, irrigation and industry
- Stormwater storage capacity to protect homes from flooding [lx]

A unique opportunity to preserve these community amenities for future generations is provided in the development density and impervious surface components of shoreland zoning.

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.

Alkalinity:

A measure of the amount of carbonates, bicarbonates, and hydroxide present in water. Low alkalinity is the main indicator of susceptibility to acid rain. Increasing alkalinity is often related to increased algae productivity. Expressed as milligrams per liter (mg/l) of calcium carbonate (CaCO3), or as microequivalents per liter (ueq/l). 20 ueq/l = 1 mg/l of CaCO3.

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.

Anion:

Refers to the chemical ions present that carry a negative charge in contrast to cations, which carry a positive charge. There must be equal amounts of positive and negative charged ions in any water sample. Following are the common anions in their order of decreasing concentration for most lakes: bicarbonate (HCO3-), sulfate (SO4--), chloride (Cl-), carbonate (CO3--), nitrate (NO3-), nitrite (NO2-), and phosphates (H2PO4-, HPO4--, and P04--).

Aquatic Invertebrates:

Aquatic animals without an internal skeletal structure such as insects, mollusks, and crayfish.

Bioaccumulation:

see "Food chain."

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 (N_2) 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 ($CaCO_3$), or milligrams per liter as calcium ion (Ca^{++}).

Cation:

Refers to chemical ions present that carry a positive charge. The common cations present in lakes in normal order of decreasing concentrations follow: calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^+), sodium (Na^+), ammonium (NH_4^+), ferric iron (Fe^{+++}) or ferrous iron (Fe^{++}), manganese (Mn^{++}), and hydrogen (H^+).

Chloride (Cl^-):

Chlorine in the chloride ion (Cl^-) form has very different properties from chlorine gas (Cl_2), 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.

Clarity:

see "Secchi disc."

Coefficient of Conservatism (c-value):

Indicates on a scale of 0 to 10 the degree to which a species can tolerate disturbance to a native plant community; a species with a c value of 10 is found only in relatively undisturbed areas of native plant community, whereas a species with a c value of 0 never grows in undisturbed areas of native plant communities. Plants with low numbers tend to occur in a wide range of more-or-less disturbed plant communities. Alien species are also assigned a c value of 0. The c values are used in this report in calculating the Floristic Quality Index for each lake.

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:

express 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.

Conductivity (specific conductance):

Measures water's ability to conduct an electric current. Conductivity is reported in micromhos per centimeter (umhos/cm) and is directly related to the total dissolved inorganic chemicals in the water. Values are commonly two times the water hardness unless the water is receiving high concentrations of contaminants introduced by humans.

Drainage basin:

The total land area that drains toward the lake.

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.

Dystrophic lake:

A typically brownish-colored lake high in dissolved organic substances associated with bog vegetation. Does not follow eutrophication's normal pattern because of natural acidity or other chemical imbalances.

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.

Flushing Rate:

see "Retention time."

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.

Ion:

A charged atom or group of atoms that has separated from an ion of the opposite charge. In water, some chemical molecules separate into cations (positive charge) and anions (negative charge). Thus the number of cations equals the number of anions.

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.

Phytoplankton:

see "Algae."

Precipitate:

A solid material which forms and settles out of water as a result of certain negative ions (anions) combining with positive ions (cations).

Retention Time:(turnover rate or 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 (02) and releases carbon dioxide (CO2). 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.

Secchi Disc (Secchi Disk):

An 8-inch diameter plate with alternating quadrants painted black and white that is used to measure water clarity (light penetration). The disc is lowered into water until it disappears from view. It is then raised until just visible. An average of the two depths, taken from the shaded side of the boat, is recorded as the Secchi disc reading. For best results, the readings should be taken on sunny, calm days.

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.

Sulfate (SO4--):

The most common form of sulfur in natural waters. The amounts relate primarily to soil minerals in the watershed. Sulfate (SO4) can be reduced to sulfide (S--) and hydrogen sulfide (H2S) under low or zero oxygen conditions. Hydrogen sulfide smells like rotten eggs and harms fish. Sulfate (SO4--) input from acid rain is a major indicator of sulfur dioxide (SO2) air pollution. Sulfate concentration is used as a chemical fingerprint to distinguish acid lakes acidified by acid rain from those acidified by organic acids from bogs.

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."

Turnover:

see "Overturn."

Watershed:

see "Drainage Basin."

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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