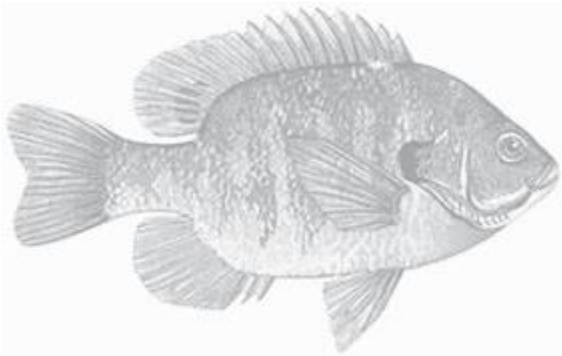
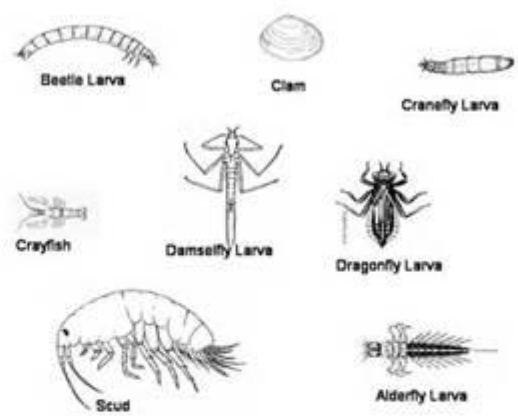




Illinois Envirothon

AQUATICS

Acknowledgements

This study was prepared in partnership with Bruce Doran and Dr. Brian Hickey, formerly with the St. Lawrence River Institute of Environmental Sciences. Originally produced in August 2001 and revised July 2015.

The guide was reviewed with support from Fleming College.

Currently revised for Illinois Envirothon by Illinois State Envirothon Coordinator and partners

Resources:

- http://isgs.illinois.edu/research/wetlands-geology
- Illinois Department of Natural Resources
- Izaak Walton League of America
- Getting to Know your Watershed Guide
- Ground Water and Surface Water: Understanding the Interaction (CTIC Know Your Watershed)
- U.S. Environmental Protection Agency, Illinois

Updated: September 2016

Contents

Contents

Learning Objectives

Students must be able to…

A. ***Understand and describe the biotic and abiotic characteristics and processes of aquatic ecosystems.***
   1. Identify the physical characteristics of water
   2. Identify the chemical properties of water and explain how those properties relate to or affect aquatic organisms
   3. Know the processes and phases for each part of the water cycle and understand the water cycle's role in nutrient erosion, salinization of agricultural lands, and climatic influences.
   4. Understand the concept and components of a watershed and be able to identify stream orders and watershed boundaries. Know the features of a healthy watershed and an unhealthy watershed and the effect people have on it.
   5. Know how to perform and interpret chemical water quality tests
   6. Be able to explain thermal stratification in lakes and lake turnover.
   7. Describe the flow of energy through aquatic systems, emphasizing aquatic food chains and webs
   8. Describe the cycling of nutrients within aquatic systems, including additions from upland systems, with particular attention to carbon, phosphorous and nitrogen
   9. Describe normal succession in Illinois' lakes, streams and wetlands
   10. Define and illustrate carrying capacity and be able to discuss fish stocking of small ponds and lakes in Illinois.
   11. Understand the main cause of summer and winter fish kills.
   12. Know how to perform and interpret biological water quality tests, using benthic macroinvertebrate testing, and understand why aquatic organisms and water quality is affected by the physical, chemical and biological conditions of the water

B. ***Describe the variety of aquatic environments, their characteristics and succession, and how they are affected by internal and external processes.***
   1. Define habitat requirements for a variety of aquatic plant and animal species and illustrate with specific examples
   2. Explain or show how a range of aquatic organisms have adapted to the characteristics of aquatic environments
   3. Illustrate the advantages of biological diversity
   4. Define a wetland and identify and describe the four major types of wetlands: swamps, marshes, fens, and bogs and their values and benefits.
   5. Understand the functions and values of riparian zones

C. ***Understand and describe practices involved in the conservation and management of healthy aquatic ecosystems and water resources***
   1. Identify and describe a variety of non-native and invasive aquatic species affecting Illinois' aquatic ecology and examine the effect of introduction of those species and possible methods of control.
   2. Identify sources of point and non-point source pollution & discuss methods to reduce them.
   3. Briefly explain water quality, the difference between surface water and ground water and the condition of these water resources in Illinois.
   4. Understand and describe the effects that climate change has on aquatic ecology
   5. Recognize types of water pollution such as organic, inorganic, thermal, toxic, etc.

Application/Analysis

Students must be able to…

1. Using a key of pictures or descriptions, identify aquatic organisms found and their indication of water quality.
2. Identify site-specific plants and animals that would be found in a given wetland
3. Be able to identify fifteen species of fish native to Illinois waters.
4. Understand common fish diseases and their possible causes.
5. Be able to identify common aquatic plants of Illinois and methods used to control aquatic vegetation
6. Calculate stream velocity and flow rate

Additional Resources Links found on the Illinois Envirothon Web Page should be used as part of this Study material:

I. Common Fresh Water Fish of Illinois

II. IDNR Aquatic Plants ID

III. IDNR Management of Small Lakes and Ponds

IV. IDNR What Fish is This

www.illinoisenvirothon.org to access material

1.0: Physical and Chemical Properties of Water

Water is one of the most essential substances and is needed by all organisms. It is the **medium** in which all cellular chemical processes occur and it provides many other functions necessary for life (e.g. transportation of solutes, pH and temperature buffer). **Aquatic organisms** depend even more heavily on water to obtain shelter and food. Aquatic ecosystems provide unique opportunities and challenges which aquatic organisms must adapt to in order to survive and reproduce.

1.1 Molecular composition of water

Water is composed of two **hydrogen atoms** both **bonded** to one atom of **oxygen** (H_20). Their arrangement is such that the molecule resembles the shape of a popular cartoon mouse character. This arrangement causes water to have weak charges at both ends of the molecule; a positive charge around the hydrogen atoms and a negative charge around the oxygen atom. Water is known as a **polar compound**, that is, a substance where molecules have weak charges at opposite ends.

The **polarity** of water contributes to some of its physical characteristics. It is the reason why water is such a good solvent, especially for salts and sugars. Due to their charges, water molecules will position themselves so that hydrogen atoms of one molecule will form weak bonds with oxygen atoms of another molecule. This bond between water particles is known as hydrogen bonds; it explains certain properties of water such as **surface tension** and the buoyancy of ice (Figure 1).

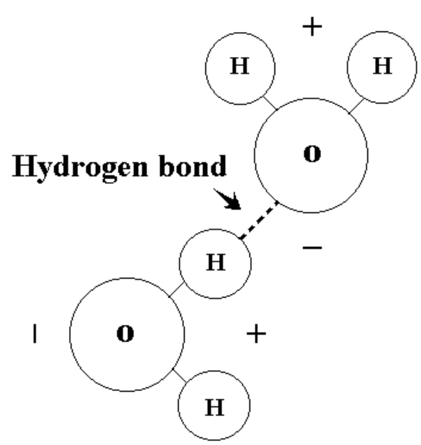


Figure 1. Hydrogen bond between two water molecules. Notice the polarity of each molecule.

1.2 Specific heat

Specific heat is defined as the capacity of a substance to absorb thermal energy (heat) in relation to the rate of temperature change at a constant **volume**. If a substance has a low specific heat it will absorb and release great amounts of heat with large changes in its temperature. Conversely, the temperature of a substance with a high specific heat will only change slightly even though it absorbs and releases lots of heat.

Water is a liquid that has a high specific heat. It will take in or lose thermal energy before it changes temperature. In fact, it is due to the hydrogen bonds that water has a high specific heat; these bonds will absorb and release an abundance of thermal energy, bringing about only slight changes in water temperature. This property of water is quite important to aquatic communities because it prevents aquatic organisms from being exposed to wide fluctuations in temperature. In Ontario, aquatic organisms are subjected to much narrower temperature ranges (4^{o}C to 27^{o}C) as compared to terrestrial organisms which must cope with annual temperatures that can range between -40^{o}C to +35^{o}C. Also, because water warms up and cools off more slowly than air, aquatic organisms are not at the mercy of sudden changes in air temperatures. For example, if a cold air mass quickly covers an area, terrestrial organisms will immediately be exposed to cold temperatures whereas aquatic organisms are insulated by water. Therefore, water acts as a buffer for aquatic organisms: they are not exposed to extreme cold or heat and temperature variations occur slowly which allow them time to adapt.

1.3 Density of water

As with all other liquids, freshwater **density** increases as it cools. It attains its maximum density at 3.98^{o}C but unlike other liquids, water becomes less dense as it freezes. Because of hydrogen bonds, water molecules arrange themselves in a highly organized fashion forming a crystalline structure. This structure has an effect of increasing the spaces between individual molecules, hence explaining why solid water (ice) expands. The increased spacing between molecules causes a drop in the density of ice. Since ice is less dense than water it will float on top of liquid. In fact, when observing ice formation on a lake or pond, ice will first start forming on the surface and then extend downward into the water. Usually, in cold winter months, the ice layer will reach a maximum thickness of 6-16 Feet and the remainder of the water will stay as a liquid underneath the ice. This property of water has important implications for aquatic life. Since the ice layer floats, aquatic organisms can continue to live in the deeper waters and remain active - albeit at a lower rate.

1.4 Turbidity

Turbidity refers to how clear water is. The greater the amount of total suspended solids (TSS) in the water, the murkier it appears and the higher the measured turbidity. The major source of turbidity in the open water zone of most lakes is typically phytoplankton, but closer to shore, particulates may also be clays and silts from shoreline erosion, re-suspended bottom sediments, and organic detritus from stream and/or wastewater discharges. Dredging operations, channelization, increased flow rates, floods, or even too many bottom-feeding fish (such as carp) may stir up bottom sediments and increase the cloudiness of the water.

High concentrations of **particulate matter** can modify light penetration, cause shallow lakes and bays to fill in faster, and smother benthic (the very bottom of the lake) habitats - impacting both organisms and eggs. As particles of silt, clay, and other organic materials settle to the bottom they can suffocate newly hatched larvae and fill in spaces between rocks which could have been used by aquatic organisms as habitat. Fine particulate material also can clog or damage sensitive gill structures, decrease organisms resistance to disease, prevent proper egg and larval development, and potentially interfere with particle feeding activities. If light penetration is reduced significantly, macrophyte growth may decrease, which would in turn impact the organisms dependent upon them for food and cover. Reduced photosynthesis can also result in a lower daytime release of oxygen into the water. Very high levels of turbidity for a short period of time may not be significant and may even be less of a problem than a lower level that persists longer. Figure 2 below shows how aquatic organisms are generally affected.

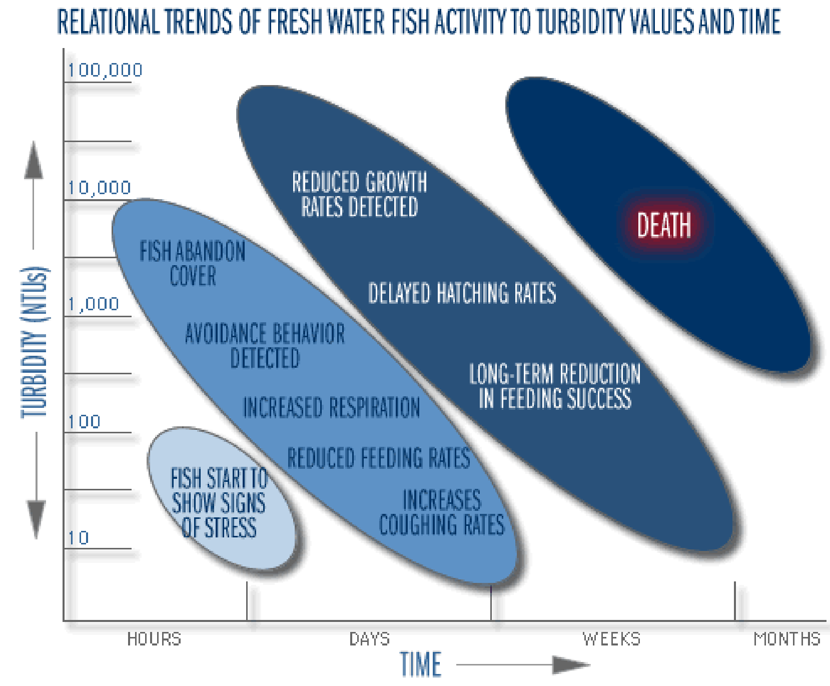


Figure 2. Schematic adapted from "Turbidty: A Water Quality Measure", Water Action Volunteers, Monitoring Factsheet Series, UW-Extension, Environmental Resources Center. It is a generic, un-calibrated impact assessment model based on Newcombe, C. P., and J. O. T. Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management. 16: 693-727

1.4.1 Impacts of Turbidity on Humans

The major effect turbidity has on humans might be simply aesthetic - people don't like the look of cloudy water. However, turbidity also adds real costs to the treatment of surface water supplies used for drinking water, since the turbidity must be virtually eliminated for effective disinfection to occur. Particulates also provide attachment sites for heavy metals such as cadmium, mercury and lead, and many toxic organic contaminants such as polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons (PAH) and many pesticides.

Example: Waukegan Harbor, Lakefront and River Watershed

The Waukegan Harbor and Lakefront and the Waukegan River Watershed were identified as areas meriting special attention in developing a Coastal Management Program for Illinois. Waukegan is rich in history and possesses unique ecological resources. The lakefront ecosystem is an example of a classic Lake Michigan dune system providing areas of unique and high quality habitat. The Waukegan River, second largest of Illinois' Lake Michigan watersheds, is now making a comeback. In fact, previous Clean Water Act Section 319 funding projects on the Waukegan River were cited by the IEPA as a success story as a result of stream stabilization, in-stream habitat enhancement, wetland restoration, and resource management efforts made by local and government officials.

Waukegan Harbor staff laid the groundwork for the renovation of the South Marina docks. The City of Waukegan prepared a Lakefront—Downtown Master Plan with a vision for transforming and developing the area consistent with national trends that support central city living, ecological restoration, and sensitive redevelopment. The plans and efforts are consistent with the policies of the Illinois Coastal Management
Program (ICMP), which can provide assistance and serve as another tool and opportunity in meeting the vision plan and goals for ecological restoration and economic development in the Waukegan area.

Waukegan Harbor

Waukegan Harbor is located on the west shore of Lake Michigan in Waukegan about 38 miles north of Chicago. The initial creation of Waukegan Harbor began in the 1880s and developed into its present configuration in 1968. The harbor is protected by a 1,894 feet long outer breakwater and two parallel piers. The north pier is 998 feet in length and the south pier is 3,225 feet in length. The harbor also includes a 390 feet wide by 22 feet deep navigation channel from Lake Michigan to the north pier head and a 200 feet wide by 18 feet deep channel between the piers leading into the inner basin. The inner basin is 18 feet deep and covers 13 acres in area. The dredging of shoaled material from the outer harbor channel was completed in October 2003. Principal commodities entering the harbor include recycleable gypsum residue and cement. The south harbor is a popular recreational site with a 1,000-slip marina. (Source: http://www.lrc.usace.army.mil/co-o/Wauk_hbr.htm)

In 1975, polychlorinated biphenyls (PCBs) were discovered in Waukegan Harbor sediments. Bioaccumulation of PCBs found in the heavily contaminated harbor sediments led to contamination of fish that resided in Waukegan Harbor. In response to the discovery of elevated levels of PCBs in the fish tissue, warning signs were placed at the harbor to warn the public not to consume Waukegan Harbor fish. Subsequent investigation of the harbor linked contaminated sediments in Waukegan Harbor to manufacturing activities at Outboard Marine Corporation (OMC). Hydraulic fluids containing PCBs were discharged through floor drains at the OMC plant and were released to Waukegan Harbor and to a drainage ditch north of the plant. The site was added to the National Priorities List in the early 1980s.
In 1981, the U.S. and Canadian governments identified Waukegan Harbor as one of 43 Areas of Concern (AOCs) or severely degraded geographic areas located within the Great Lakes Basin. The discovery of PCBs in Waukegan Harbor sediments prevented dredging of the primary navigational channels from 1975 to 1992. The Superfund Program allowed dredging of Waukegan Harbor in 1992 and 1993 when 1 million pounds of PCBs were removed from the Waukegan Harbor AOC.
(Source: http://www.epa.gov/grtlakes/aoc/waukegan.html)
The USEPA describes the cleanup of Waukegan Harbor as one of the most significant accomplishments of the federal Superfund program.
(Source:
https://www.dnr.illinois.gov/cmp/Documents/TAG_J_Waukegan%20Harbor_Lakefront_WS_2009_02_19.pdf)

1.4.2 Nephelometric Turbidity Units (NTU's)

NTU's are the units we use when we measure *Turbidity.* The term *Nephelometric* refers to the way the instrument (Nephelometer, also called a turbidimeter) estimates how light is scattered by suspended particulate material in the water. This measurement generally provides a very good correlation with the concentration of particles in the water that affect clarity, such that the more particles you have suspended in the water, the cloudier it appears which means you have a higher overall turbidity. For example, a perfectly clear lake would have a value of 0 NTU's, while a particularly turbid lake would have a value of 400 NTU's or greater (See Figure 3).

In lakes and streams, there are 3 major types of particles responsible for scattering light: **algae**, **detritus** (dead organic material), and **silt** (inorganic, or mineral, suspended sediment). The algae grow in the water and the detritus comes from dead algae, higher plants, zooplankton, bacteria, fungi, etc. produced within the water column, and from watershed vegetation washed in to the water. Sediment comes largely from shoreline erosion and from the re-suspension of bottom sediments due to wind mixing.

Figure 3. Average turbidity values of lakes impacted by silts and clays

1.4.3 Measuring Turbidity in Lakes

The **Secchi disk** depth provides an even lower "tech" method than a turbidimeter for assessing the clarity of a lake. A Secchi disk is a circular plate divided into quarters painted alternately black and white (Figure 4). The disk is attached to a rope and lowered into the water until it is no longer visible. Higher Secchi readings mean more rope was let out before the disk disappeared from sight and indicates clearer water. Lower readings mean less rope was let out and indicate turbid or coloured water. Clear water lets light penetrate more deeply into the lake than murky water, this light allows photosynthesis to occur and oxygen to be produced. The rule of thumb is that light can penetrate to a depth of about 2 - 3 times the Secchi disk depth.

Clarity is affected by algae, soil particles, and other materials suspended in the water. However, Secchi disk depth is primarily used as an indicator of algal abundance and general lake productivity. Although it is only an indicator, Secchi disk depth is the simplest and one of the most effective tools for estimating a lake's productivity. Secchi disk readings can be used to determine a lake's trophic status. Though trophic status is not related to any water quality standard, it is a mechanism for "rating" a lake's productive state since unproductive lakes are usually much clearer than productive lakes.

Figure 4. A Secchi Disc is a method to assessing the clarity of water in lakes and ponds. Secchi measurements are made in the shade with the sun to your back to make an accurate and reproducible reading.

Secchi disk readings vary seasonally with changes in photosynthesis and therefore, algal growth. In most lakes, Secchi disk readings begin to decrease in the spring, with warmer temperature and increased growth, and continue decreasing until algal growth peaks in the summer. As cooler weather sets in and growth decreases, Secchi disk readings increase again. In lakes that thermally stratify, Secchi disk readings may decrease again with fall turnover. As the surface water cools, the thermal stratification created in summer weakens and the lake mixes.

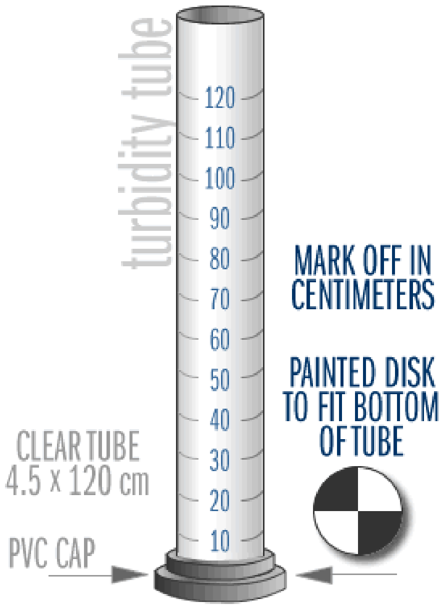
The nutrients thus released from the bottom layer of water may cause a fall algae bloom which would result in a decrease in Secchi disk reading.

Rainstorms also may affect readings. Erosion from rainfall, runoff, and high stream velocities may result in higher concentrations of suspended particles in inflowing streams and therefore decreases in Secchi disk readings. On the other hand, temperature and volume of the incoming water may be sufficient to dilute the lake with cooler, clearer water and reduce algal growth rates. Both clearer water and lower growth rates would result in increased Secchi disk readings.

The natural color of the water also affects the readings. In most lakes, the impact of color may be insignificant. But some lakes are highly colored. Lakes strongly influenced by bogs, for example, are often a very dark brown and have low Secchi readings even though they may have few algae. Pollution tends to reduce water clarity. Watershed development and poor land use practices cause increases in erosion, organic matter, and nutrients, all of which cause increases in suspended particulates and algae growth.

1.4.4 Measuring Turbidity in Rivers/streams

Turbidity is a standard measurement in stream sampling programs where suspended sediment is an extremely important parameter to monitor. A common, inexpensive method to monitoring turbidity in a river/stream is to use a device called a Turbidity tube. A Turbidity tube is a simple adaptation of the Secchi disk to be used in streams. It involves looking down a tube at a black and white disk and recording how much stream water is needed to make the disk disappear (Figure 5).



Steps to Using a Turbidity Tube

1. Pour sample water into the tube until the image at the bottom of the tube is no longer visible when looking directly through the water column at the image. Rotate the tube while looking down at the image to see if the black and white areas of the decal are distinguishable.
2. Record this depth of water on your data sheet to the nearest 1 cm. Different individuals will get different values and all should be recorded, not just the average. It is a good idea to have the initials of the observer next to the value to be able identify systematic errors.
3. If you see the image on the bottom of the tube after filling it, simply record the depth as > the depth of the tube. Then construct a longer tube, more appropriate for your stream.

Figure 5. Turbidity tube yields data for streams that is similar to a Secchi depth measurement in lakes.

1.5 Stream Flow

Stream flow, also called discharge and indicated by the symbol Q, is a measure of the volume of water that passes through a specific point in a river or stream during a set unit of time. The volume of water that passes by a specific point is often expressed in cubic meters per second (m^3/sec). Flow is a fundamental property of streams that affects everything from the temperature of the water and concentration of various substances in the water to the distribution of habitats and organisms throughout the stream.

Low flow periods in summer allow the stream to heat up rapidly in warm weather while in the fall and winter temperatures may plummet rapidly when flow is low. Flow directly affects the amount of oxygen dissolved in the water. Higher volumes of faster moving water, especially "white water," increases the turbulent diffusion of atmospheric oxygen into the water. Low flow conditions are much less conducive to oxygenation and when water temperature is high, dissolved oxygen (DO, see Section 1.10) levels can become critically low. The amount of sediment and debris a stream can carry also depends on its flow since higher velocity increases stream bank and stream channel scouring and erosion, and also keeps particulate materials suspended in the water. **Precipitation** that causes higher flows may also wash higher amounts of particulate and dissolved materials from the watershed directly into the stream. Stream flow, acting together with the downward slope (gradient), and the geology of the channel (its bottom substrate), determines the types of habitats present (pools, riffles, cascades, etc), the shape of the channel, and the composition of the stream bottom.

The volume of stream flow is determined by many factors. Precipitation is of course the primary factor- the more rain or snowmelt, the higher the flow. However, there is usually a lag period between the time a storm reaches its highest intensity and the time the stream reaches its peak flow. This lag time is affected by land use practices in the watershed. Vegetation increases the time it takes water to reach the stream by allowing it to slowly infiltrate into the soil before it reaches the stream. Wetlands and ponds in the watershed also add to this temporary storage. If it rains hard enough and long enough, the ground may saturate with water and then the precipitation will run off directly into the stream. In winter and spring, the potential of the natural soil and vegetation to absorb water is also affected by the depth to which it is frozen. This is why even moderate spring rainstorms may bring severe flash flooding. Precipitation also melts snow and ice that further contributes to the problem. In this way, stream flow patterns in Illinois, generally speaking, follow seasonal trends characterized by low or base-flow conditions in the summer and winter, and high flow periods during the spring.

1.5.1 Expected Impact of Pollution

The increased and variable flows associated with **stormwater runoff** pose a direct threat to the aquatic organisms in some streams by modifying their physical habitat. Organisms are adapted to certain ranges and intensities of water velocity. Urbanization increases impervious surfaces such as roofs, roads and parking lots which speed the delivery of water into streams. Higher velocities alter habitats by moving cobbles and boulders and flushing large woody debris (snags and shoreline brush). Increased flows create secondary impacts by increasing erosion, modifying the channel and riparian zone in addition to delivering added "natural" pollutants (leaves, soil, animal droppings), road surface chemicals (metals, hydrocarbons, salts), lawn materials (grass and garden clippings, fertilizer nutrients, pesticides), and just plain litter - cigarette butts, cans, paper, and plastic bags. Increased erosion severely affects habitats by producing increased **sedimentation** of fine silt that fills the spaces between gravel and cobbles where aquatic invertebrates live, scours organisms and clogs their gills.

1.6 Carbon Dioxide

Most of the **carbon dioxide** that enters aquatic systems originates from the atmosphere, biological activities and the breakdown of limestone. **Carbon** is a component of most biological molecules necessary for life. Carbon dioxide is usually not limited in freshwater systems but the dissolved amounts may fluctuate. For example, if photosynthesis is occurring at a high rate the amount of dissolved carbon dioxide decreases; the opposite is true if the rate of decomposition is high. Carbon dioxide in water tends to be from bicarbonates which help to buffer water against rapid shifts in **pH**. For example, if an acid is added to water, the hydrogen ions will combine with the bicarbonate ions and prevent a change in pH. This buffering capacity (known as alkalinity) has important implications for aquatic ecosystems since it protects organisms against pH fluctuations.

1.7 pH

The **pH** of a sample of water measures the concentration of hydrogen ions. The term pH was derived from the manner in which the hydrogen ion concentration is calculated - it is the negative logarithm of the hydrogen ion (H^+) concentration. What this means to those of us who are not mathematicians is that at higher pH, there are fewer free hydrogen ions and that a change of one pH unit reflects a tenfold change in the concentrations of the hydrogen ion. For example, there are 10 times as many hydrogen ions available at a pH of 7 than at a pH of 8. The pH scale ranges from 0 to 14. A pH of 7 is considered to be neutral. Substances with pH of less than 7 are acidic; substances with pH greater than 7 are basic (See Figure 6 below).

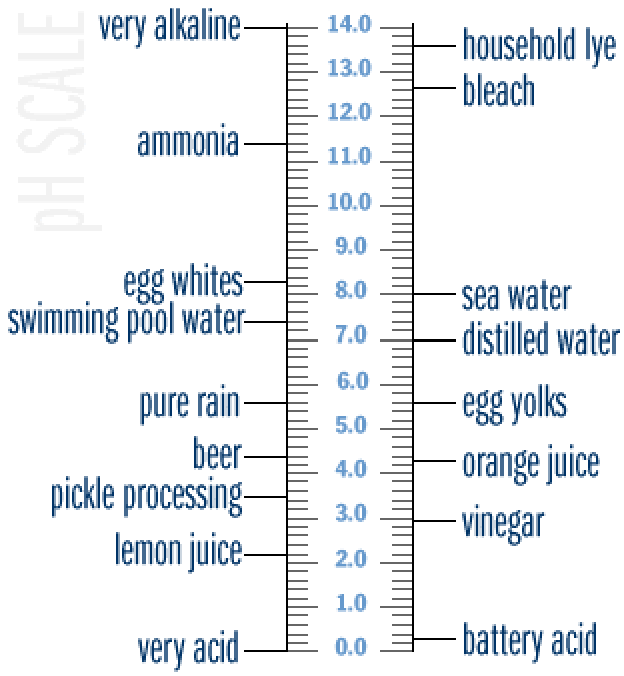


Figure 6. pH Scale

The pH of water determines the **solubility** (amount that can be dissolved in the water) and **biological availability** (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). For example, in addition to affecting how much and what form of phosphorus is most abundant in the water, pH may also determine whether aquatic life can use it. In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble.

1.7.1 Reasons for Natural Variation in pH

Photosynthesis uses dissolved carbon dioxide which acts like carbonic acid (H_2CO_3) in water. CO_2 removal, in effect, reduces the acidity of the water so pH increases. In contrast, respiration of organic matter produces CO_2, which dissolves in water as carbonic acid, thereby lowering the pH. For this reason, pH may be higher during daylight hours and during the growing season, ranging between 7.5 and 8.5, when photosynthesis is at a maximum. On the other hand, respiration and decomposition processes lower pH. pH can also vary with depth due to changes in photosynthesis and other chemical reactions. Near the bottom of the lake, decomposition releases CO_2, and because there is no light for plants to fix it, CO_2 accumulates and the pH decreases, ranging generally between 6.5 to 7.5.

1.7.2 Expected Impact of Pollution

When pollution results in higher algal and plant growth (e.g., from increased temperature or excess nutrients), pH levels may increase, as allowed by the buffering capacity of the lake. Although these small changes in pH are not likely to have a direct impact on aquatic life, they greatly influence the availability and solubility of all chemical forms in the lake and may aggravate nutrient problems. For example, a change in pH may increase the solubility of phosphorus, making it more available for plant growth and resulting in a greater long-term demand for dissolved oxygen.

1.8 Hardness

Hardness of water indicates the amount of dissolved solids, namely calcium, calcium carbonate or magnesium. Water is considered soft if it has less than 10 ppm (part per million) of dissolved solids and hard if it has over 40 ppm of dissolved solids. Generally, hard water can harbour more living matter than soft water. This is explained partly by the fact that hard water has more calcium which can be utilized by many organisms to make body structures. Therefore, hard water not only harbours a great abundance of organisms but may also be essential for the survival of certain species such as clams and snails. Lakes with high concentrations of the ions calcium (Ca^{+2}) and magnesium (Mg^{+2}) are called hardwater lakes, while those with low concentrations of these ions are called softwater lakes. For humans, hard water is not a health risk, but a nuisance because of mineral buildup on fixtures and poor soap and/or detergent performance.

1.9 Temperature

Most aquatic organisms are **poikilothermic** - i.e., "cold-blooded" - which means they are unable to internally regulate their core body temperature. Therefore, temperature exerts a major influence on the biological activity and growth of aquatic organisms. To a point, the higher the water temperature, the greater the biological activity. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have preferred temperature ranges and generally speaking, growth rates will double if temperature increases by 10°C within their "preferred" range. As temperatures move away from this preferred range the number of individuals of the species decreases until finally there are few, or none. For example, we would generally not expect to find a thriving trout fishery in ponds or shallow lakes because the water is too warm throughout the ice-free season.

Temperature is also important because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperature, which in turn affects biological activity. An important example of the effects of temperature on water chemistry is its impact on oxygen. Warm water holds less oxygen that cool water, so it may be saturated with oxygen but still not contain enough for survival of aquatic life. Some compounds are also more toxic to aquatic life at higher temperatures because the increased temperatures can increase their solubility (eg. some heavy metals like cadmium or zinc).

1.9.1 Reasons for Natural Variation in Temperature

The most obvious reason for temperature change in lakes is the change in seasonal air temperature. Daily variation also may occur, especially in the surface layers, which are warm during the day and cool at night. In deeper lakes (typically greater than 5 m for small lakes and 10 m for larger ones) during summer, the water separates into layers of distinctly different density caused by differences in temperature. Unlike all other fluids, however, as water approaches its freezing point and cools below 4°C, the opposite effect occurs and its density then begins to decrease until it freezes at 0°C. This is why ice floats. This process is called thermal stratification (See Figure 7). The surface water is warmed by the sun, but the bottom of the lake remains cold. You can feel this difference when diving into a lake. Once the stratification develops, it tends to persist until the air temperature cools again in fall. Because the layers don't mix they develop different physical and chemical characteristics. For example, **dissolved oxygen**, pH, nutrient concentrations, and species of aquatic life in the upper layer can be quite different from those in the lower layer. It is almost like having two separate lakes stacked on top of each other. The most profound difference is usually seen in the oxygen profile since the bottom layer is now isolated from the atmosphere, the major source of oxygen to the lake.

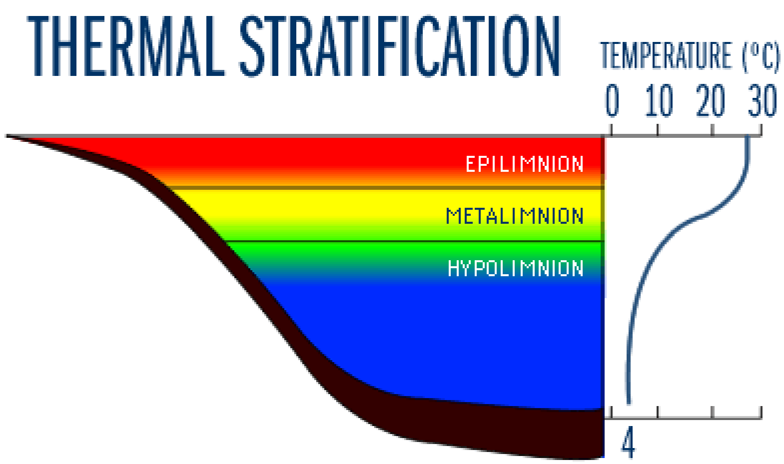


Figure 7. Example of how lakes can stratify thermally during the summer months

In the fall, the water at the surface cools down to about the same temperature as the water in the bottom layer of the lake. Consequently, thermal stratification is lost and blowing winds can cause turbulent mixing of the two water masses (fall turnover). A similar process also may occur during the spring as colder surface waters warm to the temperature of bottom waters and the lake mixes (spring turnover). The lake mixing associated with a turnover often corresponds with changes in many other chemical parameters that in turn affect biological communities. Watch for these changes in your lake this fall and spring.

Because light deceases exponentially with depth in the water column, the sun can heat a greater proportion of the water in a shallow lake than in a deep lake. This means shallow lakes can warm up faster and to a higher temperature. Lake temperature is also affected by the size and temperature of inflows (e.g., a stream during snowmelt, or springs or a lowland creek) and by how quickly water flushes through the lake. Even a shallow lake may remain cool if fed by a comparatively large, cold stream.

1.9.2 Expected Impact of Pollution

Thermal pollution (i.e., artificially high temperatures) almost always occurs as a result of discharge of municipal or industrial effluents. Except in very large lakes, it is rare to have an effluent discharge. In urban areas, runoff that flows over hot asphalt and concrete pavement before entering a lake will be artificially heated and could cause lake warming, although in most cases this impact is too small to be measured. Consequently, direct, measurable thermal pollution is not common. In running waters, particularly small urban streams, elevated temperatures from road and parking lot runoff can be a serious problem for populations of cool or cold-water fish already stressed from the other contaminants found in urban runoff. During summer, temperatures may approach their upper tolerance limit. Higher temperatures also decrease the maximum amount of oxygen that can be dissolved in water, leading to oxygen stress if the water is receiving high loads of organic matter. Water temperature fluctuations in streams may be further worsened by cutting down trees which provide shade and by absorbing more heat from sunlight due to increased water turbidity.

1.10 Dissolved Oxygen

Biological activity peaks during the spring and summer when photosynthetic activity is driven by high solar radiation. Furthermore, during the summer most lakes in temperate climates are stratified. The combination of **thermal stratification** and biological activity causes characteristic patterns in water chemistry. Figure 8 shows the typical seasonal changes in dissolved oxygen (DO) and temperature. The top scale in each graph is oxygen levels in mg O_2/L. The bottom scale is temperature in °C. In the spring and fall, both **oligotrophic** (less productive) and **eutrophic** (more productive) lakes tend to have uniform, well-mixed conditions throughout the water column. During summer stratification, the conditions in each layer diverge.

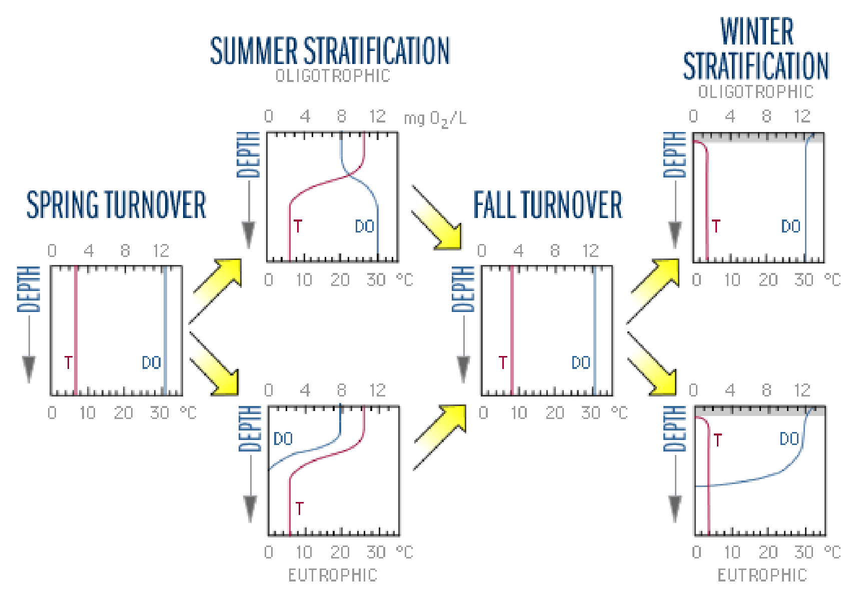


Figure 8. Typical seasonal changes in dissolved oxygen and temperature (adapted from Figure 8-1 in Wetzel, R.G. 1975. Limnology. W.B.Saunders Company)

The top water layer is known as **epilimnion** and the deep cool layer is known as the **hypolimnion** (see Figure 7). The DO concentration in the epilimnion remains high throughout the summer because of photosynthesis and diffusion from the atmosphere. However, conditions in the hypolimnion vary with trophic status. In eutrophic lakes, hypolimnetic DO declines during the summer because it is cut-off from all sources of oxygen, while organisms continue to respire and consume oxygen. The bottom layer of the lake and even the entire hypolimnion may eventually become anoxic, that is, totally devoid of oxygen. In oligotrophic lakes, low algal biomass allows deeper light penetration and less decomposition. Algae are able to grow relatively deeper in the water column and less oxygen is consumed by decomposition. The DO concentrations may therefore increase with depth below the thermocline where colder water is "carrying" higher DO leftover from spring mixing (recall that oxygen is more soluble in colder water). In extremely deep, unproductive lakes the DO may persist at high concentrations, near 100% saturation, throughout the water column all year. These differences between eutrophic and oligotrophic lakes tend to disappear with fall turnover (Figure 8).

In the winter, oligotrophic lakes generally have uniform conditions. Ice-covered eutrophic lakes, however, may develop a winter stratification of DO. If there is little or no snow cover to block sunlight, phytoplankton and some macrophytes may continue to photosynthesize, resulting in a small increase in DO just below the ice. But as microorganisms continue to decompose material in the lower water column and in the sediments, they consume oxygen, and the DO is depleted. No oxygen input from the air occurs because of the ice cover, and, if snow covers the ice, it becomes too dark for photosynthesis. This condition can cause high fish mortality during the winter, known as "winter kill." Low DO in the water overlying the sediments can exacerbate water quality deterioration; because when the DO level drops below 1 mg O_2/L chemical processes at the sediment-water interface frequently cause release of phosphorus from the sediments into the water. When a lake mixes in the spring, this new phosphorus and ammonium that has built up in the bottom water fuels increased algal growth.

1.11 General Lake Chemistry

Water is a good **solvent** and picks up impurities easily. Pure water -- tasteless, colorless, and odorless -- is often called the universal solvent. When water is combined with carbon dioxide forming a very weak carbonic acid, an even better solvent is produced. As water moves through soil and rock, it dissolves very small amounts of minerals and holds them in solution which can influence the overall water chemistry of a lake.

In the absence of any living organisms, a lake contains a wide array of molecules and ions from the weathering of soils in the watershed, the atmosphere, and the lake bottom. Therefore, the chemical composition of a lake is fundamentally a function of its climate (which affects its hydrology) and its basin geology. Each lake has an ion balance of the three major anions and four major cations (see Table 1 on next page).

Ion balance means the sum of the negative ions equals the sum of the positive cations when expressed as equivalents. These ions are usually present at concentrations expressed as mg/L (parts per million, or ppm) whereas other ions such as the nutrients phosphate, nitrate, and ammonium are present at µg/L (parts per billion, or ppb) levels.

Table 1. Major anion and cations found in Lake water

ION BALANCE FOR TYPICAL FRESH WATER			
Anions	**Percent**	**Cations**	**Percent**
HCO_3^-	73%	Ca^{+2}	63%
SO_4^{-2}	16%	Mg^{+2}	17%
Cl^-	10%	Na^+	15%
		K^+	4%
other	< 1%	other	< 1%

Humans can have profound influences on lake chemistry. Excessive landscape disturbance causes higher rates of leaching and erosion by removing vegetative cover, exposing soil, and increasing water runoff velocity. Lawn fertilizers, wastewater and urban stormwater inputs all add micronutrients such as nitrogen and phosphorus, major ions such as chloride and potassium, and, in the case of highway and parking lot runoff, oils and heavy metals. Emissions from motorized vehicles, fossil fuel-burning electric utilities and industry, and other sources produce a variety of compounds that affect lake chemistry.

Perhaps the best understood ions are H^+ (hydrogen ion, which indicates acidity), SO_4^{-2} (sulfate) and NO_3^- (nitrate) which are associated with acid rains. Mercury (Hg) is another significant air pollutant affecting aquatic ecosystems and can **bioaccumulate** in aquatic food webs, contaminating fish and causing a threat to human and wildlife health. Concentrations of other ions, especially bicarbonate, are highly correlated with the concentrations of the hardness ions, especially Ca^{+2}. The ionic concentrations influence the lake´s ability to assimilate pollutants and maintain nutrients in solution. For example, calcium carbonate ($CaCO_3$) in the form known as marl can precipitate phosphate from the water and thereby remove this important nutrient from the water.

1.12 Nutrient cycling

Carbon, nitrogen and phosphorous are some of the most important elements which determine the level of productivity in an aquatic system. Carbon enters into aquatic systems through soil surface runoffs (eg. organic residues), leachates from carbonate rocks, the atmosphere and from aquatic organisms. Phosphorous enters into aquatic systems through soil runoffs either from natural or made-made sources (eg. fertilizers) as well as from decomposition of organic matter. Man-made and natural nitrogen compounds also enter aquatic systems through runoffs, the atmosphere, decomposition of organic matter and by nitrogen fixation. **Nitrogen fixation** is a natural process where certain bacteria and algae (eg. cyanobacteria) transform biologically unavailable gaseous nitrogen into a water soluble form, such as nitrate and ammonium, which can be use by aquatic plants. Without the presence of nitrogen “fixers” very little nitrogen would be available for living organisms and most life on the planet would cease to exist.

1.12.1 Limiting factors and pollution

In aquatic systems nitrogen and especially phosphorous are known as limiting factors. In natural ecosystems these two elements are usually in short supply and therefore limit the growth of aquatic plants. If nitrogen or phosphorous are added to an aquatic system, aquatic plant growth will be stimulated causing the eutrophication of the water body. **Eutrophication** can be a natural or anthropogenic process where the release of nutrients stimulates aquatic plant growth and eventually increases animal populations. This process can be seen in time in oligotrophic lakes where the accumulation of surface runoffs and organic matter in their basins will transform it slowly to a eutrophic lake.

However, anthropogenic eutrophication can also have negative effects on aquatic ecosystems. Increased nitrogen or phosphorus inputs from agricultural fertilizers or wastes and domestic sewage can dramatically change the aquatic community. It stimulates the growth of algae (eg. algal blooms) which can cover the surface and prevent sunlight from penetrating into the water. Algal growth and the presence of suspended particles from pollution sources increases water turbidity thereby decreasing the amount of sunlight available for aquatic plants found in the water column. This situation has an effect of decreasing the amount of dissolved oxygen within the aquatic system. Plants found underneath the surface cannot add oxygen to the water since they become light starved and die. In addition, algae from the surface eventually die and sediment to the bottom where they decompose. Bacterial growth and decomposition on the bottom occurs at a high rate due to the abundance of organic matter from dead plant tissues and domestic wastes. Bacterial decomposition uses up dissolved oxygen which has an effect of creating anoxic conditions within the aquatic habitat.

1.13 Watersheds

Healthy watersheds are vital for a healthy environment and economy. Our watersheds provide water for drinking, irrigation and industry. Many people also enjoy lakes and streams for their beauty and for boating, fishing and swimming. Wildlife also need healthy watersheds for food and shelter.

In the past, most water quality problems were traced to the most obvious cause ... **point-source pollution**. This means the problem can be traced to a specific location such as a pipe or disposal site. Technical and regulatory methods have been used to detect and control these problems. Much progress has been made in preventing further water quality problems from point sources. However, water quality problems from nonpoint-source pollution are more difficult to isolate and control. These sources are often hard to identify and difficult to measure. This type of pollution results from a wide variety of activities over a wide area. **Nonpoint-source** pollutants are in the water that runs off crop or forest land. Others include failing septic systems, parking lots, construction sites, irrigation systems and drainage systems. It can even result from automobile exhaust getting in the atmosphere and falling back to earth in the rain.

1.13.1 Features of a Watershed

Your watershed has many features that make it unique.

Size.

One important feature is the size of the watershed. Some (like the Mississippi River basin) are very large and include many smaller river basins or watersheds. These smaller watersheds can be subdivided into even smaller areas. The ideal size for a voluntary partnership to work with is 50,000 acres or less. At this size your group will likely see water quality improvements sooner than in larger areas. Of course, in regions of the United States where ranchers, Foresters and others manage large tracts of land, you may be working with a much larger watershed.

Boundary.

Another important feature is the geographic boundary of the watershed. The boundary is formed by a ridge or high area from which water drains either toward or away from your watershed.

Terrain.

The topography (terrain) is another important feature. How flat or steep the land is impacts how fast water drains. The faster the drainage, the more potential for flooding and increased soil erosion.

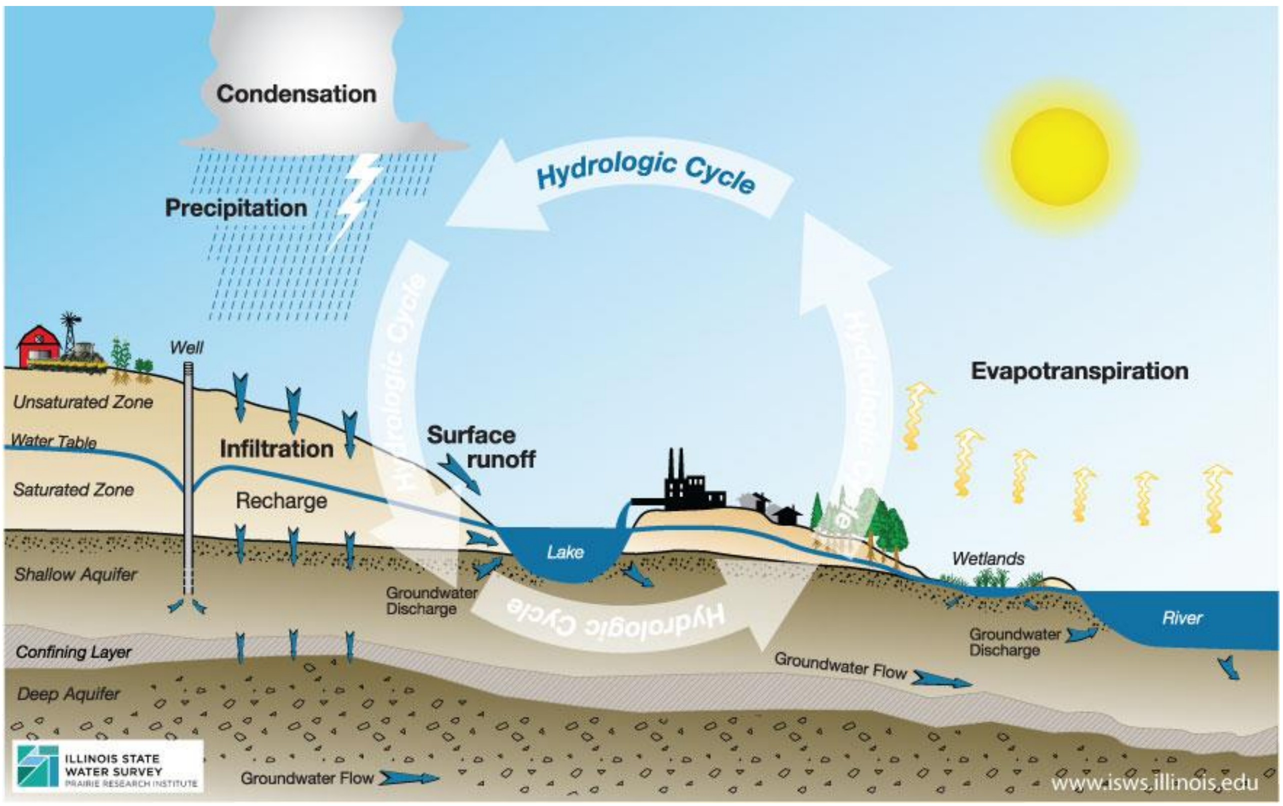
Soil type.

Soil type is also important. For example, sandy soils allow the ground to soak up water faster. This reduces surface runoff, but can affect ground water. Clay soils, on the other hand, are tighter and do not allow as much water infiltration. This can lead to more runoff and soil erosion.

Other features.

Whether your watershed drains into a stream or lake, the area nearest the water greatly affects water quality. This is why **filter/buffer strips**, wildlife habitat, wetlands and **riparian areas** are important aspects of your watershed. Both filter/buffer strips and wetlands utilize nutrients and tie up sediment to help improve water quality. Wetlands also act as natural sponges to absorb peak flows of water and reduce flooding. Many fish and wildlife species rely on wetlands for rearing their young, and for food and shelter.

(Source: Getting to Know your Watershed Guide)



1.13.2 Ground Water, Surface Water and Pollutions

Ground Water is a hidden resource. At one time, its purity and availability were taken for granted. Now contamination and availability are serious issues. Some interesting facts to consider...

- Scientists estimate ground water accounts for more than 95% of all fresh water available for use.

- Approximately 50% of Americans obtain all or part of their drinking water from groundwater.
- Nearly 95% of rural residents rely on ground water for their drinking supply.
- About half of irrigated cropland uses ground water.
- Approximately one third of industrial water needs are fulfilled by using ground water.
- About 40% of river flow nationwide (on average) depends on groundwater.

Thus, ground water is a critical component of management plans developed by an increasing number of watershed partnerships.

So how do ground water and **surface water connect**? It's crystal clear. Ground water and surface water are fundamentally interconnected. In fact, it is often difficult to separate the two because they "feed" each other. This is why one can contaminate the other.

A closer look.
To better understand the connection, take a closer look at the various zones and actions. A way to study this is by understanding how water recycles ... the hydrologic (water) cycle.

As rain or snow falls to the earth's surface:

- Some water runs off the land to rivers, lakes, streams and oceans (surface water).
- Water also can move into those bodies by percolation below ground.
- Water entering the soil can...
  - infiltrate deeper to reach groundwater
  - which can discharge to surface water or return to the surface through wells, springs and marshes.
- Here it becomes surface water again.
- And, upon evaporation, it completes the cycle.

This movement of water between the earth and the atmosphere through evaporation, precipitation, infiltration and runoff is continuous.

How ground water "feeds" surface water.
One of the most commonly used forms of groundwater comes from unconfined shallow water table aquifers.

These aquifers are major sources of drinking and irrigation water. They also interact closely with streams, sometimes flowing (discharging) water into a stream or lake and sometimes receiving water from the stream or lake.

An unconfined aquifer that feeds streams is said to provide the stream's baseflow. (This is called a gaining stream.) In fact, ground water can be responsible for maintaining the hydrologic balance of surface streams, springs, lakes, wetlands and marshes.

This is why successful watershed partnerships with a special interest in a particular stream, lake or other surface waterbody always have a special interest in the unconfined aquifer, adjacent to the water body.

How surface water "feeds" ground water.
The source of ground water (recharge) is through precipitation or surface water that percolates downward. Approximately 5-50% (depending on climate, land use, soil type, geology and many other factors) of annual

precipitation results in ground water recharge. In some areas, streams literally recharge the aquifer through stream bed infiltration, called losing streams.

Left untouched, ground water naturally arrives at a balance, discharging and recharging depending on hydrologic conditions.

Types of Water Pollutions to know:

Surface water pollution

Hazardous substances coming into contact with surface water, like rivers, lakes, lagoons and oceans, and dissolving or mixing physically with the water is called surface water pollution.

Oil Pollution

An oil spill is the release of a liquid petroleum hydrocarbon into the environment, especially marine areas, due to human activity. Oil spills usually have only a localized affect but can spread.

Chemical Water Pollution

Many industries and farmers work with chemicals that end up in water. These include chemicals that are used to control weeds, insects and pests. Metals and solvents from industries can pollute water bodies.

Ground Water Pollution

When humans apply pesticides and chemicals to soils, they are washed deep into the ground by rain water. This gets to underground water, causing pollution underground.

Thermal pollution

Thermal pollution is the rise or fall in the temperature of a natural body of water caused by human influence. Thermal pollution, unlike chemical pollution, results in a change in the physical properties of water. (Explained further in Section 1.9.2)

Agricultural Pollution

Sediment soil washed off fields is the largest source of agricultural pollution in the United States. Farmers may utilize conservation practices to reduce runoff flows and retain soil on their fields.

The quality of rivers and streams plays a fundamental role in the overall health of the environment and has a direct bearing on both the economic and recreational opportunities available to the citizens of Illinois. Consequently, public interest in the value of water quality has increased significantly in recent years.

The miles of rivers and streams that are assessed by the Illinois EPA has increased significantly. In 1986, only 3,400 miles of rivers and streams were assessed as compared to the 15,304 miles that were assessed for this 2000 report. Of the 15,304 miles assessed in 2000 for overall resource quality, 62.5 percent were rated as "good," 36.1 percent were rated as "fair," and 1.4 percent were rated as "poor."
(http://www.epa.state.il.us/water/water-quality/report-2000/index.html)

1.13.3 Characteristics of a Healthy Watershed

- Water quality is high enough to support native aquatic species and their food.
- The streams and their floodplains are able to accommodate flood flows without regular destructive flooding and erosion.

- Streamflows are close to historic conditions with moderate peak flows after winter storms and stable summer baseflows. This is strongly correlated to the amount of hard, impervious surfaces such as roofs and pavements throughout the watershed, especially those that are directly connected to streams through ditches and storm drains.

- Streams have sufficient complex habitat features including pools, gravel bars, and large pieces of wood to support fish and other aquatic wildlife even through short-term changes from drought, wildfire, landslides, or other events that alter habitat conditions in parts of the system.

- Native, keystone plant and animal species are able to sustain stable populations.

- The riparian corridor has a dense, healthy native plant community that regenerates naturally.

- Upland forests and grasslands are managed to promote rain infiltration, provide diverse habitat for native wildlife, reduce soil erosion, and deliver clean water into streams.

- Tidal areas are connected to their wetlands.

2.0 Aquatic Systems & Associated Organisms

Not all aquatic organisms can be found in every type of freshwater system. Each kind of aquatic system provides challenges which organisms need to be adapted to in order to survive. Therefore the distribution and abundance of certain species within aquatic habitats may be limited.

2.1 Lotic Systems (Streams and Rivers)

Running water habitats are collectively known as lotic systems. Generally, streams and rivers tend to be cooler and more aerated than ponds and lakes. Organisms found within streams and rivers tend to be adapted to live in cool waters that are oxygen rich. Even though many of these organisms have gills and other body structures that absorb dissolved oxygen from water, several would be unable to live in low oxygen environments such as those found in still waters. Therefore, organisms found in lotic environments need the high oxygen levels of streams and rivers in order to survive.

Inhabitants of streams and rivers must overcome the water current to be able to survive in lotic systems. In order not to be washed downstream, inhabitants have adapted to anchor themselves or developed behaviors that protect them from the current. Generally, fast flowing systems lack plankton and other floating plants since these would be constantly washed downstream. Usually plants found in lotic systems tend to be rooted or anchored to the bottom substrate. Animals found in lotic systems tend to have dorsal-ventrally flattened or streamlined bodies. Also, many have strong legs with grasping claws, while others prefer to build heavy tube-shaped homes or hide underneath rocks and stones. All of these features are essential to allow these organisms to remain in place; still water organisms lack many of these adaptations and therefore cannot live in extreme currents. Lotic systems can be separated into two major groups: streams and rivers. The following is a description of each system and its inhabitants.

2.1.1 Streams

Streams are smaller and feed into rivers. Their substrate is generally composed of stones, rocks, pebbles and some silt in areas where water current is weaker. Organic matter does not accumulate in any great extent since it is constantly washed downstream. Streams tend to be cooler than rivers and therefore will contain more dissolved oxygen.

Organisms found in streams are adapted to swift and strong currents. Sometimes the only plants found are mosses and algae (eg. diatoms) clinging to rocks. Benthic organisms found at the bottom of the basin, such as riffle beetle larvae, dobsonfly larvae, blackfly larvae, caddisfly larvae, stonefly nymphs and mayfly nymphs make up the majority of animals. Some snails and fish, such as minnow and darter, will also inhabit these systems.

Two Major category examples are: agricultural and woodland streams. Agricultural streams are those found meandering in agricultural lands and since they are exposed directly to sunlight tend to harbor lots of algal growth. On the other hand, woodland streams are shaded and have less plant growth within them. Input of organic material and energy in woodland streams come from dead plant matter and leaf litter (detritus). In both habitats, insects like riffle beetles, mayflies, blackflies and caddisflies either graze on algae found on rocks, consume dead plant material or filter water to collect organic matter. These organisms are in turn eaten by predators such as stoneflies, dobsonflies and fish. Stream systems tend to have the simplest food webs since not many species can live in a turbulent environment.

Stream ecosystems are also a very important habitat area for benthic macroinvertebrates (BMIs). BMIs are invertebrates (animals without a backbone) that live in the benthic zone (bottom) of various types of aquatic ecosystems, especially streams. Some will stay there for the duration of their life, while others are only there for the larval life stage. BMIs play an important role in stream biodiversity as they are the connection between decomposing plant and algal material and larger organisms such as fish. Without healthy populations of a variety of BMI species, the biodiversity of higher organisms would be crippled.

Another factor that makes BMIs of such great interest is that their populations are easy to sample, making stream biodiversity easier to measure. To learn more about this process or about how to identify benthic macroinvertebrates, please see the activity in section 6.0 and Appendix B.

2.1.2 Rivers

Rivers are larger and obtain all discharge material from streams. There are many different types of rivers all varying in depths and width and amount of water current. Depending on their current their substrate may resemble that of streams or lakes.

Rivers with torrential currents have little organic matter accumulating on the substrate and many of the inhabitants will be similar to those found in streams. Rivers with slow currents may have organic matter and silt as their substrate and may even have organisms normally found in still waters. These rivers may have rooted plants such as cattails, pondweeds, coontails and may even have plankton in eddies or bays where water current is lacking. The animal community of slow flowing rivers may be similar to streams but may also contain still water inhabitants such as crustaceans, worms, dragonflies, damselflies, midges, beetles, true bugs, snails, clams, fish and amphibians.

Food webs in slow flowing rivers are more complex than streams since more species are capable of living in these habitats. Energy and organic sources may come from both detritus and photosynthesis. Filter-feeders, grazers and shedders consume this plant material and may be preyed upon by larger predators.

2.2 Lentic Systems (Ponds and Lakes)

Standing waters are collectively known as lentic systems. Unidirectional water flow is minimal and these waters tend to be warmer than streams and rivers. Oxygen levels in lentic systems are generally lower than lotic systems but some standing waters may contain enough dissolved oxygen to support the growth of some lotic adapted organisms. Lentic systems differ greatly from one another in size, temperature regimes, dissolved oxygen and chemical levels. For example, standing water hardness depends on the surrounding land mass and types of substrates found within the habitat. In most lentic systems, silt and organic matter accumulates on the bottom of the basin which can have special implications for aquatic organisms.

Organisms found in lentic systems do not need special adaptations to remain in place since water current in their habitat is minimal. Several will use the water surface as a home while others will be found deep on the bottom. Deep basins tend to have variations in temperature and oxygen levels with surface waters being warmer and containing more dissolved oxygen; this thermal and oxygen stratification will influence the distribution of species within deep basins.

Lentic systems can be separated into three major groups: wetlands, ponds and lakes. The following is a description of each system and its inhabitants.

2.2.1 Wetlands

Wetlands are a diverse and extremely interesting type of ecosystem, where land and water meet and overlap. Some wetlands are inundated with water all year long, while others are seasonally wet. Either way, all wetlands are the product of water being trapped in a certain area that creates an ecosystem that caters to many types of species. Wetlands are similar to ponds in that they tend to be shallow with warm waters. It is difficult to categorize wetlands as purely aquatic since many have a recurrent dry and wet phase. However, they are important reproductive sites for many species that require water at some stage of their life cycle.

Example – Blanding's Turtle

The Blanding's turtle is a freshwater species of turtle found only in North America (Figure 10). It can be identified by its smooth and round dark green shell and vibrant yellow throat and chin. Blanding's turtles are very well adapted for colder climate conditions, and actually prefer cooler temperatures as they cannot tolerate extreme heat. Contrarily, their young cannot hatch in temperatures below 22°C, limiting this unique species to a small area concentrated around the more Northern part of the Great Lakes.

***Figure 10**: Blanding's Turtle*
Source: Ontario.ca

Blanding's turtles can live in a variety of wetland and aquatic environments, including marshes, swamps and bogs as well as ponds and other small areas of open water. Clean, shallow water is required for survival, as well as sandy areas for nesting. These two requirements are threatened by human development in natural areas, as wetlands are filled in or contaminated. Additionally sandy areas occur most often along road sides which cause a direct threat to the turtle's survival.

Example – Common Cattail

***Figure 11**: Common Cattail*
Source: USDA Plants Database

The common cattail is one of the most characteristic plants of Illinois wetlands (Figure 11). Their presence can identify soils saturated with water, where their roots (called rhizomes) grow very quickly, creating large, dense stands of this plant.

Cattails offer ideal habitat for many species, including songbirds, waterfowl, reptiles, amphibians and fish. Many other species, such as deer, raccoons, rabbits and wild turkeys take advantage of the excellent cover and protection that cattail stands offer. The common cattail is also an important building material for many species, such as muskrats that use the tall strong stocks to build their lodges, and birds that use the “fluff” to insulate their nests.

Besides providing excellent habitat for many species, cattails also purify the water in wetlands, which improves living conditions for many species, including humans. The common cattail is an important part of wetland ecosystems as it promotes and safeguards biodiversity.

2.2.2 Ponds

Ponds are generally smaller and warmer than lakes and are shallow enough to allow rooted plants to grow on the bottom of the basin. Ponds tend to be more productive than lakes and support more aquatic organisms per volume of water. Usually water temperatures throughout ponds tend to be uniform and the bottom rarely becomes anoxic. Silt and organic matter accumulates on the bottom of ponds and with time may fill up the basin.

Several of the organisms found in ponds are similar to those found in river systems and in lakes. Generally, organisms using pond habitats are those which require high to moderate dissolved oxygen levels and warm water temperatures. Many ectotherms such as insects and amphibians will use ponds since they provide the right temperature regimes to allow proper larval development. Pond water hardness tends to be higher than in lakes and therefore organisms that require “hard” water will be found in ponds. Fishless ponds also provide an excellent habitat for some species such as mosquitoes, which seek these water bodies in order to escape predation. Organisms will use different zones of a pond depending on their adaptations. Some will use the water surface and these organisms are collectively referred to as neuston. Examples of these include plants like phytoplankton, duckweeds and water lilies and animals such as mosquito larvae, water striders and “whirligig” beetles. Other organisms like some phytoplankton, zooplankton, beetles, hemipterans, fish, amphibians and reptiles will use the water column as a habitat. Most animals in ponds will be found at the bottom of the basin (benthos) or on plants (epiphytes), consuming detritus or organisms hidden in the substrate or among the plants. The benthic animal community is composed of invertebrates (animals without a backbone) such as beetles, hemipterans, dragonfly nymphs, damselfly nymphs, mayfly nymphs, caddisfly larvae, midge larvae, spiders, mites, worms, leeches, snails and clams.

Pond food webs can be quite complex due to the diversity of animal and plant life. Generally, the initial energy source of ponds comes from the photosynthetic activities of phytoplankton and plants. These are then eaten by herbivorous primary consumers which in turn may become preyed upon by consumers and predators higher up in the food chain.

2.2.3 Lakes

Lakes are larger and generally cooler than ponds. Much variation exists between lakes in their size, depth and chemical composition but all have one trait in common: their basins are too deep to allow the growth of rooted aquatic plants on the bottom. Lakes can be divided into three major categories based on their trophic status or productivity.

- **Oligotrophic lakes:** These deep and cold lakes tend to be the least productive with low levels of photosynthesis occurring and little organic matter accumulation on the bottom. Dissolved oxygen levels do not change dramatically with depth. Generally, these lakes harbour the fewest organisms.
- **Eutrophic lakes**: Shallower and warmer than oligotrophic lakes and are the most productive of all lake types. Photosynthesis occurs at high levels and lots of organic matter accumulates on the bottom. Due to microbial decomposition of detritus on the bottom, oxygen levels decrease dramatically with depth. Generally, these lakes have the highest levels of biomass.
- **Mesotrophic Lakes:** represent an intermediate condition falling between oligotrophic and eutrophic

While lakes may be lumped into a few trophic classes, each lake has a unique constellation of attributes that contribute to its trophic status. Three main factors regulate the trophic state of a lake:

1. Rate of nutrient supply - Influenced by the bedrock geology of the watershed, as well as soil and vegetation patterns and human land use practices and management.
2. Climate – amount of sunlight, temperature and hydrology (precipitation + lake basin turnover time)
3. Shape of lake basin (morphometry) – Influenced by maximum and mean depth, volume and surface area and watershed to lake surface area ratio ($A_w : A_o$).

Trophic status is a useful means of classifying lakes and describing lake processes in terms of the productivity of the system. Basins with infertile soils release relatively little nitrogen and phosphorus leading to less productive lakes, classified as oligotrophic or mesotrophic. Watersheds with rich organic soils, or agricultural regions enriched with fertilizers, yield much higher nutrient loads, resulting in more productive, eutrophic (even hyper-eutrophic) lakes.

Illinois lakes during the course of the summer undergo thermal stratification. The top water layer known as epilimnion is warm and the deep cool layer is known as the hypolimnion. These two water layers are separated by a thin water layer known as the metalimnion where we find the greatest temperature change. These differences in temperature have important implications to aquatic organisms; species will occupy depths to which they are adapted. For example, cold water fishes such as salmon and lake trout will be found in deep waters in places like Lake Michigan, whereas warm water fish such as sunfish and perch will be found in warm shallow waters. In lakes, organisms form distinct communities depending on the region which they are found. Aquatic ecologists divide lakes habitats into distinct regions, with each harbouring specific organisms.

- **Lake Surface:** Several organisms will use surface tension as a "substrate" for their activities. This community can be quite similar to that found in ponds, especially in shallow areas of lakes. The neustonic community can include plants like phytoplankton, duckweeds, water lilies and other floating plants and animals such as mosquito larvae, water striders and "whirligig" beetles. Generally, many of these organisms are only found in shallow water near the shoreline (eg. littoral zone).

- **Littoral Zone:** Region of lakes which extends from the shoreline to the limit of occupancy of rooted plants. Animal and plant communities in this region can be quite similar to those found in ponds. Generally, this is the zone where we find the greatest biodiversity and is an important reproductive site for snails, insects, fish, amphibians and waterfowl. Water in this region is usually warm and well oxygenated.
- **Limnetic Zone:** Region of open water bounded by the littoral zone. In this region there are no rooted aquatic plants and organisms found here live in the water column. Inhabitants of the limnetic zone are classified as nekton and plankton. Nekton includes organisms like fish and insects. Plankton can include plants (phytoplankton) such as algae and animals (zooplankton) like copepods and rotifers. These organisms can be found throughout the water column or in specific layers depending on their adaptations. The limnetic zone can be further subdivided into two major layers:
- **Trophogenic Zone:** Corresponds to the lighted zone and serves as habitat to phytoplankton and plant-based animal communities. Generally, water temperatures and dissolved oxygen levels are higher in this region. Organisms needing sunlight and higher dissolved oxygen levels will be found here.
- **Tropholytic Region:** Also known as the profundal zone; corresponds to the deep, cold and dark zone. Here photosynthesis does not occur and very little oxygen is added to the water. Organic matter from above accumulates on the bottom and due to microbial activities (which use oxygen) water in this zone can become anoxic. Organisms, such as midgefly larvae are found here since they are adapted to live in low oxygen environments.
- **Benthic Zone:** Corresponds to the lake basin which extends from the littoral zone to the tropholytic zone. Benthos organisms found in littoral zones are those which require high dissolved oxygen levels and warm water to complete their development. Benthos found in tropholytic zones, such as *Tubifex* worms, are adapted to live in waters with little dissolved oxygen.

Example - Walleye

Walleye are a native species to Ontario (Figure 12). They are found in great abundance in the Great Lakes basin, but also in Illinois in many water bodies. Walleye can thrive in a variety of conditions and habitats, ranging from cold clear lakes and streams to weedy cool waters. However, their ideal temperature is around 23° C. Due to their large eyes, walleye tend to frequent areas where there is minimal light, such as weed beds or other areas with sufficient cover. They tend to come close to the shore at night-time to feed, especially in the spring and fall seasons.

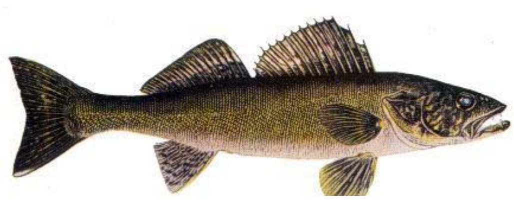


Figure 12: *Walleye*
Source: Ontario.ca

Due to their sensitivity to light, walleye are affected by the presence of zebra mussels. This invasive species feeds on various forms of plankton and other particles in the water column. This filtration feeding makes for clearer water bodies with increased light penetration, not a favorable condition for walleye. Walleye also like turbid waters. The impacts of zebra a mussel is driving walleye deeper and depriving the species of its habitat.

Walleye are a popular sport fish in Illinois. Beyond that they are an important species in lake and river environments, their populations are the source of economic income for many businesses and they are a food source for many people.

To learn more about how to identify walleye and other native Illinois fish species, please see Appendix A.

3.0 Carrying Capacity and Ecological Succession

Aquatic ecosystems are not "static", they change over time. With time, wetlands and ponds may dry up giving way to grassy meadows. These changes occur through a series of steps with specific plant groups appearing and being replaced by other plants until eventually a climax community is reached.

3.1 Carrying capacity, critical habitat and limiting factors

All organisms have habitat requirements that allow them to reproduce and grow. In many cases, organisms are flexible enough to use several components of their habitats. For example, predators like dragonfly nymphs and sunfish, can switch to a planktivorous diet if insect prey are no longer available. However, most organisms at some point in their lives will have specific requirements which can only be met by particular habitats. These critical habitats usually consist of important reproductive and developmental sites; their presence determines the survival and abundance of a species.

The abundance of species within habitats is also determined by a variety of other factors including amount of food, presence of predators and limiting factors. Limiting factors are components in the ecosystem which are in short supply and affect the abundance of organisms. Phosphorous is an example of a limiting nutrient in aquatic ecosystems. It is usually in scarce amounts and therefore limits the growth of aquatic plants. All of these factors together determine the total population of organisms that can be supported by an ecosystem, that is, the carrying capacity of a habitat. If a species population grows above the carrying capacity of its habitat this may result in a population crash. Populations can only increase without crashing if there is a change in limiting factors. By increasing the abundance of a limiting factor, the habitat's carrying capacity for that species also increases. Unfortunately, as seen previously with the addition of phosphorous to waterbodies, the addition of a limiting factor to an ecosystem can have negative effects by permitting species to reach unnaturally high levels.

Sometimes variations in the carrying capacity for one species can cause changes in other species. Imagine what would happen if a spawning site of large predatory fish, such as the Largemouth Bass, were destroyed. These fish would lose a critical reproductive habitat and eventually disappear. Smaller prey fish would now be free of predation pressure and increase in population. These smaller fish might eventually reach and "over-shoot" the carrying capacity of the ecosystem. The habitat would no longer have enough food to sustain the smaller fish causing them to either die out or become severely malnourished. Therefore; a decrease in the carrying capacity for predatory species has caused a severe change in prey species populations.

Please go to this link to study more about Management of Small Lakes and Ponds In Illinois: "Managemement of Small Lakes and Ponds in Illinois"

3.2 Ecological Succession in Aquatic Systems

In most aquatic systems we see a general progression of plant zones from deep to shallow water and finally to the shore. In each zone there are plants which are adapted to specific conditions. Aquatic ecosystems can be divided into four major plant zones: shoreline zone, emergent zone, floating-leaved zone and submerged zone.

The shoreline zone is composed of plants that require or can tolerate soil with lots of moisture. Some of these plants, including mosses, horsetails and ferns, grow at the edges of the shore since they need some surface water to reproduce. Other plants such as willows, dogwood and alders will also be found near the shoreline. Most plants found in this zone cannot endure extended periods under water.

The emergent zone is the area closest to the shoreline with the shallowest water. Plants found in this zone grow above and below the water surface. Examples of such plants include cattails, grasses, sedges, rushes, arrowheads, burreeds, calla lilies and purple loosestrife. These plants cannot survive complete submergence in water. In order to complete their lifecycle (e.g. seed production), they require that some growth above the water surface.

The floating-leaved zone is composed of plants which have leaves that float on the water surface. Water lilies, pondweeds, spatterdocks and water-shields are some of the common rooted plants. Duckweeds can also be found here and in deeper waters. Unlike most plants, all floating-leaved plants have stomata on the upper surface of their leaves. This adaptation allows them to obtain carbon dioxide directly from the air. Rooted plants will be found in areas that are shallow enough to permit their leaves to reach the water surface.

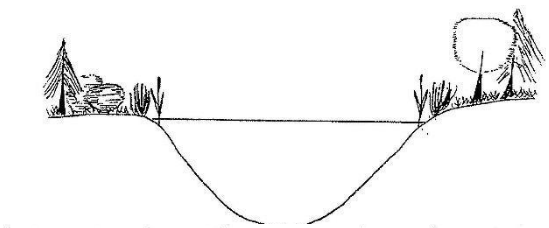
The submerged zone is the deepest area in basin that allows rooted plant growth. Plants found here, such as coontails, watermilfoils, stoneworts, bladderworts and common waterweeds, are completely submerged under water. Some of these plants (eg. bladderworts and watermilfoils) may have some structures growing above the water surface.

Although there are no rooted plants growing on the deep substrates of lakes, we can find phytoplankton growing in the water column. Phytoplankton generally makes up an important part of the plant community in deep basins.

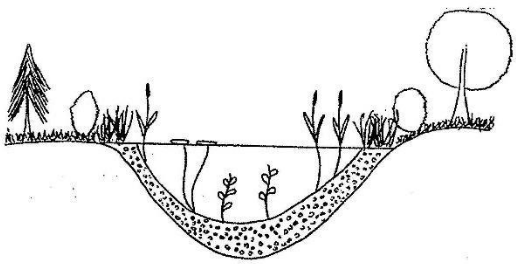
Please see this link to study more about Aquatic Plant Life go to: "Aquatic Plants their identification and management"

3.2.1 Ecological Succession of a Pond

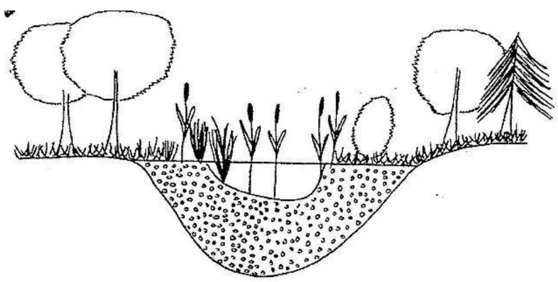
Aquatic systems change over time with the accumulation of silt and organic matter in their basins. For example, oligotrophic lakes can slowly change to a more productive eutrophic system. In some circumstances, the aquatic habitat disappears and is replaced by a terrestrial community. The following is an example of ecological **succession** seen in some ponds:



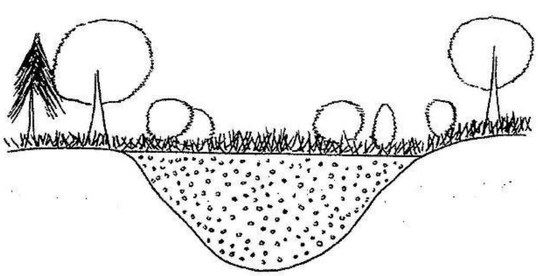
The basin is mostly composed of open water with very little silt or organic matter accumulated in the basin. Plants like mosses, sedges, grasses and woody plants are found growing near or on the banks. Phytoplankton may be found in open water



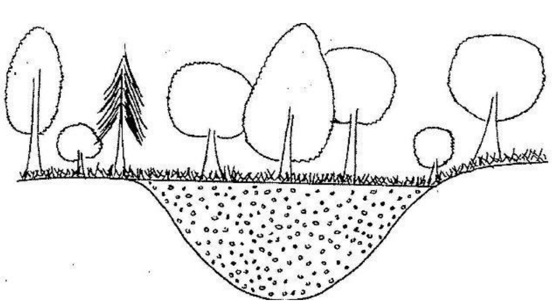
Plants are slowly invading the shallow regions of the basin and are growing out from the edges. Silt and organic material from aquatic and terrestrial sources is accumulating on the bottom. The depth of the basin slowly decreases eventually forming marsh-like conditions.



As more silt and organic matter accumulates, more plants can grow out from the edges. Eventually, submerged and floating-leaved plants are replaced by emergent, shoreline plants creating a fen-like habitat. Shrubs are slowly starting to invade the basin



The basin is completely filled with organic matter and silt. Most plants growing in the basin are grasses and shrubs, giving the basin a meadow-like appearance. Eventually, these plants will be replaced by fast-growing trees such as aspen and birch



Fast-growing trees are replaced with longer lived species such as maple and beech. As this point succession stops and the basin has a relatively stable climax community. Keep in mind that the animal community also changes during the process of succession.

3.2.2 Ecological Succession of a Lake

Eutrophication, the progress of a lake toward a eutrophic condition, is often discussed in terms of lake history. A typical lake is said to age from a young, oligotrophic lake to an older, eutrophic lake. Geological events, such as glaciation, created lakes in uneven land surfaces and depressions. The landscapes surrounding lakes were often infertile, and thus many lakes were oligotrophic. Eventually some of the shoreline and shallow areas supported colonizing organisms that decomposed unconsolidated materials into reasonably fertile sediments. Active biological communities developed and lake basins became shallower and more eutrophic as decaying plant and animal material accumulated on the bottom. Shallow lakes tend to be more productive than deep lakes, in part because they do not stratify, thereby allowing nutrients to remain in circulation and accessible to plants. They also tend to have a smaller lake volume, so **nutrient loading** from their watershed has a larger impact. There are undoubtedly exceptions to this typical progression from oligotrophy to eutrophy where geology, topography, and lake morphology caused eutrophic conditions from the start.

This concept of lake aging has unfortunately been interpreted by some as an inevitable and irreversible process whereby a lake "dies." In fact, many oligotrophic lakes have persisted as such since the last glaciation and some ultra-oligotrophic lakes, may have been unproductive for millions of years. Furthermore, research in paleolimnology has provided evidence that contradicts the idealized version of a lake becoming more and more eutrophic as it ages. Changes in climate and watershed vegetation seem to have both increased and decreased. Some lakes probably experienced high rates of photosynthesis fairly soon after glacial retreat and then became less productive until recent times. It is also possible that water sources for some lakes have changed over the past thousands of years through diversions of stream flow. In such cases water supplies to a lake (and therefore nutrient supplies) could have changed, leading to changes in the lake's productivity.

However, lakes may be culturally eutrophied by accelerating their natural rate of nutrient inflow. This occurs through poor management of the watershed and introduction of human wastes through failing septic systems. Such changes may occur over periods of only decades and are reversible if anthropogenic nutrient loading can be controlled. In the 1960s this was a serious issue, exemplified by the hyper-eutrophic condition of Lake Erie. Although it was pronounced "dead," it eventually returned to less eutrophic conditions, when major point sources of phosphorus were controlled in the early 1970s.

In North America many of the problems associated with the direct discharge of domestic wastewater have been successfully mitigated. Now the regulatory focus is on the much more difficult problem of controlling non-point sources (NPS) of nutrient pollution such as agricultural drainage, stormwater runoff, and inadequate on-site septic systems. NPS pollution is particularly difficult to address because it is diffuse, not attributable to a small number of polluters, and associated with fundamental changes in the landscape, such as agriculture, urbanization and shoreline development. Water quality impacts associated with eutrophication include:

- Noxious algae (scums, blue-greens, taste and odor, visual)
- Excessive macrophyte growth (loss of open water)
- Loss of clarity (secchi depth goes down)
- Possible loss of macrophytes (via light limitation by algae and periphyton)
- Low dissolved oxygen (loss of habitat for fish and fish food)
- Excessive organic matter production (smothering eggs and bugs)
- Blue-green algae inedible by some zooplankton (reduced food chain efficiency)
- "Toxic" gases (ammonia, H_2S) in bottom water (more loss of fish habitat)
- Possible toxins from some species of blue-green algae
- Drinking water degradation from treatment disinfection by-products
- Carcinogens, such as chloroform (from increased organic matter reacting with disinfectants like chlorine)

4.0 Preserving Aquatic Biodiversity

Biodiversity is defined as the sum total of all bacterial, protozoan fungal, plant and animal species found within a given habitat. In other words, it is the variety of life, the number of different species found in a certain area. Tropical rainforests have the highest levels of biodiversity on the planet. Illinois' is a mosaic of diversity including the Wisconsin Driftless, the Southern Till Plain, the Shawnee Hills, the Mississippi and Illinois River Bottomlands and so much more. Each of these areas in Illinois contain unique habitats and species and because they are so diverse the biodiversity in Illinois is very diverse. **Aquatic biodiversity** can be defined as the number and abundance of species that live in aquatic ecosystems. In Illinois, aquatic ecosystems include freshwater ecosystems such as lakes, streams, wetlands and river ecosystems including our Illinois, Mississippi and Wabash Rivers. . The level of biodiversity within a habitat is a good measure of the health of an ecosystem. Generally, healthy ecosystems will have a greater variety of organisms. You can imagine that a polluted ecosystem will have lower biodiversity; pollution tolerant organisms may be found in great numbers but the total number of different species in a polluted habitat will be lower than a clean, healthy ecosystem. Therefore, a drop in biodiversity is a good indication that negative factors are influencing an ecosystem.

4.1 Importance of Biodiversity

Biodiversity has some important implications for both humans and the natural world. Protecting biodiversity is in our self- interest. The diversity of organisms on our planet supports humans industries such as agriculture, cosmetics, pharmaceuticals, pulp and paper, horticulture, construction and waste treatment. Decreased biodiversity will result in threatened food supplies, building materials, medicines and energy. Natural resources such as fish, timber, minerals, and wildlife are processed and sold to provide income to hundreds of thousands of families.

The diversity of life also provides recreational benefits that have become part of Illinois' culture. Activities such as fishing, hunting, hiking, photography and camping are all based around the biodiversity found within Illinois. With a loss of species diversity in Illinois there will be a corresponding loss of economic gain and recreational enjoyment.

Preserving Illinois biodiversity also has an ecological benefit. Increased biodiversity in an area results in increased redundancy and resiliency of the ecosystem. Redundancy occurs when there is more than one species that performs the same or similar vital functions in an ecosystem. High redundancy is beneficial to ecosystems because if one species is removed from the ecosystem there will be another species to perform its function.

Resiliency is the ability to recover from, or to resist being affected by a disturbance. Biodiversity plays crucial roles in ecosystem resilience by ensuring ecosystems are capable of reorganizing after a disturbance. Resiliency increases when there is high redundancy within an ecosystem as species are able to replace each other in times of disturbance.

4.2 Dangers to biodiversity

There are many factors that can affect and change biodiversity within aquatic ecosystems. Aquatic biodiversity can experience a decline due to loss or fragmentation of habitat, pollution or the introduction of an invasive species. Human activity and development have had an immense effect on biodiversity in all ecosystem types, and aquatic ecosystems are no exception.

Take for example the construction of a subdivision at the edge of a town or city. Before construction begins land is often leveled and cleared, which often means wetland areas are drained or filled in and streams disappear after they are filled with loose soil from the site. Wetland birds that spend part of their year among reeds will need to find a new seasonal home, and fish that depend on small tributary streams for spawning will have difficulty producing offspring to ensure healthy future populations.

Biodiversity as a whole, as well as individual species are dependent on healthy ecosystems for survival. The activities described above can have devastating effects on local aquatic biodiversity and can eventually result in species becoming extirpated from an area. If this type of pattern happens all across a region it can result in species extinction, which is a loss of biodiversity. The following are some of the major causes of current extinction:

4.2.1 Habitat destruction

The destruction of habitats is one of the major reasons why species populations have been dramatically decreasing. Species are adapted to a particular habitat and need them to fulfil all of their needs. About 70% of Illinois' original wetlands have been destroyed. Remaining natural wetlands cover only about 2.6% of the state's land area. Since many of these wetlands harbor most of our species in Illinois, their destruction has brought a corresponding decline in biodiversity.

4.2.2 Overhunting, overfishing and overharvesting

The killing and harvesting of organisms has led to declines in population and even extinction. Overharvesting of peat has contributed to the destruction of of our bogs. Overfishing of lake trout in the Great Lakes has led to the collapse of the fish population and consequently the collapse of the fishing industry. Overhunting has almost caused the extinction of several of our waterfowl species.

In most cases, overhunting and overfishing do not remove or kill all members of a species. However, populations may be so low that the species may never recover. Other factors, such as low reproductive rates, natural predators, habitat destruction and pollution, may act upon small populations and drive the species to extinction.

4.2.3 Pollution

The release of pollutants into our environment has had negative effects on most communities. Acid rain caused by fossil fuel emissions has decreased the pH of many aquatic systems resulting in fish kills and “death” of lakes. Toxic pollutants not only kill organisms immediately but in many cases remain in the environment and affect future generations. In aquatic systems, pollutants like mercury and PBCs (Polychlorinated biphenyls), accumulate in the sediments and are released slowly over time into the ecosystem which means the effects of pollution can be felt over long periods.

Many pollutants bioaccumulate in the ecosystem, with top predators having the highest concentrations of pollutants. Although low concentrations of some pollutants may not affect organisms, their accumulation within living tissues can have serious consequences. High pollutant concentrations can cause i) body deformations, ii) behavioral abnormalities, iii) motor and neural dysfunctions, iv) reproductive failure and v) death. All of these factors depress a species ability to function properly with an ecosystem.

4.2.4 Invasive species

Invasive species are organisms which have been brought intentionally or accidentally from another continent, or even from state to state, into our ecosystem. In many cases, these invasive species have no natural predators in Illinois. Free from predation pressure, many invasive species can proliferate and overrun the habitat. They change the ecosystem by either directly killing or out-competing native species for space and food. Some native species can eventually die out if invasive species are not controlled.

Aquatic invasive species (AIS) tracking has expanded over the years. AIS are freshwater organisms that spread or are introduced outside their native habitats and cause negative environmental and/or economic impacts. Unfortunately, more than 85 AIS have been introduced into Illinois. The zebra mussel, Eurasian water milfoil, and silver carp are all examples of invaders that have impacted our state.

Aquatic invaders such as these have been introduced and spread through a variety of activities including those associated with recreational water users, backyard water gardeners, aquarium hobbyists, natural resource professionals, the baitfish industry, and commercial shipping. The Illinois Volunteer Lake Monitoring Program (VLMP) is partnering with Illinois-Indiana Sea Grant, the Illinois Natural History Survey, and the Midwest Invasive Plant Network to monitor for and help prevent the spread of aquatic invasive species to Illinois lakes.

The zebra mussel (*Dreissena polymorpha*) is an example of an invasive species which has invaded many of Illinois waterways (Figure 20). Larvae of this organism were transported in ballast waters of ships from Asia and released into the Great Lakes. Since very few of our native animals eat zebra mussels, bivalve populations exploded. They colonized hard surfaces and soon clogged up water intake and drain pipes. Their ecological effects were quite dramatic. By attaching themselves to the surfaces of organisms, they would suffocate and kill aquatic plants and native clams; native clam species (Unionidae) in the St. Lawrence River in New York State, have practically disappeared with the arrival of the exotic mussel

***Figure 20**: Zebra mussels*
Source: Ontario Invading Species

species. Zebra mussels have also blanketed the bottom of basins making it difficult for fish, amphibians and waterfowl to find and eat benthic invertebrates. Being efficient filter feeders, zebra mussels out-competed many of our native plankton feeders. Many of our aquatic ecosystems have changed as a result of zebra mussels; the decrease in plankton abundance has caused a reduction in numbers of plankton feeders which in turn has reduced predator numbers.

For a complete list of invasive species in Illinois, visit http://www.invasive.org/illinois/speciesofconcern.html.

4.2.5 Climate Change

Climate change can also largely influence changes in aquatic biodiversity. For example, the longer, hotter summers that have become fairly frequent result in higher temperatures in bodies of water such as lakes and streams that used to be much cooler. Fish species each have their own unique set of tolerances, including maximum water temperature in which they can survive. Coldwater fish species have felt the effects of climate change in their habitats, and as a result may show population declines.

Keep in mind that usually a combination of the above negative factors causes a drop in population numbers. Marshes are a good example of this. Many wetlands in Illinois have been filled or drained to make way for human development. Overhunting of waterfowl and overfishing has reduced the abundance of native species. Marshes collect much of the runoff and associated pollutants from surrounding lands. These pollutants accumulate in the habitat causing deleterious effects on organisms. Exotic species such as Purple loosestrife (*Lythrum salicaria*) and the carp (*Cyprinus carpio*) are negatively changing marsh habitat ecosystems. It is the combination of these effects that has brought about a dramatic decrease in the population of our native marsh species.

4.3 Measuring Aquatic Biodiversity

As the state of aquatic biodiversity becomes of increasing of concern it is important to find ways to monitor and measure biodiversity. This is done so that scientists can communicate their findings with other scientists, politicians and the general public. This sharing of information allows for a greater understanding of the importance of aquatic biodiversity and how it is changing.

Measuring aquatic biodiversity can be accomplished in many ways. Everything from fish to bird to insect to plant species can be, in one way or another, counted and therefore measured and evaluated. The presence, absence and abundance of species give scientists an idea of the state of aquatic biodiversity within a particular aquatic ecosystem. If the same type of information is collected from the same ecosystem every year biodiversity of that area can be monitored. This is how changes in biodiversity over time are detected. For examples on various ways in which diversity is measured in aquatics ecosystems, refer to section 2.

5.0 Wetlands

Wetlands are important habitats for many terrestrial and aquatic organisms. In Illinois, approximately 42 percent of all the native plant species are wetland species (Illinois Department of Natural Resources 1994). There are also are a number of plant species usually associated with upland areas that can survive in wetlands. The US Fish and Wildlife Service has identified a total of 6,728 species of plants that occur in wetlands throughout the United States (Reed 1988). Because wetlands are highly productive and support a diversity of plant life, they are an important source of food and habitat for wildlife. This productivity helps support commercial and recreational fish and waterfowl harvests throughout the Illinois and the rest of the world (Illinois Department of Natural Resources 1997).

There are several species of animals dependent upon wetlands for their day to day survival. Most people readily identify some of these animals, such as frogs and ducks, as wetland species. There are, however, many other species of wildlife usually associated with upland or deepwater areas that depend on or use wetlands for feeding, spawning, and/or resting grounds at some point in their life cycles. Most people do not readily identify these various species of shiners, sunfish, bats, and terns with wetlands. They also do not realize many well-known species, such as bald eagles and bobcats, are also commonly found in and around wetlands. The following statistics reflect the diversity of organisms that use wetlands in Illinois.

- 46 of the 59 mammal species in Illinois use wetlands to some extent.
- 37 of the 41 amphibian species in Illinois depend upon wetlands at least part of the year.
- 47 of the 60 reptile species found in Illinois use wetlands to some extent.
- 105 bird species depend upon, or are strongly associated with, wetlands in Illinois.
- 169 additional bird species use wetlands in Illinois opportunistically for nesting, foraging, and resting (Illinois Department of Natural Resources 1994)

In rivers, streams, and most lakes the constant flow of water washes away many of these nutrients. But in marshes, and other wetlands, nutrients tend to remain and accumulate. In northern regions, where water levels are relatively stable, nutrients often become trapped in the bottom sediments; but in southern regions they are released each year during spring flooding. This is one of the reasons why wetlands in southern regions are so productive and why they attract so many forms of wildlife. Wetlands also provide necessary and valuable services to humans. The main characteristics of wetlands include:

- Rich in nutrients and teeming with life
- May be ponds, marshes, swamps, or peatbogs; each of which has its own characteristics
- Act like sponges, soaking up rain and snowmelt and slowly releasing water

reducing flooding and easing the worst effects of drought

- Home for at least some part of the year to many fish, birds, and other animals. Without wetlands, some wildlife species would disappear
- Are being destroyed across the country by industry, commerce, agriculture etc.

5.1 Definition of a Wetland

Wetlands include areas that are seasonally or permanently covered by shallow water and areas where the water table is close to, or at, the surface. Usually soils are water saturated and water-tolerant and water-loving plants are common. Wetlands sometimes form an ecotone or transitional zone between deep water and terrestrial systems.

Wetlands comprise an incredible array of landscapes. They can be found near the banks of rivers and streams, along the edges of lakes and ponds, or in open fields and wooded areas where the water table is near the surface. Some of these wetlands may be ephemeral (temporary) and can be very small or thousands of acres in size. Particularly near cities and towns, wetlands may be the only remaining "wild" spaces. Saltwater wetlands are usually caused by ocean tides. Some are flooded and dry up twice each day. Others are flooded only by particularly high tides that occur at less regular intervals.

Throughout the world many different names are used to describe wetland areas. Ephemeral wetlands, marshes, swamps, bogs and fens are the types of wetlands found in Illinois.

5.1.1 Marshes

Marshes are wetlands that are covered by standing or very slowly moving water. While some marshes experience a loss of surface water during dry seasons, the soil and root base of plants is always saturated. This allows for growth of the many species of emergent plants typical to marsh ecosystems. Marshes are very rich in nutrients and are considered to be the most productive type of wetland. Non-woody plants such as sedges, cattails, reeds and water lilies make up the majority of the plant community. Most marshes have some open water which may contain aquatic plants such as pondweed and duckweed. Shrubs like red-osier dogwood might be found growing in drier areas around the marsh. Due to their high productivity and habitat types offered, marshes are home to many different species. Everything from large birds of prey to reptiles and amphibians to fish depend on marshes as their primary habitat.

5.1.2 Swamps

Swamps are essentially wooded marshes, a waterlogged area supporting trees, tall shrubs, herbs, and mosses that are permanently or semi permanently flooded with spring rains, overflows etc.. Woody plants such as Swamp Rose, Bald Cypress, Swamp White Oak and Virginia Willow are just a few that make up the majority of plants in the community. Shrubs like willow, dogwood and alder can also be present.

We usually find a combination of aquatic and terrestrial animals in swamps. Some marsh insects, amphibians, waterfowl and mammals can use this habitat provided that it remains wet long enough to allow the proper development of young. A variety of song birds will nest in swamps since it provides an abundance of nesting cavities and food in the form of insects, nuts and berries.

5.1.3 Bogs

Bogs are found in northern regions and are permanently flooded. Bogs are depressions which fill up with rainwater or snow melt and have poor drainage. The most predominant vegetation growing in bogs is sphagnum moss. Sedges, sundew, pitcher plants and Tamarack can also be found in this type of wetland. Since bogs have no outflows, dead plant material accumulates and forms a type of soil known as peat. Peat soils act like sponges in that they retain excess runoff and slowly release water to surrounding lands. Bogs do not support much animal life because they are quite acidic.

5.1.4 Fens

Fens are found in northern regions and are also permanently flooded. Fens obtain their water from rainwater, snow melt and underground springs. They are similar to bogs but have better drainage and less peat accumulation. Sedges are predominant but mosses, grasses, reeds, shrubs, sundews, pitcher plants, bladderworts, cedar and tamarack can also grow in fens. Increased drainage in fens results in lower acidity and in many cases this habitat is alkaline. Fens can support plants and animals found in marshes but generally fen animal biodiversity is lower. This habitat supports a variety of rare plants specifically adapted to fens.

5.1.5 Ephemeral wetlands

Ephemeral wetlands are temporary wetlands which become flooded with rainwater and snow melt and dry out in late summer. They can be found in meadows or prairies. Usually only sedges and grasses grow in these wetlands.

Plant matter accumulation is minimal. Ephemeral wetlands can be important resting areas for migrating waterfowl. Some animals will only be found in these habitats. Many mosquito species use ephemeral pools extensively for growth and reproduction; in many pools these insects comprise the majority of the invertebrate community.

5.2 Ecological Functions and Benefits of Wetlands

Wetlands are essential to the health of our lakes, rivers and streams. The survival of hundreds of plant and animals species depends on the unique and specialized habitats found only in wetlands. Wetlands play a critical role in the maintenance of our water supply, in cleaning up polluted waters and in flood damage control. Beneficial functions of wetlands include:

- Providing important habitat for a wide variety of wildlife species, including insects, amphibians, reptiles, migratory birds, waterfowl and mammals. They also provide spawning and nursery areas for fish
- Providing essential habitats to some of our rarest plant and animals such as the, American Bittern (*Botaurus lentiginosus)* and Blanding Turtle (*Emys blandingii)*
- Acting as a buffer zone between terrestrial and aquatic ecosystems. Wetlands trap moderate amounts of soils before entering lakes and streams. They protect shorelines from erosion caused by flowing water and wave action
- Absorbing large quantities of water, thereby reducing flood damage. Wetlands also renew groundwater supplies when surrounding lands become drier
- Maintaining and improving water quality by filtering contaminants and excessive nutrients
- Existing wetlands perform many economically and ecologically important functions in Illinois, such as storing floodwaters, removing sediment and chemicals from surface water, replenishing groundwater, maintaining low flows in streams, providing wildlife habitat and recreational opportunities, and many others. (USGS)

5.3 Threats to Wetlands

There are many factors which threaten wetlands and the biodiversity associated with them. The major threats include the following:

5.3.1 Drainage for conversion to alternative uses

This represents one of the major reasons why wetlands are disappearing in Illinois. Many wetlands have been drained or filled to create agricultural lands and for urban development. In many cases, once wetlands have been modified in this way they cannot be restored.

5.3.2 Contaminants

Although wetlands act as filters, removing contaminants from runoffs and surrounding water, an overabundance of toxic compounds will destroy them. Contaminants such as pesticides, fertilizers, cleaning products, motor oils and hydraulic fluids can find their way in wetlands and kill plants and animals. Some contaminants may even bioaccumulate in the food chain causing health problems to many animals. For example, a pesticide known as DDT (Dichloro-diphenyl-trichloro-ethane) was applied by US farmers in the 1950s and 1960s on their crops to kill insect pests. This insecticide would eventually runoff into wetlands where it was consumed by insects. These insects would then be eaten by other animals which in turn where eaten by raptors, such as falcons and hawks. The DDT accumulated in the fatty tissues of these organisms and therefore top predators had the highest pesticide concentrations within their bodies. These toxic concentrations inhibited proper calcification of egg shells and eggs laid by female raptors would be crushed under the parent's weight. Raptor populations dramatically decreased during this time since they could not successfully reproduce. Once scientists discovered this, DDT use was banned in Canada and United States and raptor populations slowly increased. It is still used in other parts of the world and can affect migratory species.

5.3.3 Forestry and economic operations

Some forestry practices such as logging and controlling water levels have negatively affected wetlands by upsetting the natural flood cycle. Commercial harvesting of peat and draining for Ag has destroyed many of our bogs. Overhunting and overfishing have also contributed to the decreasing biodiversity of our wetlands.

5.3.4 Introduction of Invasive species

Invasive animal and plants species have caused much damage to our wetlands. In many cases, these exotic species have established themselves in our wetlands and are proliferating greatly since no natural herbivores or predators are present to control them. These exotic species can use up resources and displace native wildlife. A good example of this is a plant known as Purple loosestrife (*Lythrum salicaria*).

5.4 Approaches to Protect, Enhance and Restore Wetlands

There are many ways to protect, enhance or restore wetlands:

- If the wetland is unaffected by human activity, leave it alone! Protect the habitat from any future human activities.
- Restore native vegetation by planting a mixture of native grasses, wildflowers and shrubs around the wetland. This will create a diverse long-lasting plant community that will provide food, cover and nesting habitats for a wide range of animal species.
- Create buffer strips which are zones around wetland areas which provide buffering from surrounding land uses. This is done in order to protect both wetland and uplands. Encourage the growth of grasses, shrubs and trees in these buffer zones.
- Restore natural hydrological functions of wetlands by restoring the natural patterns of seasonal flooding and drying
- Introduce nesting structures where there is an absence of nesting opportunities for certain species, such as wood duck (*Aix sponsa*) boxes, osprey (*Pandion halioetus*) platforms or floating mats of vegetation for Black terns (*Chlidonias nigra*)
- Control livestock access to wetlands by putting up fences.
- In 2008, EPA and the U.S. Army Corps of Engineers jointly promulgated regulations revising and clarifying requirements regarding compensatory mitigation. According to these regulations, compensatory mitigation means the restoration (re-establishment or rehabilitation), establishment (creation), enhancement, and/or in certain circumstances preservation of wetlands, streams and other aquatic resources for the purposes of offsetting unavoidable adverse impacts which remain after all appropriate and practicable avoidance and minimization has been achieved Control exotic species by removing them or preventing their establishment in the wetland

Purple Loosestrife in Illinois's Wetlands

Purple loosestrife is a tall, vibrant flowering wetland plant (Figure 21). This European plant grows quite well in wetlands and outcompetes native plants for water, minerals and space. Within a few growing seasons, Purple loosestrife can overrun an entire wetland. This causes a disruption in the wetland ecosystem since very few of our native herbivores can eat this exotic plant. Purple loosestrife eventually displaces native plant and animal species.

Figure 21: *Purple Loosestrife*
Source: Ontario Invading Species

It was introduced into North America at the beginning of the 19th century by European settlers who enjoyed it as a garden plant. Seeds were also present in the ballast water of ships as a result of soil being used to weigh down ships during long voyages.

Purple loosestrife quickly became a threat to native wetland vegetation, with seeds capable of germinating in soil immediately after release or surviving in water for extended periods of time (as in the case of ballast water) to germinate at a later date. Mature purple loosestrife plants are also capable of spreading through underground root systems, making it an extremely aggressive colonizer.

Approximately two hundred years after its first introduction, purple loosestrife is now prominently established across Canada and the United States. Since purple loosestrife is capable of spreading extremely quickly and aggressively, it poses a great threat to native wetland vegetation. It is known to out-compete native plants and replace them within the wetland ecosystem. This poses an imminent threat to wetland biodiversity, as a large variety of native plants are being replaced by one foreign species.

The expansion of purple loosestrife is also a threat to wetland wildlife. While purple loosestrife is very well adapted to live in wetlands, native wildlife have not adapted to use it for their many needs. Native plant species provide a wealth of wildlife species with food, shelter and construction materials. When purple loosestrife moves into a wetland ecosystem, not only does it affect plant populations but wildlife populations as well, putting the overall biodiversity of the ecosystem in jeopardy. Depending on the size and location of the infestations, different methods and techniques, or a combination of several, may be used to eliminate the species.

For small stands of purple loosestrife on private property, landowners are encouraged to dig up the plants, including their roots. This will eliminate all current plants as well as prevent spread through root systems or seed dropping. Plants can also be cut off at the base; however this does not necessarily destroy the underground root systems, which may still thrive and produce new plants. Both methods are best done throughout late spring an early summer, when the plant is easy to recognize but has not yet released its seed. As with any invasive plant species, these efforts most often need to be repeated for several years in a row to thoroughly extinguish the plant's presence in one location.

6.0 Why Study Benthic Macroinvertebrates?

Benthic macroinvertebrates are an important part of aquatic food chains. In most streams, the energy stored by plants is available to animal life either in the form of leaves that fall in the water or in the form of algae that grows on the stream bottom. The algae and leaves are eaten by macroinvertebrates. The macroinvertebrates are in turn a source of energy for larger animals such as fish which are preyed upon by birds, raccoons, water snakes and even fishermen.

Some benthic macroinvertebrates cannot survive in polluted water. Others can survive or even thrive in polluted water (See Table 2 below for specific species tolerance to pollution). In a healthy stream, the benthic community will include a variety of pollution-sensitive macroinvertebrates. In an unhealthy stream, there may be only a few types of nonsensitive macroinvertebrates present.

Table 2: Pollution tolerance levels of the major benthic macroinvertebrate groups found in Illinois

Pollution Sensitive	Somewhat Pollution Sensitive	Pollution Tolerant
Caddisfly	Beetle larvae	Aquatic Worms
Mayfly	Clams	Blackfly
Riffle Beetle (Adults)	Cranefly	Leeches
Stonefly	Crayfish	Midges
Water penny (Larvae)	Damselfly	
	Dragonfly	
	Scuds	
	Sowbugs	
	Fishfly/Alderfly	

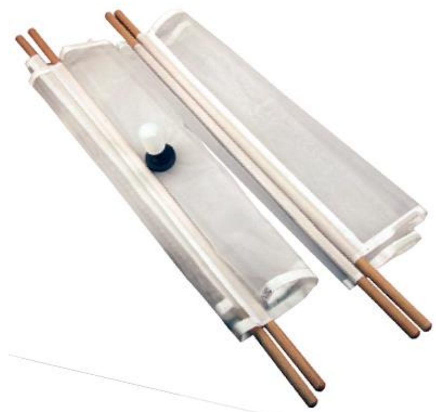
It may be difficult to identify overall stream pollution with water analyses, which can only provide information for the time of sampling. Even the presence of fish may not provide information about a pollution problem because fish can move away to avoid polluted water and return when conditions improve. However, most benthic macroinvertebrates cannot move to avoid pollution. A macroinvertebrate sample may thus provide information about pollution that is not present at the time of sample collection.

Useful benthic macroinvertebrate data are easy to collect without expensive equipment. The data obtained by macroinvertebrate sampling can serve to indicate the need for additional data collection, possibly including water analysis and fish sampling.

6.1 Benthic Macroinvertebrate Sample Collection Techniques

The most common method for collecting benthic macroinvertebrates is to use a kick seine (also known as a kick net).

A simple kick seine can be constructed from the following materials:



- 3.5' x 4' nylon screening or netting (1/16" mesh)
- 2 broom handles or wooden dowels (5-6' long) for handles
- heavy tacks and hammer or heavy staples and staple gun

Instructions:

1. Make a hem along the 4' sides of the netting by folding over and sewing the edges, leaving a 3' x 4' section of net. (If the netting is too difficult to sew, a hem can be constructed using a strip of canvas or cloth.)
2. Spread the netting out flat and place the handles along the unhemmed 3' edges.
3. Roll 6" of netting around each handle, leaving a 3'x 3' section of net between the handles. Then nail or staple the net to the handles.

An alternate approach is to fold over and sew the 3' edges of the net to form sleeves for the handles. In any case, the final size of the net should be 3' x 3'.

6.1.1 Selecting a site for sampling:

Find a riffle that is typical of the stream. A good riffle for sampling will have rounded natural stone anywhere between 3" and 12" in size, fast-moving water, and a depth of 3 to 12 inches. Select a 3-foot by 3-foot area within the riffle for sampling.

NOTE: If the site is to be used for long-term monitoring it will be easier to relocate it if there are nearby permanent landmarks that can be used to identify the site.

6.1.2 Positioning the kick seine:

Have one person hold the net upright facing the flow at the downstream edge of the sampling area. The net should be stretched out to its full 3-foot width with the bottom edge lying firmly against the stream bed. No water should wash under or over the net. If needed, small rocks can be used to weigh down the bottom edge of the net.

NOTE: To avoid losing macroinvertebrates that should be part of the sample, do not stand in or disturb the sampling area before the kick seine is in place. To avoid capturing macroinvertebrates that should not be part of the sample, do not stand in or disturb the stream bed above the sample area.

6.1.3 Collecting the sample

All macroinvertebrates in the 3-foot by 3-foot sample area are to be washed into the kick seine. While one person holds the net, a second person first brushes all the cobbles in the sampling area to dislodge the attached macroinvertebrates. As each cobble is brushed, it can be placed outside the sampling area. When all the cobbles are brushed, stir up the entire sampling area with hands and feet to dislodge any burrowing macroinvertebrates. Finally, for at least sixty seconds, kick the stream bed with a sideways shuffling motion towards the net. The object is to thoroughly work up the stream bed to a depth of several inches.

6.1.4 Removing the kick seine from the water

When Step 3 is completed, lift the kick seine out of the water with a forward scooping motion. The object is to avoid losing any macroinvertebrate specimens while the seine is lifted. This will be easier if one person holds the top of the kick seine handles while the other person holds the bottom of the handles.

6.1.5 Removing the sample from the kick seine

Carry the kick seine to the stream bank and spread it out flat. Carefully examine the net and the collected debris for macroinvertebrates. Look carefully as many specimens will be small and hard to see. Using tweezers or fingers, place all the specimens in white containers filled with stream water. Sort them into different types as you remove them from the net, and place each type in a separate container.

NOTE: If your plan is to transport the sample back to your "lab" before sorting and identification, you can place the contents of the kick seine (including the debris) into a bucket that is partly filled with stream water. If you put a lid on the bucket (recommended), you should leave some air space above the water in the bucket to allow mixing of oxygen.

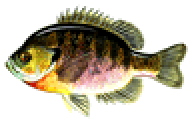
6.1.6 Identification

Once the macroinvertebrates are collected and sorted, they can be identified in the field using the identification key provided in Appendix B.

Appendix A

Source: http://www.ifishillinois.org/species/species.html

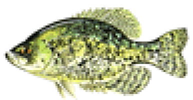
Sunfish and Basses



BLUEGILL

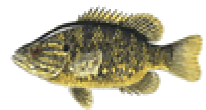
LARGEMOUTH BASS

SMALLMOUTH BASS

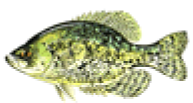


BLACK CRAPPIE

PUMPKINSEED

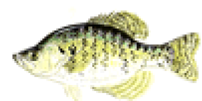


WARMOUTH



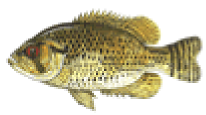
CRAPPIE

REDEAR SUNFISH



WHITE CRAPPIE

GREEN SUNFISH

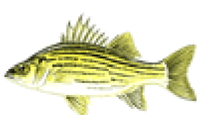


ROCK BASS

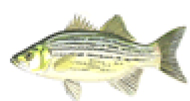
Temperate Basses

STRIPED BASS

HYBRID STRIPED BASS



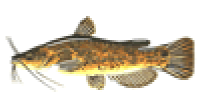
YELLOW BASS



WHITE BASS

Catfish and Bullheads

BLACK BULLHEAD



BROWN BULLHEAD

YELLOW BULLHEAD


BLUE CATFISH


CHANNEL CATFISH


FLATHEAD CATFISH

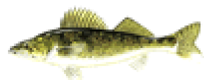
Cool and Coldwater Species


MUSKELLUNGE


SAUGER

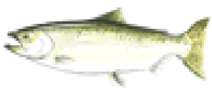

YELLOW PERCH


NORTHERN PIKE


WALLEYE

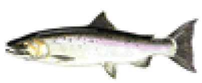

SAUGEYE

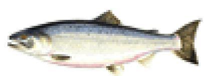
Salmon and Trout


CHINOOK SALMON


LAKE TROUT


RAINBOW TROUT


COHO SALMON


PINK SALMON

Common Bowfishing Species


LONGNOSE GAR

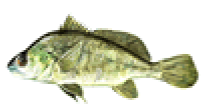

SHORTNOSE GAR


SPOTTED GAR


CARP


BOWFIN


BIGMOUTH BUFFALO


FRESHWATER DRUM

Appendix B

Source: Izaak Walton League of America

Izaak Walton League of America

A Volunteer Monitor's Field Guide to Aquatic Macroinvertebrates

Illinois Envirothon

Biological Monitoring

Water quality monitoring is an essential step in the process of conserving and restoring local waterways. Evaluating the biological community of a stream is a sensitive and cost effective way to assess water conditions. The League has a protocol that uses the presence of benthic macroinvertebrates to measure water quality.

- Macroinvertebrates are large enough to see with the naked eye (macro) and have no backbone (invertebrate).
- Benthic macroinvertebrates live in the benthos, or stream bottom, and include insect larvae, crustaceans, mollusks, and worms.

Stream-bottom macroinvertebrates are good indicators of water quality because they differ in their sensitivity to water degradation. Some benthic macroinvertebrates are very sensitive to pollution and cannot survive in degraded water. Others are less sensitive to pollution and can be found even in very degraded streams. Macroinvertebrates are relatively immobile and cannot avoid pollution events or other forms of stress often missed by other sampling methods. If water quality is generally poor, or if a polluting event occurred within the past several months, it will be reflected in the macroinvertebrate population.

Biological monitoring (biomonitoring) is fun and easy. The Izaak Walton League's Save Our Streams (SOS) methodology involves getting into the stream, using a net to collect macroinvertebrates, sorting and identifying the catch, and using easy calculations to determine an ecological score for water quality.

Using This Field Guide

This field guide is a handy reference tool designed to help volunteer monitors identify aquatic macroinvertebrates when conducting a water quality survey. The macroinvertebrates are grouped into biological categories to provide basic identification information that can be used with a variety of monitoring protocols across the United States. Although macroinvertebrates can tolerate different levels of degradation in different geological areas, the symbols used in this field guide indicate the relative sensitivity categories (sensitive, less sensitive, and tolerant) for each based on the League's SOS biomonitoring protocol. Most macroinvertebrates are presented at the order level for easy and accurate identification in the field.

The drawings in this field guide display common features that characterize each organism type. Most aquatic insects listed include diagrams of the larval and adult life cycles. The larval stage occurs in the water and is therefore used for biomonitoring. The adult stage is terrestrial and often flies near the surface of the water. While not included in the rating for the final SOS water quality score, the adult stage for some of the organisms is included for the curious.

When identifying macroinvertebrates in the field, simply match the illustrations with the specimens in hand. Read the description provided to verify the identification. Rely primarily on body shape and number of legs and tails because different organisms can vary considerably in size and color. For more information on biomonitoring, please visit our Web site at www.iwla.org/sos.

Insects

○ **Stoneflies** (Order Plecoptera). Body length: $1/2''$ – $1\,1/2''$. Six legs, with two claws on the tip of each, antennae, two hair-like tails. No gills on rear half of body. Structurally similar to mayfly nymphs, but have two tails instead of three. Almost all species of stoneflies are very sensitive to pollution.

Slender Winter Stonefly (Larva)

Common Stonefly (Larva)

Common Stonefly (Adult)

○ **Mayflies** (Order Ephemeroptera). Body length: $1/4''$ – $1''$. Brown, cream, or whitish-colored gills on sides or top of rear half of body, which may be flat disks, pointed filaments, or feathery tufts. Larvae also have six clawed legs, antennae, and usually three long, hair-like tails (but sometimes only two). Tails may be webbed together or break off during collection. Tails are most easily seen on submerged organism. Most species are very sensitive to pollution and therefore indicate good stream health.

Spiny Crawler Mayfly (Larva)

Pronggilled Mayfly (Adult)

Pronggilled Mayfly (Larva)

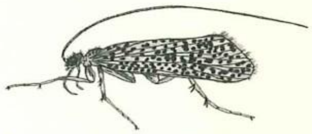
○ **Caddisflies** (Order Trichoptera), except Common Net Spinning Caddisfly. Body or case length: $1/2''$ – $1\,1/2''$. Six legs with claws on upper third of body, two hooks at back end. May be found in a stick, rock or leaf case with its head sticking out. May have finger-like gill filaments on the rear half of body. Larva has caterpillar-like appearance and tends to curl up slightly on a flat surface. Most species are sensitive to pollution.

Free Living Caddis (Larva)

Giant Case Caddis (Larva)

◐ **Common Net Spinning Caddisflies** (Order Trichoptera). Body length: up to $1''$. Six legs with one claw on each tip and three hard plates on top of upper third of body adjacent to legs. Two hooks at back end. Body is caterpillar-like and strongly curved. Color varies from bright green to dark brown, gill tufts on underside. More tolerant of degraded water than other caddisfly larvae. They become very abundant in streams with moderate levels of organic and nutrient pollution, which provides more food in suspension for them to catch. *

Common Net Spinning Caddisfly (Larva)



Common Net Spinning Caddisfly (Adult)

○ **Water Pennies** (Order Coleoptera). Length: up to $1/2''$. Larvae look like flat, oval discs because plates extend from all sides, covering head and legs. They cling to rocks, especially on undersides, and are best found by direct inspection of rocks at the river's edge. Like most clingers, they cannot survive where rocks are covered with excessive algae, fungi, or inorganic sediment.

Water Penny (Larva)

○ **Riffle Beetles** (Order Coleoptera). Body length: $1/16''$ – $1/8''$. Very small, dark colored, with six legs. To find these beetles, watch the seine net closely for movement because they blend well with rock and leaves. If uncertain beetle is aquatic or terrestrial, submerge in water to see how it adapts. Most require high levels of dissolved oxygen found in healthy streams.

Riffle Beetle (Larva)

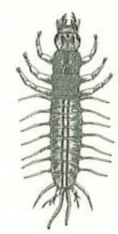
Riffle Beetle (Adult)

○ **Water Snipe Flies** (Order Diptera). Length: $1/4''$ – $1''$. Body is pale to green color and mostly cylindrical, with the front tapering to a cone-shaped point. Larvae have many caterpillar-like prolegs (stubby, unsegmented legs) and two stout, pointed tails with feathery hairs at back end. Most species are very sensitive to pollution. *

Water Snipe Fly (Larva)

◐ **Dobsonflies/Hellgrammites and Fishflies** (Order Megaloptera). Body length: $3/4''$ – $4''$. Stout body with large pinching jaws, six legs, and paired cotton-like gill tufts along underside. Larva also has eight pairs of pointed appendages and a pair of stubby, unjointed legs (prolegs), each with a pair of claws, on the rear end of the body. Spend most of their time hunting for prey in the swift areas of the riffle. To avoid getting pinched, grasp larvae directly behind the head. Fishfly larva has two hooks on the tail end with a lighter reddish-tan color or yellow streaks. They are found only in healthy to moderately healthy aquatic environments. *

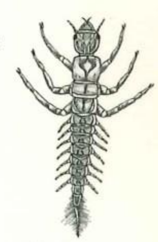
Dobsonfly (Larva)



Fishfly (Larva)

Fishfly (Adult)

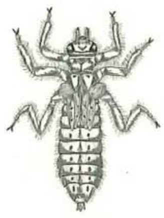
◐ **Alderflies** (Order Megaloptera). Body length: up to $1\,1/2''$. Looks similar to a small hellgrammite, but has no gill tuffs underneath. Alderfly has six legs, seven pairs of pointed appendages on rear half of body, and one long, thinly branched tail at back end. They can be found in a wide range of water quality conditions, ranging from healthy to poor.



Alderfly (Larva)

◐ **Damselflies and Dragonflies** (Order Odonata). Body length: 1/2" – 2". Both of these have large eyes, six legs with two claws on each, and a large lower lip that covers much of the bottom or front of the head. Damselflies are slender with three tails that resemble leaves at the end of the body. Dragonflies have stocky bodies without tails on the end. Both are easily found around stream vegetation and calmer areas along the stream's edge. Primarily less sensitive, some are very sensitive to tolerant of water pollution.

Dameselfly (Larva)



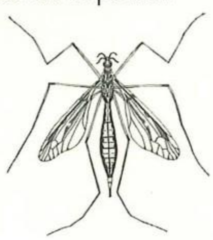
Clubtail Dragonfly (Larva)

Clubtail Dragonfly (Adult)

Spreadwinged Damselfly (Larva)

◐ **Crane Flies** (Order Diptera). Length: 1/3" – 2 1/2". The worm-like, plump body of the crane fly larvae can be found in a variety of colors, including translucent (clear), white, brown and green and grows slightly thicker than a pencil. Body is segmented with small tentacles at back end. The head is usually not seen because it is pulled back into front end of body. Crane Fly species are ecologically diverse, so different tolerances are expected.

Crane Fly (Larva)



Crane Fly (Adult)

● **Midge Flies** (Order Diptera). Length: up to 1/4". The worm-like segmented body has a distinct head with two small, stubby, unjointed legs on each end of the body, often whitish to clear, but occasionally bright red. These true flies are best identified by their spastic squirming action. They are very small, slender organisms that can easily slip through the seine net unnoticed. They can indicate poor stream health caused by some type of pollution if found in large numbers.

Midge Fly (Larva)

Midge Fly (Adult)

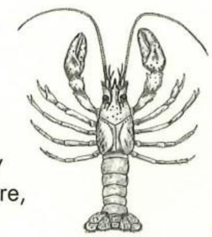
● **Black Flies** (Order Diptera). Length: up to 1/4". Larva is small and slightly bulbous at the rear of body (like the shape of a bowling pin). This true fly has a distinct head and fanlike mouth brushes might be visible. It will often curl into a "u" shape when held in hand. They indicate moderate organic or nutrient pollution when they dominate the sample collection.

Black Fly (Larva)

Black Fly (Adult)

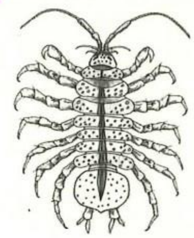
CRUSTACEANS

◐ **Crayfishes** (Order Decapoda). Length: up to 1/2" – 5". The crayfish resembles a lobster with ten legs (unless broken off), and the two front legs have very large claws or pinchers. They are also known as crawdads. They can withstand wide ranges in temperature, pH, and alkalinity, but are sensitive to certain toxic substances.



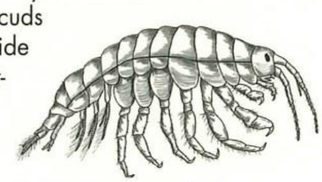
Crayfish

◐ **Aquatic Sow Bugs** (Order Isopoda). Length: 1/4" – 3/4". The sow bug's gray oblong body is flat, segmented, and has an "armored" appearance. They have seven pairs of legs, two long antennae and are most easily found along the stream's edge. Sow bugs may be confused with scuds, however sow bugs are flattened top to bottom and scuds are flattened side to side. They are less sensitive, especially to organic waste.

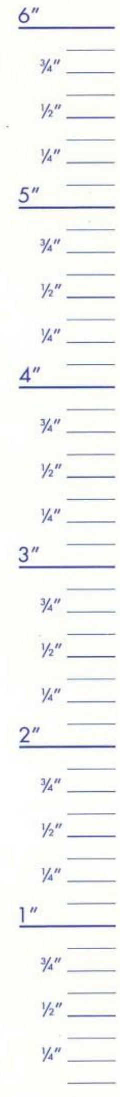


Sow bug

◐ **Scuds** (Order Amphipoda). Length: 1/8" – 1/4". The scud, or side swimmer, has seven pairs of legs and resembles a small shrimp. Body is usually somewhat translucent with some silvery-gray or tan coloration. Scuds may be confused with sow bugs, however, scuds are flattened side to side and sow bugs are flattened top to bottom. Scuds can tolerate a wide range of water quality conditions.



Scud



* Sensitivity ranking updated from 1995 version.
Drawings by Daryl Ratajczak
Spring 2003

Printed on recycled paper

Mollusks

○ **Gilled Snails** (Class Gastropoda). Length: 1/4″ – 1″. Shell opening covered by thick plate called an operculum and usually opens to the right when the narrow end of the snail is pointed up. When monitoring, do not count empty shells. Gill-breathing snails are different from lunged snails in Group Three. They require high levels of dissolved oxygen found in healthy streams.

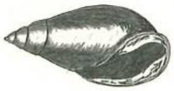

Gilled Snail

◐ **Clams and Mussels** (Class Bivalvia). Length: 1/8″– 5″. Fleshy body enclosed between two clamped shells. Clams are usually buried in the stream bottom and if they are alive, the shells cannot be pried apart without harming clam. When monitoring, do not count empty shells. Certain species are sensitive to some types of pollution.


Fingernail Clam


Unionid Mussel

● **Lunged Snails** (Class Gastropoda). Length: up to 2″. These snails obtain oxygen from the air and have no operculum. Most shells open to the left when narrow end is pointed up. When monitoring, do not count empty shells. They can tolerate severe organic or nutrient pollution that consumes all oxygen in the water.

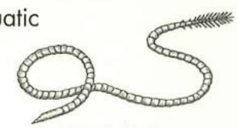

Lymnaea Snail


Physa Snail


Helisoma shell

Worms

● **Aquatic Worms** (Class Oligochaeta). Length: 1/4″ – 2″. Can be very tiny and slender or look similar to earthworms. They can slip through the seine net quite easily. Worms do not have legs, distinct head or any mouthparts. Aquatic worms can represent organic pollution when they dominate the majority of the sample collection (and when they occur with high numbers of red midge larvae).


Tubicifid Worm

● **Leeches** (Class Hirudinea). Length 1/4″ – 2″. Slimy, soft body usually has brown or gray pattern (can be colored) on top and two suckers on the bottom of the body, one in the front and one in the rear. A leech can be confused with a flatworm. The flatworm has many segments in their body, which look like fine lines across the body. Some leeches can tolerate several days without dissolved oxygen and large numbers can indicate oxygen depletion or pollution.


Leech

Symbols

The symbols located on the left of each organism indicate macro-invertebrate sensitivity categories designated by the Izaak Walton League's SOS program. Adaptations may be required for specific geographic locations and conditions.

○ **Group One: Sensitive.** These organisms will not be found in abundance where water quality is degraded. Their dominance generally signifies good water quality.

◐ **Group Two: Less Sensitive.** These organisms can exist in a wide range of water quality conditions.

● **Group Three: Tolerant.** These organisms can be found where water quality is degraded. Their dominance usually signifies poor water quality.

Who We Are

In 1922, 54 anglers and conservationists from Chicago, Ill., joined together to promote clean water. The group named itself the Izaak Walton League of America, after the 17th century author of the literary classic, "The Compleat Angler". Ever since, the League has created a long history of achievement in conservation and outdoor recreation.

As true grassroots voices throughout the United States, the League is committed to promoting a centrist, common sense approach to conservation that reflects the public's continued interest in the protection and responsible use of our natural resources. League members promote conservation in our local communities, in states and watersheds, and nationally.

What We Do

The League's Watershed Programs engage in hands-on, local conservation action, such as monitoring streams and wetlands. For more than 30 years, the League has developed innovative watershed education programs for groups and individuals and provided networking and technical assistance through its Watershed Literacy Assistance Center. The League motivates citizens to clean up streams, monitor stream health, restore degraded streambanks, plant trees, and protect dwindling wetland acreage.

We invite you to become an active steward of our nation's streams, rivers and wetlands. To help stewards like you, the League has developed a variety of handbooks and videos about stream monitoring, habitat restoration, and wetland stewardship. This field guide for aquatic macroinvertebrates is one of many tools designed to assist your watershed stewardship program. If you would like to learn more about our educational resources, League chapters active in your community, or our toll-free technical assistance, please contact the League at (800) BUG-IWLA or visit our Web site at www.iwla.org.

The Izaak Walton League is a great way to get involved locally in environmental protection. Citizen action at the local level does make a difference!

Izaak Walton League of America
707 Conservation Lane
Gaithersburg, MD 20878
Phone: 301-548-0150
Fax: 301-548-0149
Technical Assistance: 800-BUG-IWLA
Email: sos@iwla.org
Web: www.iwla.org/sos

References

McCafferty, W.P. 1981 *Aquatic Entomololgy. The Fisherman's and Ecologists Illustrated Guide to Insects and Their Relatives.* Science Books International, Boston, MA.

Merrit, R.W., and K.W. Cummins, editors. 1996. *An Introduction to the Aquatic Insects of North America.* 3rd edition. Kendall/Hunt Publishing Company, Dubuque, IA.

Voshell, J.R. 2002. *A Guide to Common Freshwater Invertebrates of North America.* The McDonald & Woodward Publishing Company, Blacksburg, VA.

The League wishes to thank the following experts for their advice and comments:

J. Reese Voshell, Jr., Ph.D., Department of Entomology, Virginia Polytechnic Institute & State University

Phil Emmling, Environmental Chemistry & Technology Program, University of Wisconsin, Madison

Glossary

Algae: simple nonflowering plants of a large group that includes the seaweeds and many single-celled forms. Algae contain chlorophyll but lack true stems, roots, leaves, and vascular tissue.

Aquatic biodiversity: the variety of life and the ecosystems that make up the freshwater, tidal, and marine regions of the world and their interactions

Aquatic organism: an animal, either vertebrate or invertebrate, which lives in water for most or all of its life

Benthic: of, relating to, or occurring at the bottom of a body of water

Bioaccumulation: the accumulation of a substance, such as a toxic chemical, in various tissues of a living organism

Biological availability: the degree and rate at which a substance is absorbed into a living system or is made available at the site of physiological activity

Bog: an area of wet, spongy ground consisting mainly of decayed or decaying peat moss (sphagnum) and other vegetation

Bonded: a mutual attraction between two atoms resulting from a redistribution of their outer electrons

Carbon: the chemical element of atomic number 6, a nonmetal that has two main forms (diamond and graphite) and that also occurs in impure form in charcoal, soot, and coal

Carbon dioxide: a colorless, odorless gas produced by burning carbon and organic compounds and by respiration. It is naturally present in air and is absorbed by plants in photosynthesis.

Clarity: the state or quality of being clear or transparent to the eye

Density: the degree of compactness of a substance

Detritus: waste or debris of any kind such as gravel, sand, silt, or other material produced by erosion and organic matter produced by the decomposition of organisms

Dissolved oxygen (DO): the amount of oxygen dissolved in a body of water as an indication of the degree of health of the water and its ability to support a balanced aquatic ecosystem

Eutrophication: the process by which a body of water becomes enriched in dissolved nutrients (ie. phosphates) that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen

Eutrophic lakes: lakes characterized by an abundant accumulation of nutrients that support a dense growth of algae, the decay of which depletes the shallow water of oxygen in summer

Epilimnion: the upper layer of water in a stratified lake

Fen: low land that is covered wholly or partly with water unless artificially drained and that usually has peaty alkaline soil and characteristic flora (as of sedges and reeds)

Filter/buffer strips: Grassy areas located at the borders of fields. They are particularly important on the edge of lakes or streams since they remove sediment and other types of pollution as well as provide a home for wildlife.

Hardness: (water) a measure of the amount of calcium and magnesium salts in water. Calcium and magnesium enter water mainly through the weathering of rocks. The more calcium and magnesium in water, the harder the water.

Hydrogen: a colorless, odorless, flammable gas that combines chemically with oxygen to form water

Hypolimnion: the lower layer of water in a stratified lake, typically cooler than the water above and relatively stagnant

Invasive species: an organism (plant, animal, fungus, or bacterium) that is not native and has negative effects on our economy, our environment, or our health

Ion balance: a state of equilibrium that exists when acidic and basic ions in solution neutralize each other

Marsh: a tract of low wet land, often treeless and periodically inundated, generally characterized by a growth of grasses, sedges, cattails, and rushes

Medium: an intervening substance, as water, through which a force acts or an effecis produced

Mesotrophic Lakes: lakes with an intermediate level of productivity between the oligotrophic and eutrophic stages

Nitrogen fixation: the chemical processes by which atmospheric nitrogen is assimilated into organic compounds, especially by certain microorganisms as part of the nitrogen cycle

Nonpoint-source pollution: This occurs from widely dispersed land areas and is carried in runoff water from a field, forest, or urban area into a stream, lake, or groundwater.

Nutrient loading: quantity of nutrients such as nitrogen or phosphorus entering an ecosystem in a given period of time

Oligotrophic lakes: lakes characterized by a low accumulation of dissolved nutrient salts, supporting but a sparse growth of algae and other organisms, and having a high oxygen content owing to the low organic content

Oxygen: a colorless, odorless reactive gas, the chemical element of atomic number 8 and the life-supporting component of the air

Particulate matter: also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles.

pH: a measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with inceasing alkalinity and decreasing with increasing acidity. The pH scale ranges from 0 to 14.

Poikilothermic: (of all animals except birds and mammals) having a body temperature that varies with the temperature of the surroundings

Point-source pollution: This originates from the discharge of pollutants from a single, readily identifiable source such as an industrial or sewage discharge pipe.

Polar compound: a compound in which the electric charge is not symmetrically distributed, so that there is a separation of charge or partial charge and formation of definite positive and negative poles, ie.H_2O

Polarity: the property or characteristic that produces unequal physical effects at different points in a body or system

Precipitation: rain, snow, sleet, or hail that falls to the ground

Riparian area: Land and vegetation adjacent or near the banks of water (stream, river, bayou, lake, etc.)

Secchi disk: an opaque disk, typically white, used to gauge the transparency of water by measuring the depth (*Secchi depth*) at which the disk ceases to be visible from the surface

Sedimentation: the natural process in which material (such as stones and sand) is carried to the bottom of a body of water and forms a solid layer

Silt: fine sand, clay, or other material carried by running water and deposited as a sediment, especially in a channel or harbor

Solubility: the amount of a substance that will dissolve in a given amount of another substance (solvent)

Solvent: a substance in which another substance is dissolved, forming a solution

Specific heat: the amount of heat needed to raise the temperature of one gram of a substance by one degree Celsius, or to raise the temperature of one pound of a substance by one degree Fahrenheit

Stormwater runoff: water from rain or melting snow that flows across the land instead of seeping into the ground

Stream flow: the water that flows in a specific stream site, especially its volume and rate of flow

Succession: (ecology) the gradual and orderly process of change in an ecosystem brought about by the progressive replacement of one community by another until a stable climax is established

Surface tension: the elasticlike force existing in the surface of a body, especially a liquid, tending to minimize the area of the surface, caused by asymmetries in the intermolecular forces between surface molecules

Swamp: permanently waterlogged ground that is usually overgrown and sometimes partly forested.

Thermal stratification: the formation of layers of different temperatures in a lake or reservoir

Turbidity: the cloudiness or haziness of a fluid caused by large numbers of individual particles such as stirred up sediment

Volume: the amount of space, measured in cubic units, that an object or substance occupies

Watershed: the area of land where all of the water that is under it or drains off of it goes into the same place

Wetlands: A low-lying area of land that is saturated with moisture, especially when regarded as the natural habitat of wildlife. Marshes, swamps, and bogs are examples of wetlands.