2026

NCF-ENVIROTHON MISSISSIPPI

STUDY RESOURCES

AQUATIC ECOLOGY

ENVIROTHON

MISSISSIPPI 2026

2026

Aquatic Ecology

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Any hyperlinks included in the study resources, apart from those explicitly listed as Resources on the Key Topics page and featuring a dedicated page in the resources (such as YouTube videos), are considered supplemental material ONLY. While they can provide extra information, they are not mandatory study resources.

NCF-Envirothon 2026 Mississippi

Aquatic Ecology Study Resources

Key Topic #1: Hydrology

1. Describe the physical and chemical properties of water that affect aquatic ecosystems and explain the processes.
2. Diagram the water cycle and describe each component in detail.
3. Identify the indicators used for classifying and delineating wetlands.
4. Define an aquifer and elaborate on how aquifers relate to the local and global water supply.
5. Analyze the role the water table plays in an aquatic ecosystem and how it affects the ecosystems, as well as human activity and water use.
6. Identify the indicators used for classifying Riparian areas and why they are important.
7. Identify the indicators used for classifying Estuaries and why they are important.
8. Describe how different lake stratification classifications can affect how lakes functions

Resource Title	Source	Located on Page
Benefits of Riparian Zones	*Dede Christopher. (n.d.). Benefits of riparian zones. Tennessee Valley Authority.*	4
Water Table	*Water table. (n.d.). https://education.nationalgeographic.org/resource/water-table/*	8
Aquifers and Groundwater	Aquifers and groundwater. (2018, October 9). USGS. https://www.usgs.gov/water-science-school/science/aquifers-and-groundwater	9
Lake Stratification – Light and Temperature Zones	Dodd, C. (2021, August 2). Lake stratification. World Atlas. https://www.worldatlas.com/lakes/lake-stratification.html	13
Water cycle	Water cycle. (n.d.). USGS. https://www.usgs.gov/water-science-school/water-cycle	17
Water Cycle poster	Anderson, E., et al. (2024). Water cycle processes [poster]. General Information Product. U.S. Geological Survey. https://doi.org/10.3133/gip235	19
The Properties of Water	*Riggert, C. & Stream Team. (2019). The properties of water. Stream Team Academy Fact Sheet (No. 29). https://irp.cdn-website.com/2c37d579/files/uploaded/factsheet29.pdf*	20
Functions and Value of Wetlands	*US EPA, Office of Water, Office of Wetlands, Oceans and Watersheds. (2016). Functions versus values.*	22
Hypoxia 101	*Hypoxia 101 | US EPA. (2025, November 18). US EPA. https://www.epa.gov/ms-htf/hypoxia-101*	24
What is an Estuary?	*Basic Information about Estuaries | US EPA. (2026, February 3). US EPA. https://www.epa.gov/nep/basic-information-about-estuaries*	26
What is a Wetland?	*What is a Wetland? | US EPA. (2026, April 16). US EPA. https://www.epa.gov/wetlands/what-wetland*	28

Riparian Restoration

Benefits of Riparian Zones

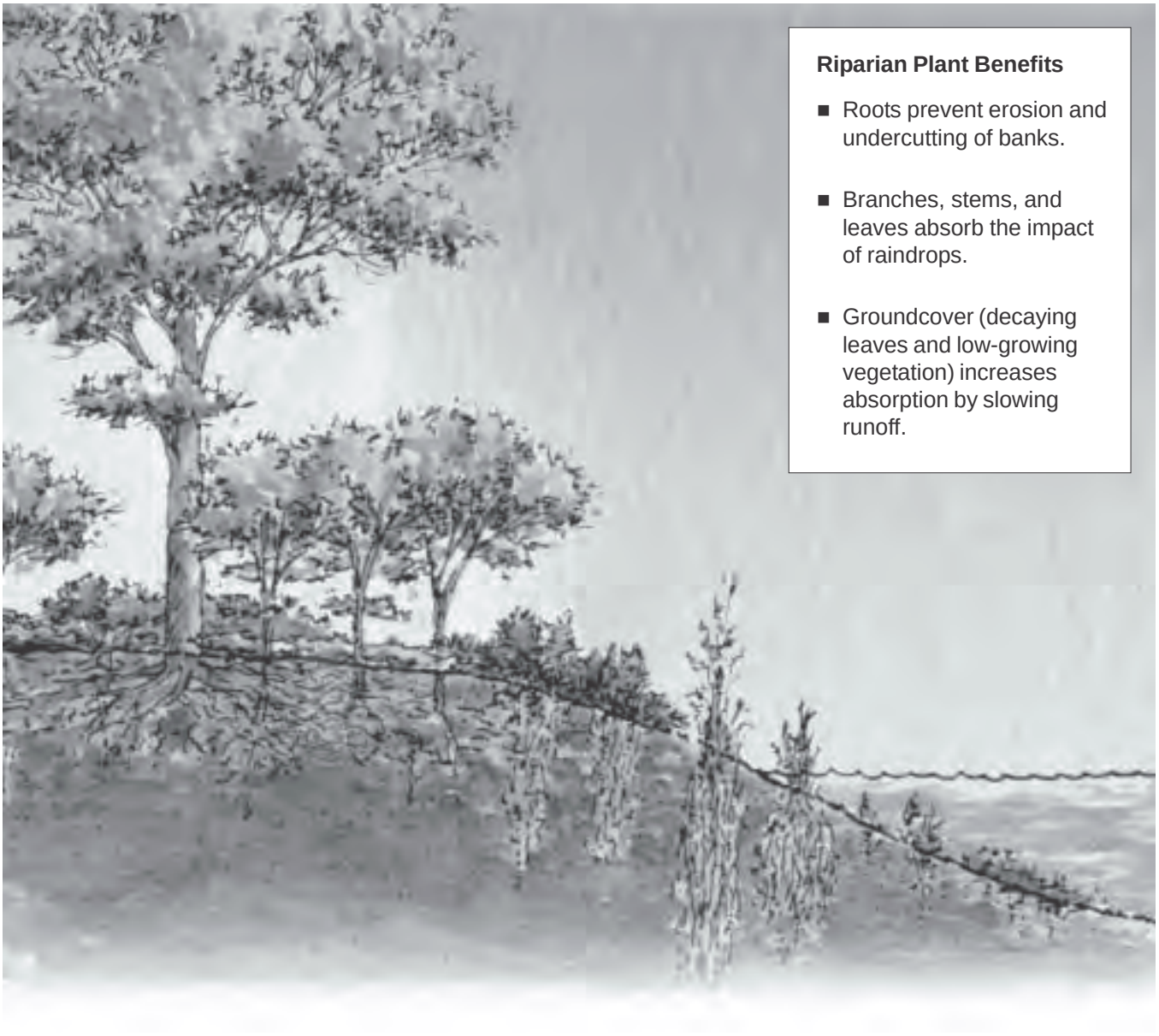
That Use Native Plants

The biologically distinctive area that borders the waterfront is called the "riparian zone." Diverse vegetation that grows along streams, rivers or reservoirs acts as a protective buffer between the land and the water. Waterfront property owners with well-vegetated riparian zones enjoy some of the most biologically diverse and scenic communities in the Tennessee Valley. Native vegetation that occurs along waterfronts provides an attractive landscape with many important benefits, and helps preserve plants and animals that make our area unique. By selecting native plants, you help to create a more natural condition on your property—a practice that benefits you as well as the health of our water resources.

Benefits of Riparian Zones

Maintaining or developing an attractive riparian zone can:

- Increase your property value
- Reduce property loss from excessive erosion
- Protect water quality
- Enhance wildlife habitat
- Contribute to the natural beauty of the land
- Dissipate noise from reservoir traffic, roads and nearby properties
- Reduce maintenance time and related costs
- Provide privacy
- Screen unsightly views
- Enhance scenic views



Dede Christopher

Benefits of Native Plants

Native plants have evolved under local conditions. They are tolerant of drought, extreme temperatures, and they are naturally resistant to pests and diseases. After they become established, native plants usually require much less physical effort to maintain than lawns. They can reduce or eliminate the need for lawn mowers, trimmers, and other gasoline-powered equipment. Native plants are also less costly to maintain because they generally don't need the fertilizers and pesticides turf grass and other non-native species may require.

Waterfront vegetation enhances habitat for wildlife and increases opportunities for wildlife viewing. Native plants along waterways provide food and shelter for a variety of insects, amphibians, reptiles, songbirds, mammals, and fish. Native vegetation also helps to prevent the establishment and spread of exotics (non-native plants).

Native riparian plants protect the streambank and shoreline from the erosive forces of moving water. The deep, extensive root structure of native grasses, shrubs, and trees prevents erosion and undercutting of banks.

The branches, stems, and leaves of these plants absorb the impact of raindrops. Decaying leaves and low-growing vegetation form a groundcover that further lessens the erosive force of raindrop impact. This groundcover slows runoff, increasing the amount of water that is absorbed into the soil and then released slowly into the stream, reservoir, groundwater, or atmosphere. The water that is absorbed may contain nutrients, pesticides, and other pollutants that will eventually be taken up by plants or broken down over time. By slowing runoff, trapping sediments, and increasing absorption, these plants act as a living filter to protect water quality.

Focusing on the facts and clearing up some misconceptions

It's certainly true that every piece of property is unique—with characteristics and circumstances that dictate particular "fixes" that might not be appropriate elsewhere. For property owners concerned about preserving their streambanks or shorelines, establishing a riparian zone of native vegetation is often the best way to go.

Here are some common concerns of property owners about using trees, shrubs, and grasses to protect shorelines and streambanks.

Concerns	**Concerns Addressed**
It'll block my view of the water.	Many native trees, shrubs, and grasses are fairly low-growing. With a well-designed landscaping plan, you'll be able to enhance scenic views and increase your privacy.
I like keeping my lawn looking neat and trimmed.	Some people are concerned that riparian vegetation will look unkempt. Sure, it's a switch from a manicured lawn; however, native trees, shrubs, and grasses along the streambank or shoreline can be a low-maintenance landscaping alternative that is aesthetically pleasing in a very "natural" way.
All that weedy growth will attract rats and snakes.	Actually, native shrubs and trees are much more likely to attract beneficial wildlife, including butterflies and songbirds. The secret is to think about the types of wildlife you'd like to attract, and then choose native plants that provide food and/or shelter for those species.
It's difficult to find native trees and shrubs at my local garden center.	TVA Watershed Teams can provide information about varieties that will thrive in your location—and give you information on where you might obtain them.
A bunch of plants won't make much difference; if I'm really going to try to stop erosion, riprap will work better and last longer.	Without a doubt, there are certain locations experiencing severe erosion which require rock riprap. For maximum benefits, establish a vegetative riparian zone by planting native plants above the rock riprap.

Why Not Exotic Plants?

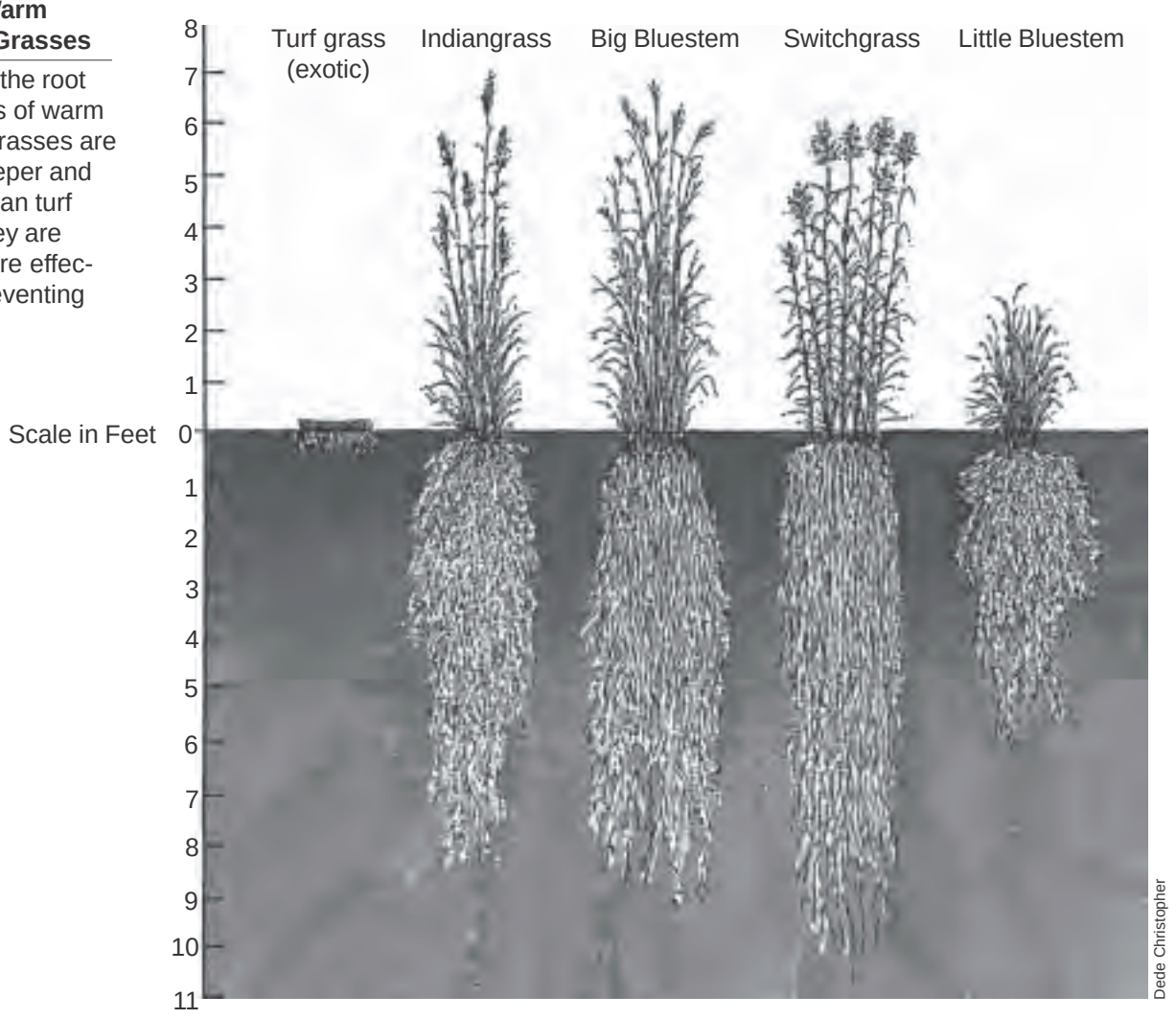
Exotic plants have the potential to become invasive because they are not subject to the same limiting factors that exist in their native habitat. Invasion by exotic plants is second only to habitat destruction as the greatest threat to the natural ecosystems of the United States. Here in the South, kudzu is one extreme example of an exotic plant growing out of control. Privet, mimosa, and Japanese honeysuckle are other exotic plants that have become invasive after being introduced to our area. Once exotics become established, they are very difficult to control.

Why Not Turf Grass?

Shoreline and streambank property planted with turf grass is really an unnatural landscape. The common turf grasses, such as fescue, bermuda, zoysia or bluegrass, were imported from other countries. Because these plants did not evolve under the specific conditions of the Tennessee Valley, keeping a lush, weed-free lawn is almost always costly, labor intensive, and potentially damaging to the environment. While turf grasses slow runoff, their root systems are too shallow to stabilize streambanks or shorelines. Consequently, lawns mowed to the water's edge will do little to control shoreline erosion. In fact, removing native vegetation and replacing it with turf grass usually results in accelerated streambank and shoreline erosion that degrades water quality.

Native Warm Season Grasses

Because the root structures of warm season grasses are much deeper and denser than turf grass, they are much more effective in preventing erosion.



Visit **www.tva.com/river/landandshore** to obtain contact information for your local Watershed Team

Water Table

https://education.nationalgeographic.org/resource/water-table/

The water table is the boundary between the unsaturated zone and the saturated zone underground. Below the water table, groundwater fills any spaces between sediments and within rock.

Article

The water table is an underground boundary between the soil surface and the area where groundwater saturates spaces between sediments and cracks in rock. Water pressure and atmospheric pressure are equal at this boundary.

The soil surface above the water table is called the unsaturated zone, where both oxygen and water fill the spaces between sediments. The unsaturated zone is also called the zone of aeration due to the presence of oxygen in the soil. Underneath the water table is the saturated zone, where water fills all spaces between sediments. The saturated zone is bounded at the bottom by impenetrable rock.

The shape and height of the water table is influenced by the land surface that lies above it; it curves up under hills and drops under valleys. The groundwater found below the water table comes from precipitation that has seeped through surface soil. Springs are formed where the water table naturally meets the land surface, causing groundwater to flow from the surface and eventually into a stream, river, or lake.

The water table level can vary in different areas and even within the same area. Fluctuations in the water table level are caused by changes in precipitation between seasons and years. During late winter and spring, when snow melts and precipitation is high, the water table rises. There is a lag, however, between when precipitation infiltrates the saturated zone and when the water table rises. This is because it takes time for water to trickle through spaces between sediments to reach the saturated zone, although the process is helped by gravity. Irrigation of crops can also cause the water table to rise as excess water seeps into the ground.

During the summer months, the water table tends to fall, due in part to plants taking up water from the soil surface before it can reach the water table. The water table level is also influenced by human extraction of groundwater using wells; groundwater is pumped out for drinking water and to irrigate farmland. The depth of the water table can be measured in existing wells to determine the effects of season, climate, or human impact on groundwater. The water table can actually be mapped across regions using measurements taken from wells.

If water is not extracted through a well in a sustainable manner, the water table may drop permanently. This is starting to be the case around the world. Some of the largest sources of groundwater are being depleted in India, China, and the United States to the point where they cannot be replenished. Groundwater depletion occurs when the rate of groundwater extraction through wells is higher than the rate of replenishment from precipitation.

USGS Aquifers and Groundwater

By Water Science School
October 16, 2019
https://www.usgs.gov/water-science-school/science/aquifers-and-groundwater

A huge amount of water exists in the ground below your feet, and people all over the world make great use of it. But it is only found in usable quantities in certain places underground — aquifers. Read on to understand the concepts of aquifers and how water exists in the ground.

Groundwater and aquifers

Groundwater is one of our most valuable resources—even though you probably never see it or even realize it is there.

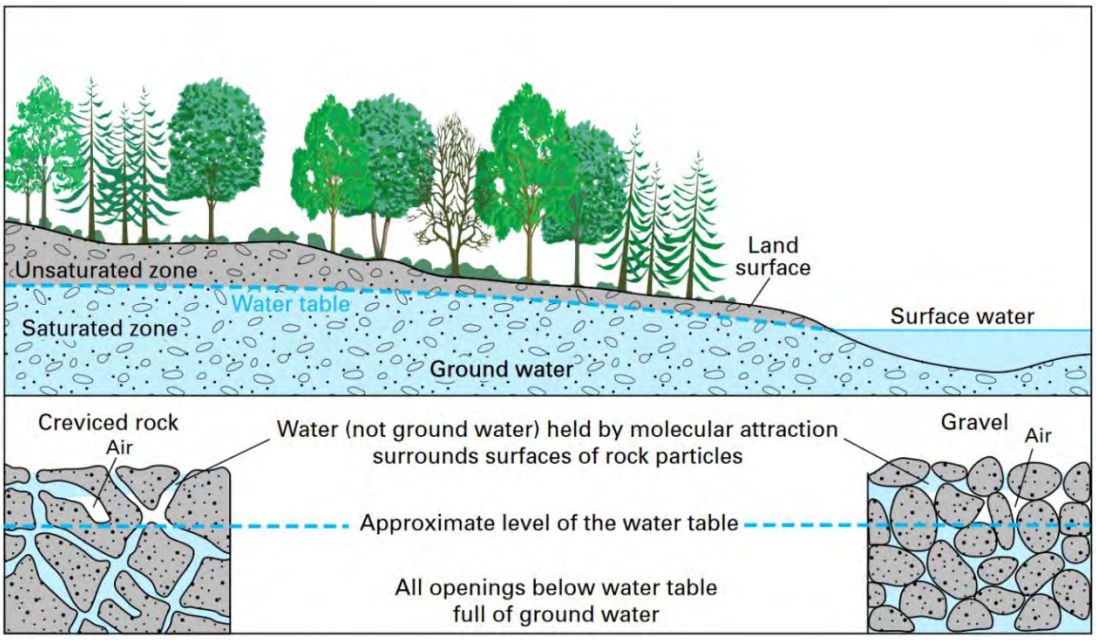
Have you ever dug a hole at the beach and watched as it partially filled with water from the underlying sand? This is a great way to illustrate the concept of how the ground, if it is permeable enough, can hold water but still stay solid. The upper surface of this water-filled area, or "zone of saturation", is called the water table. The saturated area beneath the water table is called an aquifer, and aquifers are huge storehouses of water. In our sand hole example, you have essentially dug a "well" that exposes the water table, with an aquifer beneath it. At the beach, the level of the water table is always at the same level as the **ocean**, which is just below the surface of the beach.

As you may have read, most of the void spaces in the rocks below the water table are filled with water. These rocks have different porosity and permeability characteristics, which means that water does not move around the same way in all rocks below ground.

When a water-bearing rock readily transmits water to wells and **springs**, it is called an aquifer. **Wells** can be drilled into the aquifers and water can be pumped out. **Precipitation** eventually adds water (**recharge**) into the porous rock of the aquifer. The rate of recharge is not the same for all aquifers, though, and that must be considered when pumping water from a well. Pumping too much water too fast draws down the water in the aquifer and eventually causes a well to yield less and less water and even run dry. In fact, pumping your well too much can even cause your neighbor's well to run dry if you both are pumping from the same aquifer.

Visualizing groundwater

In the diagram below, you can see how the ground below the water table (the blue area) is saturated with water. The “unsaturated zone" above the water table (the gray area) still contains water (after all, plants' roots live in this area), but it is not totally saturated with water. You can see this in the two drawings at the bottom of the diagram, which show a close-up of how water is stored in between underground rock particles.



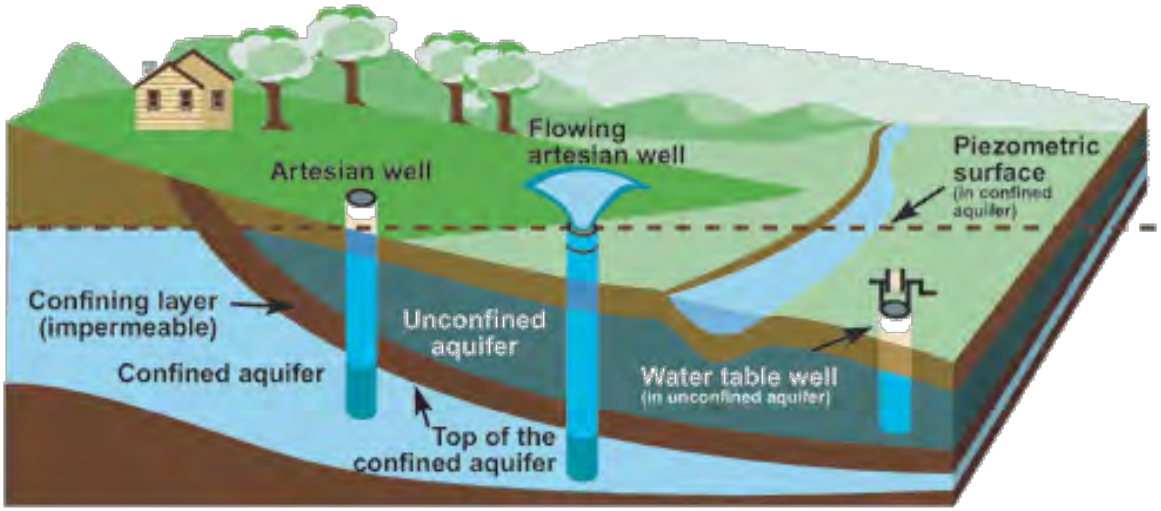
How ground water occurs in rocks.

How Groundwater Occurs

Sometimes the porous rock layers become tilted in the earth. There might be a confining layer of less porous rock both above and below the porous layer. This is an example of a confined aquifer. In this case, the rocks surrounding the aquifer confines the pressure in the porous rock and its water. If a well is drilled into this "pressurized" aquifer, the internal pressure might(depending on the ability of the rock to transport water) be enough to push the water up the well and up to the surface without the aid of a pump, sometimes completely out of the well. This type of well is called artesian. The pressure of water from an artesian well can be quite dramatic.

A relationship does not necessarily exist between the water-bearing capacity of rocks and the depth at which they are found. A very dense granite that will yield little or no water to a well may be exposed at the land surface. Conversely, a porous sandstone may lie hundreds or thousands of feet below the land surface and may yield hundreds of gallons per minute of water. Rocks that yield freshwater have been found at depths of more than 6,000 feet, and salty water has come from oil wells at depths of more than 30,000 feet. On the average, however, the porosity and permeability of rocks decrease as their depth below land surface increases; the pores and cracks in rocks at great depths are closed or greatly reduced in size because of the weight of overlying rocks.

Aquifers and wells



The illustration shows an artesian well and a flowing artesian well, which are drilled into a confined aquifer, and a water table well, which is drilled into an unconfined aquifer. Also shown are the Piezometric surface in the confined aquifer and the impermeable, confining layer between the confined and unconfined aquifer.
Credit: Environment and Climate Change Canada

Pumping can affect the level of the water table

Groundwater occurs in the saturated soil and rock below the water table. If the aquifer is shallow enough and permeable enough to allow water to move through it at a rapid-enough rate, then people can drill wells into it and withdraw water. The level of the water table can naturally change over time due to changes in weather cycles and precipitation patterns, streamflow and geologic changes, and even human-induced changes, such as the increase in impervious surfaces on the landscape.

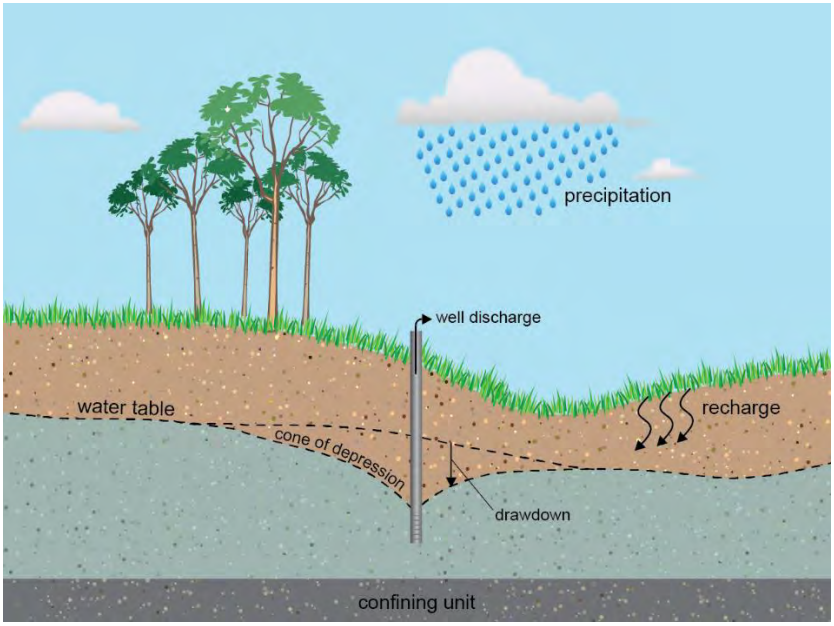
The pumping of wells can have a great deal of influence on water levels below ground, especially in the vicinity of the well, as this diagram shows. If water is withdrawn from the ground at a faster rate that it is replenished, either by infiltration from the surface or from streams, then the water table can become lower, resulting in a "cone of depression" around the well. Depending on geologic and hydrologic conditions of the aquifer, the impact on the level of the water table can be short-lived or last for decades, and it can fall a small amount or many hundreds of feet. Excessive pumping can lower the water table so much that the wells no longer supply water—they can "go dry."

Water movement in aquifers

Water movement in aquifers is highly dependent of the permeability of the aquifer material. Permeable material contains interconnected cracks or spaces that are both numerous enough and large enough to allow water to move freely. In some permeable materials groundwater may move several meters in a day; in other places, it moves only a few centimeters in a century.

Groundwater moves very slowly through relatively impermeable materials such as clay and shale. (Source: Environment Canada)

After entering an aquifer, water moves slowly toward lower lying places and eventually is discharged from the aquifer from springs, seeps into streams, or is withdrawn from the ground by wells. Groundwater in aquifers between layers of poorly permeable rock, such as clay or shale, may be confined under pressure. If such a confined aquifer is tapped by a well, water will rise above the top of the aquifer and may even flow from the well onto the land surface. Water confined in this way is said to be under artesian pressure, and the aquifer is called an artesian aquifer.



Schematic showing a **cone of depression** around the well, usually the result of over pumping.

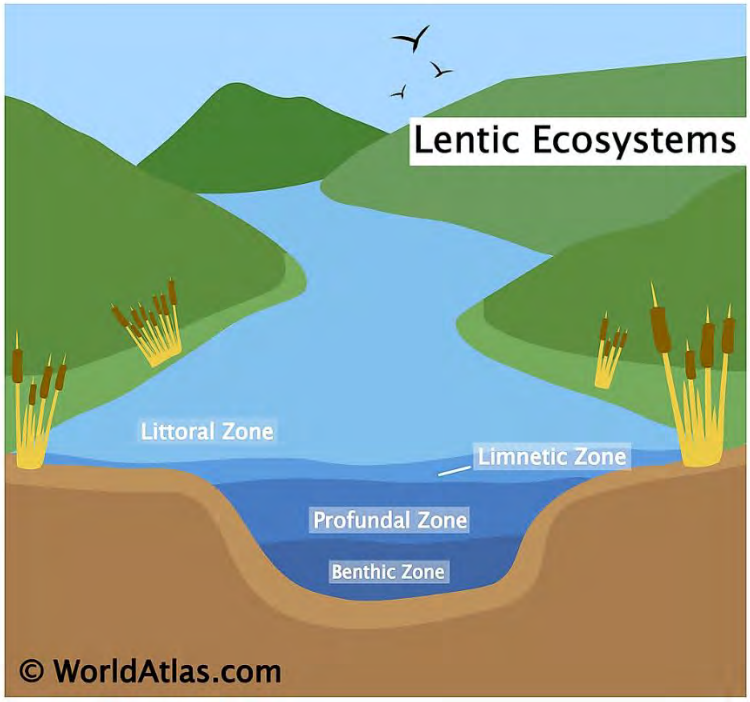
Lake Stratification

World Atlas

There are many different types of lakes in all different shapes, sizes, compositions and types. Lakes can be fresh water or saline, free flowing or stagnant, and occur in various different areas all over the world. When studying lakes, it can be helpful to break down different sections of that body of water, and understand the way in which the lake itself functions. There are a series of classifications within a lake which can be used to further understand the inner workings of these types of bodies of water.

Lake Zones

Firstly, there are four different types of lake zones. These zones divide the body of water into different sections, depending on depth. The four lake zones are littoral, limnetic, profundal, and benthic.



Littoral Zone

The littoral zone is the term for the shore region of a lake or pond. It includes everything around the shore or bank, from the dry land to the water's edge. This zone can vary greatly in size or depth, depending on the location or age of the lake. This zone is typically shallow, though, and full of nutrients from runoff and inbound water sources. For this reason it is generally the zone with the most aquatic or semi aquatic vegetation such as reeds, grasses and algaes.

Limnetic Zone

The next layer is called the limnetic zone and is the surface or open water section of the lake. The limnetic zone is classified by the amount of light that penetrates the body of water. This upper water layer is also referred to as the euphotic zone, and is the part of the lake that is

warmest and receives the most sunlight. Once the sunlight can no longer penetrate the lake, the zone ends. Like the Littoral zone, aquatic plants thrive in this region, due to the presence of sunlight. Oxygen levels are also higher in this section of the lake, meaning the majority of fish also live in this zone.

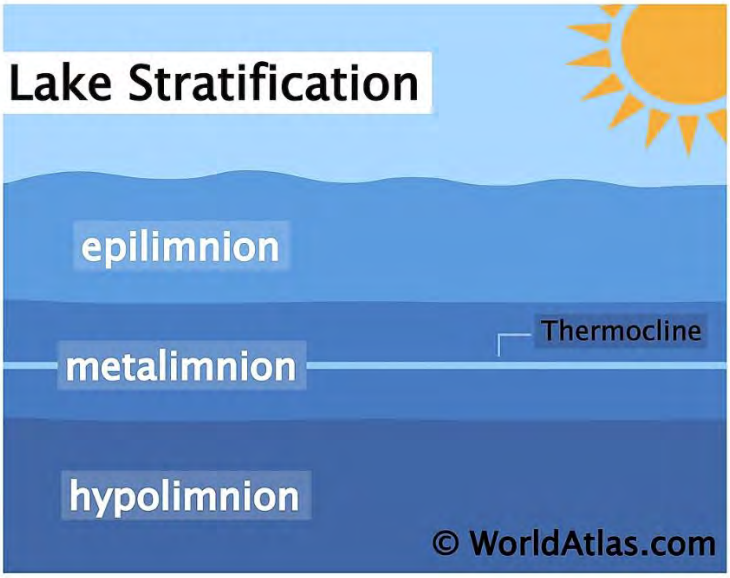
Profundal Zone

The profundal zone is the section that follows the Limnetic once the sunlight cannot penetrate the lake's surface any further. The temperature in these waters is also significantly colder, as the warmth from the sun is unable to reach these depths. The water clarity and composition has a significant effect on how deep the sunlight is able to reach, and therefore the size and depth of the profundal layer will vary from lake to lake. There is also a decreased amount of oxygen in this region of the lake, so the amount of fish in this area are also significantly less.

Benthic Zone

The benthic zone is essentially the area along the floor of the lake. It consists over everything in the bottom of the body of water, including the sediment, silt, and soil which builds up at the bottom of the lake. At this lowest point, bacteria live and work to decompose and break down any organic matter which has fallen to the lake floor. Everything from deceased fish and animals to dead plants, or animal droppings. Older lakes have larger or increased benthic zones as there is a larger amount of matter to be decomposed.

Lake Layers Based On Temperature



Lake stratification is the term used to describe the way lakes separate into layers based on temperature. Though related to the lake zones, this classification is strictly thermal. The change in temperature is due in part to the amount of light which can penetrate that lake's waters. Because of this, lake density plays a key role in the temperature of the layers, and stratification more generally.

When it comes to lake stratification, there are three different categories or layers. When the surface of a lake is warmed by the sun, water density begins to change, and thus the process of stratification begins. WInd then plays a significant part in mixing the upper layer of water, creating motion for the warm water and cool water to shift. Water that is cooler is denser, and so it circulates to the bottom of the lake, while the warmer water remains closer to the surface.

The cooler water that settles towards the lake bottom becomes the hypolimnion. The top warm layer is known as the epilimnion. In between the two, the water is in constant motion, and is a mixture of the two, as the thermal changes are taking place. This layer in the middle is known as the metalimnion.

Stratification is affected by the size, shape and depth of the lake. Larger and deeper lakes tend to have greater stratification. With small or shallow lakes, wind can affect much more of the water within the lake, thereby causing the entire lake to mix and move with the wind currents.

Lake Types

The temperature of a lake can also be classified into what are known as lake types. The lake types, based on temperature, are holomictic, monomictic, dimictic, polymictic, meromictic, amictic. This thermal classification also factors in which lakes have full circulation, and which do not.

Amictic lakes are the coldest lakes, are covered in ice permanently, and as such do not experience any circulation.

Holomictic have circulation throughout at some point in a given year. This means that although it may experience freezing over, it cannot be permanently frozen, and at some point, when at a higher thermal temperature, the water within the lake completely circulates.

Dimictic lakes experience seasons. This means they have both a winter stratification below ice and a summer stratification. Circulation only occurs in these lakes during the fall and spring months.

Polymictic is the term used for lakes which undergo stratification at irregular times. This can include lakes that startify in warm climates, or in cold climates.

Meromictic lakes on the other hand, do not experience a full circulation at any point throughout the year. These lakes usually do not mix due to the presence of chemicals which make the waters hold different densities that are always separate.

The process of stratification can therefore be either seasonal, and temporary, or ongoing, depending on the climate in which the lake exists, as well as the composition of the lake itself. All of these systems of lake classification can work together in order to categorize and better

understand lakes generally,but also climate and the effects of elements on various bodies of water.

From thermal classification to stratification, and the lake zone categories, all of these systems of categorizing lakes rely on the influence of external factors such as the sun, the lake's density and composition, and the climate in which the lake sits. The continued study of lakes and the systematic classification of those lakes allows for clearer scientific research into everything from climate change to habitat conservation, weather patterns and aquatic compositions. This research furthers human's understanding of a variety of topics, not just the specific lake being studied.

https://www.worldatlas.com/lakes/lake-stratification.html

USGS Water cycle

By Water Science School
https://www.usgs.gov/water-science-school/water-cycle

The water cycle describes where water is on Earth and how it moves. Human water use, land use, and climate change all impact the water cycle. By understanding these impacts, we can work toward using water sustainably.

What is the water cycle?
The water cycle describes where water is on Earth and how it moves. Water is stored in the atmosphere, on the land surface, and below the ground. It can be a liquid, a solid, or a gas. Liquid water can be fresh or saline (salty). Water moves between the places it is stored. Water moves at large scales, through watersheds, the atmosphere, and below the Earth's surface. Water moves at very small scales too. It is in us, plants, and other organisms. Human activities impact the water cycle, affecting where water is stored, how it moves, and how clean it is.

Pools store water
Oceans store 96% of all water on Earth. Ocean water is saline, meaning it's salty. On land, saline water is stored in saline lakes. The rest of the water on Earth is fresh water. Fresh water is stored in liquid form in freshwater lakes, artificial reservoirs, rivers, and wetlands. Water is stored in solid, frozen form in ice sheets and glaciers, and in snowpack at high elevations or near Earth's poles. Water vapor is a gas and is stored as atmospheric moisture over the ocean and land. In the soil, frozen water is stored as permafrost and liquid water is stored as soil moisture. Deeper below ground, liquid water is stored as groundwater in aquifers. Water in groundwater aquifers is found within cracks and pores in the rock.

Fluxes move water between pools
As it moves, water can change form between liquid, solid, and gas. Circulation mixes water in the oceans and transports water vapor in the atmosphere. Water moves between the atmosphere and the surface through evaporation, evapotranspiration precipitation. Water moves across the surface through snowmelt, runoff, and streamflow. Water moves into the ground through infiltration and groundwater recharge. Underground, groundwater flows within aquifers. Groundwater can return to the surface through natural discharge into rivers, the ocean, and from springs.

What drives the water cycle?
Water moves naturally and because of human actions. Energy from the sun and the force of gravity drive the continual movement of water between pools. The sun's energy causes liquid water to evaporate into water vapor. Evapotranspiration is the main way water moves into the atmosphere from the land surface and oceans. Gravity causes water to flow downward on land. It causes rain, snow, and hail to fall from clouds.

Humans alter the water cycle
In addition to natural processes, human water use affects where water is stored and how water moves. We redirect rivers. We build dams to store water. We drain water from wetlands for development. We use water from rivers, lakes, reservoirs, and groundwater aquifers. We use that

water to supply our homes and communities. We use it for agricultural irrigation and grazing livestock. We use it in industrial activities like thermoelectric power generation mining, and aquaculture. We also affect water quality. In agricultural and urban areas, irrigation and precipitation wash fertilizers and pesticides into rivers and groundwater. Power plants and factories return heated and contaminated water to rivers. Runoff carries chemicals, sediment, and sewage into rivers and lakes. Downstream from these sources, contaminated water can cause harmful algal blooms, spread diseases, and harm habitats for wildlife.

The water cycle and climate change

Climate change is actively affecting the water cycle. It is impacting water quantity and timing. Precipitation patterns are changing. The frequency, intensity, and length of extreme weather events, like floods or droughts, are also changing. Ocean sea levels are rising, leading to coastal flooding. Climate change is also impacting water quality. It is causing ocean acidification which damages the shells and skeletons of many marine organisms. Climate change increases the likelihood and intensity of wildfires , which introduces unwanted pollutants from soot and ash into nearby lakes and streams.

What determines water availability?

Humans and other organisms rely on water for life. The amount of water that is available depends on how much water there is in each pool (water quantity). Water availability also depends on when and how fast water moves (water timing) through the water cycle. Finally, water availability depends on how clean the water is (water quality).By understanding human impacts on the water cycle, we can work toward using water sustainably.

Viewed from space, the most striking feature of our planet is the water. In both liquid and frozen form, it covers 75% of the Earth's surface. It fills the sky with clouds. Water is practically everywhere on Earth, from inside the planet’s rocky crust to inside the cells of the human body (NASA). What's important to keep in mind is that all of this water is in constant motion across our planet.

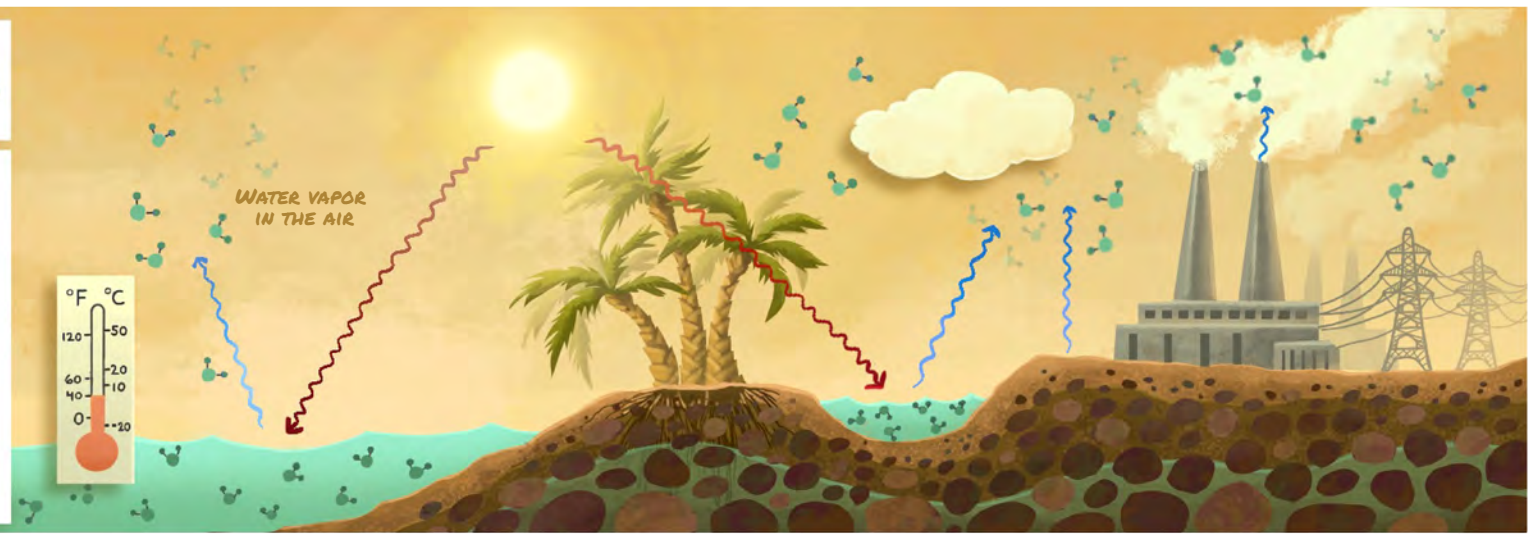
Credit: NASA

USGS
science for a changing world

Evaporation

Liquid → Gas

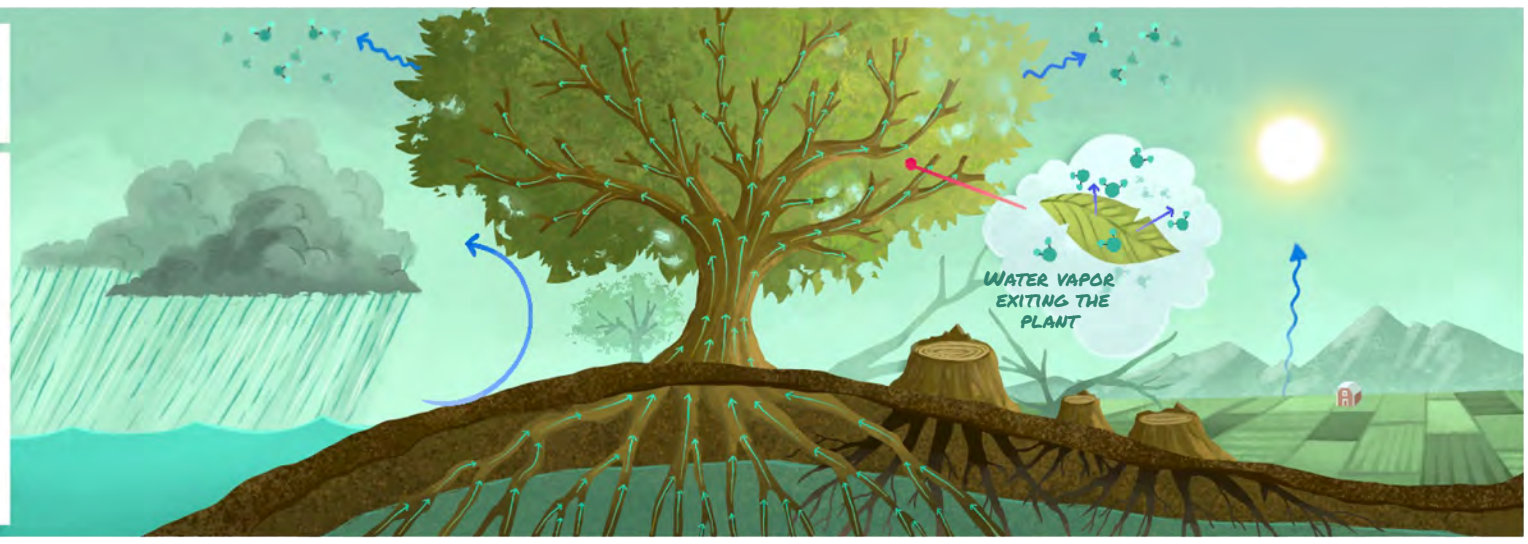
Liquid water can turn into water vapor even if it is not boiling. **Evaporation** can happen when the surface of the water is heated by the sun's energy. This energy causes some water molecules to float off as water vapor. Humans also cause **evaporation** when we heat water. **Evaporation** occurs over oceans, lakes, and rivers, and even from soil.



Transpiration

Liquid → Gas

A plant's roots take up liquid water from the soil, then that water moves through the plant and **evaporates** from the leaves as water vapor. This process is called **transpiration** and is responsible for about 10% of the water vapor in the atmosphere. When humans change the number, location, and types of plants on Earth, we change how much and where water vapor enters the atmosphere.



Condensation

Gas → Liquid

Clouds are made of tiny droplets of liquid water that are small enough to float around in the atmosphere. These droplets form when water vapor changes from a gas to a liquid by **condensing** around particles of ice, ash, dust, pollen, or manufactured particles like silver iodide (AgI). Clouds disappear as water droplets absorb the sun's energy and **evaporate** back into a gas.

Precipitation

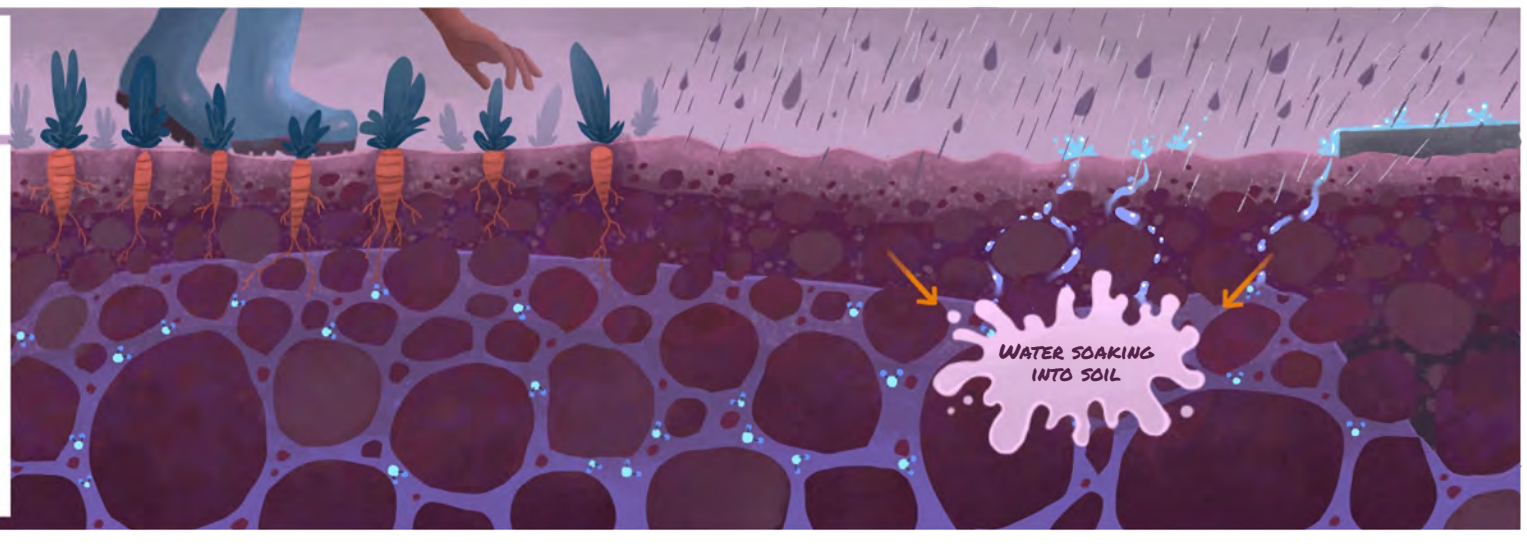
↓ Liquid ↓ Solid

As water vapor moves through the atmosphere on air currents, it can cool, **condense**, and fall to earth as **precipitation**. Larger water droplets **precipitate** as rain. When water vapor freezes onto airborne particles like dust or pollen, ice crystals can form and combine and **precipitate** as snow. Hail falls when water droplets lifted by air currents freeze, combine, then drop to earth.

Infiltration

Liquid ↓

Water can soak into, or **infiltrate**, soil, and then percolate, or move deeper underground. During **infiltration**, some nutrients, metals, and salts filter out naturally, but other chemicals may stay dissolved in the water. Water can collect in cracks and pores in rock layers, forming aquifers. When humans pump this aquifer water out, it can take many years to be replenished.



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General Information Product 235
March 2024

The Properties of Water

An Educational Series For Stream Teams To Learn and Collect

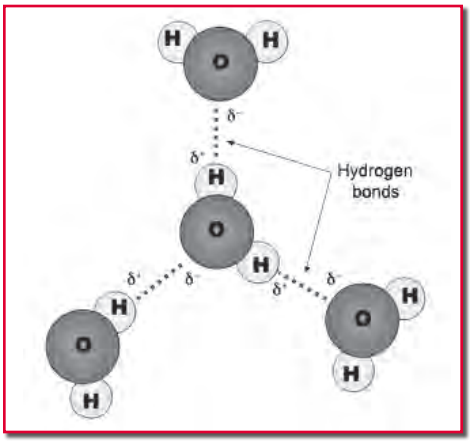
By Chris Riggert, Stream Team Program Coordinator

H_2O

One oxygen and two hydrogen atoms. It seems like such a simple equation. But, this "simple" compound and its structure lead to some complex and interesting properties and interactions, some of which are what make life on this planet possible.

Earth is sometimes referred to as the water planet because about 70% of its surface is covered with water. Nearly all of it is contained in our oceans, with only about 3% of earth's water as freshwater, and most of that is frozen in glaciers and polar ice caps. Life as we know it would not be possible without water. It is the only natural substance which can be found as a solid, liquid, and gas at temperatures normally found on Earth. This creates many opportunities for life to flourish.

Water is part of every living organism on the planet. In fact, water makes up to 90% of body weight of some organisms. Humans are about 60% water.



Polarized hydrogen bonds between water molecules attract water molecules to each other, forming the strongest cohesive non-metal liquid compound on Earth.

How much water are we?

- Lungs: about 83%
- Kidneys: about 79%
- Brain and heart: about 73%
- Skin: about 64%
- Bones: about 31%

Hydrogen ions are positively charged (+) and are attracted to the negatively charged (-) oxygen ion. They attach at a 105° angle through covalent bonds. This molecular structure gives the water molecule **polarity**, or a lopsided electrical charge that attracts other atoms. The end of the molecule with the two hydrogen atoms is positively charged and the end with the oxygen is negatively charged. This positive/negative charge makes the molecule "sticky" and is held together through hydrogen bonds. It is these hydrogen bonds that make water molecules so cohesive and water so special. In fact, water is the most cohesive non-metallic liquid.

Water's hydrogen bonds create tugging forces between water molecules, resulting in a high surface tension, allowing water molecules to clump together in drops. If you look closely at a water droplet, it appears to be coated in plastic. If you were to pour a small amount onto a flat surface, a small mound forms, preventing it from simply running off the edge. This surface tension forms a thin film where organisms such as water striders can "walk" across the water. However, it is this

(continued on back)

MISSOURI STREAM TEAM

Stream Team Academy Fact Sheet Series

#1 Tree Planting Guide
#2 Spotlight on Big Muddy
#3 Lewis & Clark
#4 Missouri Is Number One?
#5 Responsible ATV Use
#6 Headwater Streams
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#13 Aquatic Insects (Part 1)
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#25 Native Plants
#26 Invasive Species: Hydrilla
#27 Invasive Species: Didymo
#28 Invasive Species: Honeysuckle
#29 The Properties of Water

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same surface tension many benthic insects must overcome when hatching into an adult.

Surface tension also allows water to move upwards against the pull of gravity through capillary action. Water's high surface tension also allows water to be held by soil particles, providing a medium for plants to obtain nutrients. Water's adhesive properties are responsible for capillary action, allowing water and dissolved substances to be absorbed into porous materials and move through roots of plants and through tiny blood vessels in our bodies.

Water's many hydrogen bonds give it a high **Specific Heat Index**, or the amount heat per unit mass required to raise the temperature by one degree Celsius. It takes a lot of energy to break water's hydrogen bonds. This means it can absorb a lot of heat before it gets hot, making it an excellent insulator. Because our planet is mostly water, oceans help regulate the rate at which air temperatures change and is the reason why seasonal temperature changes are gradual rather than sudden. This gradual change in temperatures allows organisms to survive by adjusting gradually themselves. It also helps regulate the earth's overall temperatures as well as influences weather patterns.

Water is considered the "**universal solvent**" because it dissolves more substances than any other liquid. Its adhesive properties allow it to pick up valuable chemicals, minerals, nutrients, and waste as water moves through the ground or through our bodies. From a biological standpoint, water brings food into and carries waste away from cells. Water also absorbs heat when it evaporates; allowing humans to regulate body temperatures by releasing water through our skin pores, which then evaporates, cooling us off.

One additional interesting property of water deals with its **density** at different temperatures, or mass per unit volume. Most compounds become less dense as they warm because molecules move further apart, and become denser when they cool as molecules come closer together. Water does get denser as its temperature decreases. However, it is the densest at 4° C and then begins to expand, with maximum number of hydrogen bonds forming a crystal lattice as it freezes with molecules which are further apart. This allows frozen water (0° C) to float on the slightly warmer water below it. This is very important to aquatic life. If ice were denser than liquid water it would sink and eventually freeze solid. However, by floating, ice creates an insulating layer, preventing the water below from freezing and allowing the living things underneath to survive the winter.

Because water can exist as a vapor, it can be stored in the atmosphere and delivered as rain across the planet.

The next time you take a sip of water, paddle a canoe across the surface, listen to the rain, or watch the snow, think of these properties and their importance to life on the "water planet."

Physical States of Water

- Freezing point at sea level: 32° F
- Boiling point at sea level: 212° F
- Boiling point at 14,000 feet: 186.4° F
- Freezing and boiling points are baselines with which temperature is measured

A water strider is able to "skate" across water due to high surface tension formed by the strong bonds between water molecules.

United States
Environmental Protection
Agency

Office of Water
Office of Wetlands,
Oceans and Watersheds (4502T)

EPA 843-F-01-002c
September 2001

Functions and Values of Wetlands

Dave Davis

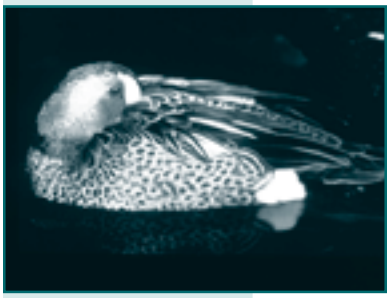
Long regarded as wastelands, wetlands are now recognized as important features in the landscape that provide numerous beneficial services for people and for fish and wildlife. Some of these services, or functions, include protecting and improving water quality, providing fish and wildlife habitats, storing floodwaters, and maintaining surface water flow during dry periods. These beneficial services, considered valuable to societies worldwide, are the result of the inherent and unique natural characteristics of wetlands.

Wetlands are considered valuable because they clean the water, recharge water supplies, reduce flood risks, and provide fish and wildlife habitat. In addition, wetlands provide recreational opportunities, aesthetic benefits, sites for research and education, and commercial fishery benefits.

Functions Versus Values

Wetland functions include water quality improvement, floodwater storage, fish and wildlife habitat, aesthetics, and biological productivity. The value of a wetland is an estimate of the importance or worth of one or more of its functions to society. For example, a value can be determined by the revenue generated from the sale of fish that depend on the wetland, by the tourist dollars associated with the wetland, or by public support for protecting fish and wildlife.

Although large-scale benefits of functions can be valued, determining the value of individual wetlands is difficult because they differ widely and do not all perform the same functions or perform functions equally well. Decision-makers must understand that impacts on wetland functions can eliminate or diminish the values of wetlands.



Water storage. Wetlands function like natural tubs or sponges, storing water and slowly releasing it. This process slows the water's momentum and erosive potential, reduces flood heights, and allows for ground water recharge, which contributes to base flow to surface water systems during dry periods. Although a small wetland might not store much water, a network of many small wetlands can store an enormous amount of water. The ability of wetlands to store floodwaters reduces the risk of costly property damage and loss of life—benefits that have economic value to us. For example, the U.S. Army Corps of Engineers found that protecting wetlands along the Charles River in Boston, Massachusetts, saved $17 million in potential flood damage.

Water filtration. After being slowed by a wetland, water moves around plants, allowing the suspended sediment to drop out and settle to the wetland floor. Nutrients from fertilizer application, manure, leaking septic tanks, and municipal sewage that are dissolved in the water are often absorbed by plant roots and microorganisms in the soil. Other pollutants stick to soil particles. In many cases, this filtration process removes much of the water's nutrient and pollutant load by the time it leaves a wetland. Some types of wetlands are so good at this filtration function that environmental managers construct similar artificial wetlands to treat storm water and wastewater.

Red-osier dogwood

Biological productivity. Wetlands are some of the most biologically productive natural ecosystems in the world, comparable to tropical rain forests and coral reefs in their productivity and the diversity of species they support. Abundant vegetation and shallow water provide diverse habitats for fish and wildlife. Aquatic plant life flourishes in the nutrient-rich environment, and energy converted by the plants is passed up the food chain to fish, waterfowl, and other wildlife and to us as well. This function supports valuable commercial fish and shellfish industries.

The Great Flood of 1993 in the upper Mississippi River Basin caused billions of dollars in property damage and resulted in 38 deaths. Historically, 20 million acres of wetlands in this area had been drained or filled, mostly for agricultural purposes. If the wetlands had been preserved rather than drained, much property damage and crop loss could have been avoided.

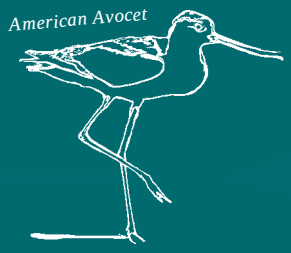
DID YOU KNOW?

- In 1991 wetland-related ecotourism activities such as hunting, fishing, bird-watching, and photography added approximately $59 billion to the national economy.
- According to the Pacific Coast Federation of Fishermen's Associations, almost $79 billion per year is generated from wetland-dependent species, or about 71 percent of the nation's entire $111 billion commercial and recreational fishing industry in 1997.
- An acre of wetland can store 1–1.5 million gallons of floodwater.
- Up to one-half of North American bird species nest or feed in wetlands.
- Although wetlands keep only about 5 percent of the land surface in the conterminous United States, they are home to 31 percent of our plant species.

Steve Delaney

Seventy-five percent of commercially harvested fish are wetland-dependent. Add shellfish species and that number jumps to 95 percent.

The Wetland Fact Sheet Series



Wetlands Overview
Types of Wetlands
Functions & Values of Wetlands
Threats to Wetlands
Wetland Restoration
Funding Wetland Projects
Wetland Monitoring & Assessment
Sustainable Communities
Volunteering for Wetlands
Teaching about Wetlands

For more information, visit www.epa.gov/owow/wetlands.

Wetland Resources

On the Internet

Ecosystem Valuation ..... www.ecosystemvaluation.org

Economic Valuation of Wetlands ..... www.ramsar.org/lib_val_e_index.htm

In Print

Restoration, Creation, and Recovery of Wetlands: Wetland Functions, Values, and Assessment, R.P. Novitzki, R.D. Smith, and J.D. Fretwell. United States Geological Survey Water Supply Paper 2425. Available on-line at http://water.usgs.gov/nwsum/WSP2425/functions.html.

Technical Aspects of Wetlands: Wetland Hydrology, Water Quality, and Associated Functions, Virginia Carter. United States Geological Survey Water Supply Paper 2425. Available on-line at http://water.usgs.gov/nwsum/WSP2425/hydrology.html.

Wetlands Functions and Values. Visit the North Carolina State University Water Quality Group's on-line informational database, WATERSHEDSS, at http://h2osparc.wq.ncsu.edu/info/wetlands/funval.html.

Hypoxia 101

(*https://www.epa.gov/ms-htf/hypoxia-101*)

What is Hypoxia?

Hypoxia, or low levels of dissolved oxygen (less than 2-3 milligrams of oxygen per liter of water), occurs in waters all over the world. A variety of factors - including the effects of excess nutrients and waterbody stratification (layering) due to saline or temperature gradients - can create hypoxic conditions. Hypoxia can have detrimental effects on the ecological and economic health of impacted areas. Excess nutrients delivered to a waterbody can lead to both overgrowth of algae and eutrophication. As dead algae decompose, oxygen is consumed in the process, resulting in low levels of oxygen in the water. In some cases, large areas of water may become hypoxic. These areas are often called "dead zones" because they are unable to sustain normal populations of fish, shellfish, corals, and other aquatic life (NOAA 2021; ESA N.D.).

When and Where Does Hypoxia Occur?

Hypoxia occurs naturally but has increased since the 20th century due to human activity. Hypoxic conditions have been reported worldwide (Diaz and Rosenburg 2008). They occur most often in estuaries and coastal waters, but also in inland lakes, rivers, and streams (Jean-Philippe et al. 2016). Hypoxia often occurs in shallow coastal areas associated with developed watersheds that export large quantities of nutrients in runoff (Diaz and Rosenburg 2008). Climate change may increase the occurrence of hypoxic conditions. More frequent, intense storms and warming waters can lead to increased stratification of the water column, increased nutrient input, and diminished oxygen capacity (Rabalais et al. 2010).

Dead Zones Worldwide

Smaller areas experiencing periodic hypoxia can grow into dead zones if contributing factors are not addressed. Dead zones have spread exponentially since the 1960s and have been reported in more than 400 receiving waters, affecting more than 245,000 km2 worldwide (Diaz and Rosenburg 2008).

Dead Zones in the United States

Dead zones are found throughout the United States, mostly along coastlines (Diaz and Rosenburg 2008). The largest dead zone in the United States forms each summer in the Gulf of America over the Louisiana/Texas continental shelf (LUMCON 2018); at its largest the zone was measured at over 22,000 km2 in 2017 (USEPA 2022). This area contains almost half of the nation's coastal wetlands and supports fisheries generating $1 billion/year (NCCOS 2017). Another dead zone forms in the main stem of the Chesapeake Bay each summer (up to 40% of its area and 5% of its volume) (VIMS 2021).

How Does Hypoxia Occur in the Gulf of America?

The amount of oxygen in a waterbody varies naturally due to certain biological and chemical processes, changing seasons, temperature, and atmospheric processes. Each summer, seasonal stratification in the Gulf of America results in less oxygen because of the waters differing densities at different depths. When water flows from the Mississippi/Atchafalaya River into the Gulf, the less dense freshwater remains above the denser saline seawater and create layers that prevent the mixing of oxygen-rich surface water with oxygen-poor bottom water. Without mixing, oxygen in the bottom water is low and the hypoxic condition remains (NOAA 2021).

Why is Hypoxia a Concern?

Marine Life and Habitat Loss

If the dissolved oxygen concentration in water begins to fall to hypoxic levels (below 2-3 milligrams of oxygen per liter of water), organisms will begin to avoid or migrate out of the area. Less mobile and immobile animals, like mussels and crabs, cannot move to more oxygenated waters and are often killed during hypoxic events (Rabalais et al. 2010).

Mobile fish and other marine life can be impacted by reduced-oxygen conditions. Hypoxia may contribute to physiological, developmental, growth, and reproductive abnormalities in fish (Rabalais et al. 2010) and can result in some fish kills (Rao et al. 2014).

Impacts on Ecosystem Services

Hypoxia can alter or interrupt ecosystem services like nutrient cycling and biodiversity (Rabalais et al. 2010). Nutrient cycling is important to maintain because it can affect the rate of marine plant and algal growth, which are critical to keep in balance (Diaz and Rosenberg 2008). Biodiversity is essential to the existence and proper functioning of all ecosystems and provides a variety of ecosystem services such as maintaining global temperatures, habitat for species, and food supply (Hong et al. 2022).

Economic Impacts on Fisheries

Hypoxia reduces and destabilizes fish and shellfish stocks, which impacts the global economy (ESA N.D.). Aquaculture is a significant source of food and income for much of the world's population. It accounts for almost 46% of total world fish production (FAO 2020).

What is an Estuary?

(https://www.epa.gov/nep/basic-information-about-estuaries)

An estuary is a partially enclosed, coastal water body where freshwater from rivers and streams mixes with salt water from the ocean. Estuaries, and their surrounding lands, are places of transition from land to sea. Although influenced by the tides, they are protected from the full force of ocean waves, winds and storms by land forms such as barrier islands or peninsulas.

Estuarine environments are among the most productive on earth, creating more organic matter each year than comparably-sized areas of forest, grassland or agricultural land. The sheltered waters of estuaries also support unique communities of plants and animals specially adapted for life at the margin of the sea.

Many different habitat types are found in and around estuaries, including shallow open waters, freshwater and saltwater marshes, swamps, sandy beaches, mud and sand flats, rocky shores, oyster reefs, mangrove forests, river deltas, tidal pools and seagrass beds.

Why are Estuaries Important?

Estuaries provide us with a suite of resources, benefits and services. Some of these can be measured in dollars and cents, while others cannot. Estuaries provide places for recreational activities, scientific study and aesthetic enjoyment. Estuaries are an irreplaceable natural resource that must be managed carefully for the mutual benefit of all who enjoy and depend on them. Below are additional ways in which estuaries are important (click to expand):

Estuaries Are Critical Natural Habitats

Thousands of species of birds, mammals, fish and other wildlife depend on estuarine habitats as places to live, feed and reproduce. And many marine organisms, including most commercially-important species of fish, depend on estuaries at some point during their development.

Because they are biologically productive, estuaries provide ideal areas for migratory birds to rest and refuel during their long journeys. Because many species of fish and wildlife rely on the sheltered waters of estuaries as protected spawning places, estuaries are often called the "nurseries of the sea."

Estuaries Have Economic Value

Estuaries have important commercial value and their resources provide economic benefits for tourism, fisheries and recreational activities. The protected coastal waters of estuaries also support important public infrastructure, serving as harbors and ports vital for shipping and transportation.

The economy of many coastal areas is based primarily on the natural beauty and bounty of estuaries. When those natural resources are imperiled, so too are the livelihoods of those who live and work in estuarine watersheds. Over half the U.S. population lives in coastal areas, including along the shores of estuaries. Coastal watershed counties provided 69 million jobs and contributed $7.9 trillion to the Gross Domestic Product in 2007 (National Ocean Economics Program, 2009).

Estuaries Perform Environmental Services

Estuaries also perform other valuable services. Water draining from uplands carries sediments, nutrients and other pollutants to estuaries. As the water flows through wetlands such as swamps and salt marshes, much of the sediments and pollutants are filtered out. This filtration process creates cleaner and clearer water, which benefits both people and marine life.

Salt marsh grasses and other estuarine plants also help prevent erosion and stabilize shorelines.

Estuaries Act as Protective Buffers

Wetland plants and soils also act as natural buffers between the land and ocean, absorbing flood waters and dissipating storm surges. This protects upland habitat as well as valuable real estate from storm and flood damage.

How are Estuaries Threatened?

Coastal counties are growing three times faster than counties elsewhere in the nation. Unfortunately, this increasing concentration of people:

- upsets the natural balance of estuarine ecosystems;
- threatens their integrity; and
- imposes increased pressures on vital natural resources like estuaries.

What happens on the land affects the quality of the water and health of the organisms that live in an estuary. For example, if a river or stream flows through an agricultural area, it picks up fertilizer, manure and pesticides from farming operations that run off the land after a rainstorm. As it passes urbanized and suburbanized areas, it gathers substances such as:

- fertilizers or pet waste that wash off lawns;
- untreated sewage from failing septic tanks;
- wastewater discharges from industrial facilities;
- sediment from construction sites; and
- runoff from impervious surfaces like parking lots.

What is a Wetland?

(https://www.epa.gov/wetlands/what-wetland)

Definition of a Wetland

Wetlands are areas where water covers the soil, or is present either at or near the surface of the soil all year or for varying periods of time during the year, including during the growing season. Water saturation (hydrology) largely determines how the soil develops and the types of plant and animal communities living in and on the soil. Wetlands may support both aquatic and terrestrial species. The prolonged presence of water creates conditions that favor the growth of specially adapted plants (hydrophytes) and promote the development of characteristic wetland (hydric) soils.

For Clean Water Act regulatory purposes, wetlands are "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." See 40 CFR 120.2(c)(1).

Categories of Wetlands

Wetlands vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation and other factors, including human disturbance. Indeed, wetlands are found from the tundra to the tropics and on every continent except Antarctica. Two general categories of wetlands are recognized: coastal or tidal wetlands and inland or non-tidal wetlands.

For more information about wetlands, please visit our Wetland Factsheet Series.

NCF-Envirothon 2026 Mississippi

Aquatic Ecology Study Resources

Key Topic #2: Aquatic Ecosystems

9. Explain the seasonal changes in temperature, water level, flow rate, nutrient sources, nutrient availability, runoff, and inputs that occur in aquatic ecosystems.
10. Analyze the major differences between freshwater and saltwater ecosystems.
11. Determine the order of a stream and describe what the order indicates.
12. Explain the role of aquatic ecosystems in biogeochemical cycles, such as carbon, nitrogen, and phosphorus cycles.

Resource Title	Source	Located on Page
Aquatic Ecosystems and Global Climate, *Foreword and Executive Summary*	*Center for Climate and Energy Solutions. (2025b, September 16). Aquatic Ecosystems and Global Climate Change - Center for Climate and Energy Solutions.*	30
Biogeochemical cycles	*Education, U. C. F. S. (n.d.). Biogeochemical Cycles | Center for Science Education. UCAR. https://scied.ucar.edu/learning-zone/earth-system/biogeochemical-cycles*	34
BACK TO BASICS: How and Why Phosphorus Cycles through a Lake	*Dickenson, L. (2022, September 20). BACK TO BASICS: How and Why Phosphorus Cycles through a Lake. IISD. https://www.iisd.org/ela/blog/back-to-basics-how-and-why-phosphorus-cycles-through-a-lake/*	38
How Stream Orders Work (*Strahler method*)	*How stream order works—ArCGIS Pro | Documentation. (n.d.). https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-stream-order-works.htm*	41
Stream Order: A Classification of the Rank of Streams and Rivers	*Briney, A. (2025, April 29). Stream Order. ThoughtCo.com. https://www.thoughtco.com/what-is-stream-order-1435354*	43
Lake Stratification and Mixing (Seasonal Changes)	*Hudson, H., & Kirschner, B. (1997). Lake stratification and mixing. In Lake Notes. Illinois Environmental Protection Agency.*	46
Saline Water and Salinity, *excerpts*	*Saline water and salinity. (2018, November 13). USGS. https://www.usgs.gov/water-science-school/science/saline-water-and-salinity#overview*	50

Aquatic Ecosystems and Global Climate

Center for Climate and Energy Solutions (C2ES)/ https://www.c2es.org/document/aquatic-ecosystems-and-global-climate-change/

Aquatic ecosystems are critical components of the global environment. In addition to being essential contributors to biodiversity and ecological productivity, they also provide a variety of services for human populations, including water for drinking and irrigation, recreational opportunities, and habitat for economically important fisheries. However, aquatic systems have been increasingly threatened, directly and indirectly, by human activities. In addition to the challenges posed by land-use change, environmental pollution, and water diversion, aquatic systems are expected to soon begin experiencing the added stress of global climate change.

"Aquatic Ecosystems and Global Climate Change" is the seventh in a series of reports examining the potential impacts of climate change on the U.S. environment. It details the likely impacts of climate change over the next century on U.S. aquatic ecosystems. Report authors, Drs. N. LeRoy Poff, Mark Brinson, and John Day, Jr. find:

- Increases in water temperatures as a result of climate change will alter fundamental ecological processes and the geographic distribution of aquatic species. Such impacts may be ameliorated if species attempt to adapt by migrating to suitable habitat. However, human alteration of potential migratory corridors may limit the ability of species to relocate, increasing the likelihood of species extinction and loss of biodiversity.
- Changes in seasonal patterns of precipitation and runoff will alter hydrologic characteristics of aquatic systems, affecting species composition and ecosystem productivity. Populations of aquatic organisms are sensitive to changes in the frequency, duration, and timing of extreme precipitation events, such as floods or droughts. Changes in the seasonal timing of snowmelt will alter stream flows, potentially interfering with the reproduction of many aquatic species.
- Climate change is likely to further stress sensitive freshwater and coastal wetlands, which are already adversely affected by a variety of other human impacts, such as altered flow regimes and deterioration of water quality. Wetlands are a critical habitat for many species that are poorly adapted for other environmental conditions and serve as important components of coastal and marine fisheries.
- Aquatic ecosystems have a limited ability to adapt to climate change. Reducing the likelihood of significant impacts to these systems will be critically dependent on human activities that reduce other sources of ecosystem stress and enhance adaptive capacity. These include maintaining riparian forests, reducing nutrient loading, restoring damaged ecosystems, minimizing groundwater withdrawal, and strategically placing any new reservoirs to minimize adverse effects.

The authors and the Center gratefully acknowledge the input of Drs. Virginia Burkett, Judy Meyer, Elizabeth Strange, and Alan Covich on this report. The Center would also like to thank Joel Smith of Stratus Consulting for his assistance in the management of this Environmental Impacts Series.

Executive Summary

Climate change of the magnitude projected for the United States over the next 100 years will cause significant changes to temperature regimes and precipitation patterns across the United States. Such alterations in climate pose serious risks for inland freshwater ecosystems (lakes, streams, rivers, wetlands) and coastal wetlands, and they may adversely affect numerous critical services they provide to human populations.

The geographic ranges of many aquatic and wetland species are determined by temperature. Average global surface temperatures are projected to increase by 1.5 to 5.8oC by 2100 (Houghton et al., 2001), but increases may be higher in the United States (Wigley, 1999). Projected increases in mean temperature in the United States are expected to greatly disrupt present patterns of plant and animal distributions in freshwater ecosystems and coastal wetlands. For example, cold-water fish like trout and salmon are projected to disappear from large portions of their current geographic range in the continental United States, when warming causes water temperature to exceed their thermal tolerance limits. Species that are isolated in habitats near thermal tolerance limits (like fish in Great Plains streams) or that occupy rare and vulnerable habitats (like alpine wetlands) may become extinct in the United States. In contrast, many fish species that prefer warmer water, such as largemouth bass and carp, will potentially expand their ranges in the United States and Canada as surface waters warm.

The productivity of inland freshwater and coastal wetland ecosystems also will be significantly altered by increases in water temperatures. Warmer waters are naturally more productive, but the particular species that flourish may be undesirable or even harmful. For example, the blooms of “nuisance” algae that occur in many lakes during warm, nutrient-rich periods can be expected to increase in frequency in the future. Large fish predators that require cool water may be lost from smaller lakes as surface water temperatures warm, and this may indirectly cause more blooms of nuisance algae, which can reduce water quality and pose potential health problems.

Warming in Alaska is expected to melt permafrost areas, allowing shallow summer groundwater tables to drop; the subsequent drying of wetlands will increase the risk of catastrophic peat fires and the release of vast quantities of carbon dioxide (CO_2) and possibly methane into the atmosphere.

In addition to its independent effects, temperature changes will act synergistically with changes in the seasonal timing of runoff to freshwater and coastal systems. In broad terms, water quality will probably decline greatly, owing to expected summertime reductions in runoff and elevated temperatures. These effects will carry over to aquatic species because the life cycles of many are tied closely to the availability and seasonal timing of water from precipitation and runoff. In

addition, the loss of winter snowpack will greatly reduce a major source of groundwater recharge and summer runoff, resulting in a potentially significant lowering of water levels in streams, rivers, lakes, and wetlands during the growing season.

The following summarizes the current understanding regarding the potential impacts of climate change on U.S. aquatic ecosystems:

1. Aquatic and wetland ecosystems are very vulnerable to climate change. The metabolic rates of organisms and the overall productivity of ecosystems are directly regulated by temperature. Projected increases in temperature are expected to disrupt present patterns of plant and animal distribution in aquatic ecosystems. Changes in precipitation and runoff modify the amount and quality of habitat for aquatic organisms, and thus, they indirectly influence ecosystem productivity and diversity.

2. Increases in water temperature will cause a shift in the thermal suitability of aquatic habitats for resident species. The success with which species can move across the landscape will depend on dispersal corridors, which vary regionally but are generally restricted by human activities. Fish in lowland streams and rivers that lack northward connections, and species that require cool water (e.g., trout and salmon), are likely to be the most severely affected. Some species will expand their ranges in the United States.

3. Seasonal shifts in stream runoff will have significant negative effects on many aquatic ecosystems. Streams, rivers, wetlands, and lakes in the western mountains and northern Plains are most likely to be affected, because these systems are strongly influenced by spring snowmelt and warming will cause runoff to occur earlier in winter months.

4. Wetland loss in boreal regions of Alaska and Canada is likely to result in additional releases of CO2 into the atmosphere. Models and empirical studies suggest that global warming will cause the melting of permafrost in northern wetlands. The subsequent drying of these boreal peatlands will cause the organic carbon stored in peat to be released to the atmosphere as CO2 and possibly methane.

5. Coastal wetlands are particularly vulnerable to sea-level rise associated with increasing global temperatures. Inundation of coastal wetlands by rising sea levels threatens wetland plants. For many of these systems to persist, a continued input of suspended sediment from inflowing streams and rivers is required to allow for soil accretion.

6. Most specific ecological responses to climate change cannot be predicted, because new combinations of native and non-native species will interact in novel situations. Such novel interactions may compromise the reliability with which ecosystem goods and services are provided by aquatic and wetland ecosystems.

7. Increased water temperatures and seasonally reduced streamflows will alter many ecosystem processes with potential direct societal costs. For example, warmer waters, in combination with high nutrient runoff, are likely to increase the frequency and extent of nuisance algal blooms, thereby reducing water quality and posing potential health problems.

8. The manner in which humans adapt to a changing climate will greatly influence the future status of inland freshwater and coastal wetland ecosystems. Minimizing the adverse impacts of human activities through policies that promote more science-based management of aquatic resources is the most successful path to continued health and sustainability of these ecosystems. Management priorities should include providing aquatic resources with adequate water quality and amounts at appropriate times, reducing nutrient loads, and limiting the spread of exotic species.

Overall, these conclusions indicate climate change is a significant threat to the species composition and function of aquatic ecosystems in the United States. However, critical uncertainties exist regarding the manner in which specific species and whole ecosystems will respond to climate change. These arise both from uncertainties about how regional climate will change and how complex ecological systems will respond. Indeed, as climate change alters ecosystem productivity and species composition, many unforeseen ecological changes are expected that may threaten the goods and services these systems provide to humans.

Biogeochemical Cycles

https://scied.ucar.edu/learning-zone/earth-system/biogeochemical-cycles

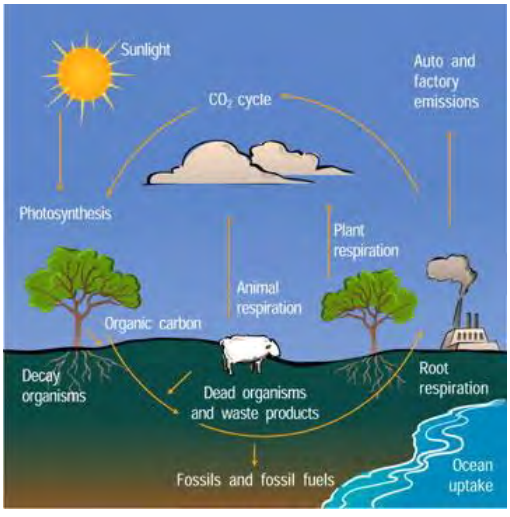
There are a few types of atoms that can be a part of a plant one day, an animal the next day, and then travel downstream as a part of a river's water the following day. These atoms can be a part of both living things like plants and animals, as well as non-living things like water, air, and even rocks. The same atoms are recycled over and over in different parts of the Earth. This type of cycle of atoms between living and non-living things is known as a biogeochemical cycle.

All of the atoms that are building blocks of living things are a part of biogeochemical cycles. The most common of these are the carbon and nitrogen cycles.

Tiny atoms of carbon and nitrogen are able to move around the planet through these cycles. For example, an atom of carbon is absorbed from the air into the ocean water where it is used by little floating plankton doing photosynthesis to get the nutrition they need. There is the possibility that this little carbon atom becomes part of the plankton's skeleton, or a part of the skeleton of the larger animal that eats it, and then part of a sedimentary rock when the living things die and only bones are left behind. Carbon that is a part of rocks and fossil fuels like oil, coal, and natural gas may be held away from the rest of the carbon cycle for a long time. These long-term storage places are called "sinks". When fossil fuels are burned, carbon that had been underground is sent into the air as carbon dioxide, a greenhouse gas.

Recently, people have been causing these biogeochemical cycles to change. When we cut down forests, make more factories, and drive more cars that burn fossil fuels, the way that carbon and nitrogen move around the Earth changes. These changes add more greenhouse gases in our atmosphere and this causes climate change.

The Carbon Cycle



The element carbon is a part of seawater, the atmosphere, rocks such as limestone and coal, soils, as well as all living things. On our dynamic planet, carbon is able to move from one of these realms to another as a part of the carbon cycle.

- Carbon moves from the atmosphere to plants. In the atmosphere, carbon is attached to oxygen in a gas called carbon dioxide (CO2). Through the process of photosynthesis, carbon dioxide is pulled from the air to produce food made from carbon for plant growth.
- Carbon moves from plants to animals. Through food chains, the carbon that is in plants moves to the animals that eat them. Animals that eat other animals get the carbon from their food too.

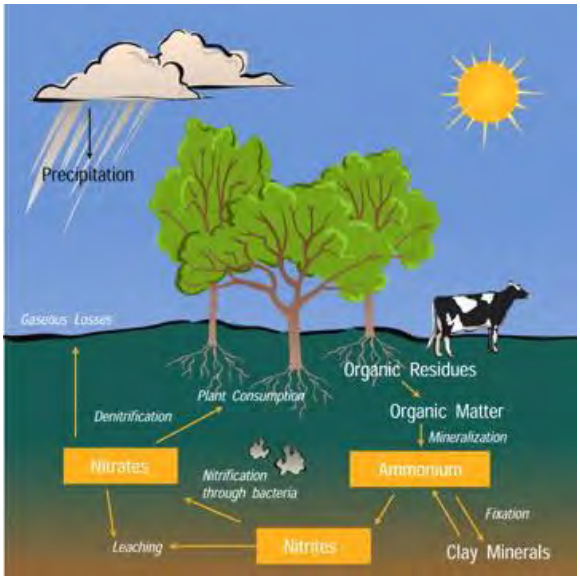
- Carbon moves from plants and animals to soils. When plants and animals die, their bodies, wood and leaves decays bringing the carbon into the ground. Some is buried and will become fossil fuels in millions and millions of years.
- Carbon moves from living things to the atmosphere. Each time you exhale, you are releasing carbon dioxide gas (CO2) into the atmosphere. Animals and plants need to get rid of carbon dioxide gas through a process called respiration.
- Carbon moves from fossil fuels to the atmosphere when fuels are burned. When humans burn fossil fuels to power factories, power plants, cars and trucks, most of the carbon quickly enters the atmosphere as carbon dioxide gas. Each year, five and a half billion tons of carbon is released by burning fossil fuels. Of this massive amount, 3.3 billion tons stays in the atmosphere. Most of the remainder becomes dissolved in seawater.
- Carbon moves from the atmosphere to the oceans. The oceans, and other bodies of water, absorb some carbon from the atmosphere. The carbon is dissolved into the water.

Carbon dioxide is a greenhouse gas and traps heat in the atmosphere. Without it and other greenhouse gases, Earth would be a frozen world. But since the start of the Industrial Revolution about 150 years ago humans have burned so much fuel and released so much carbon dioxide into the air that global climate has risen over one degree Fahrenheit. The atmosphere has not held this much carbon for at least 420,000 years according to data from ice cores. The recent increase in amounts of greenhouse gases such as carbon dioxide is having a significant impact on the warming of our planet.

Carbon moves through our planet over longer time scales as well. For example, over millions of years weathering of rocks on land can add carbon to surface water which eventually runs off to the ocean. Over long time scales, carbon is removed from seawater when the shells and bones of marine animals and plankton collect on the sea floor. These shells and bones are made of limestone, which contains carbon. When they are deposited on the sea floor, carbon is stored from the rest of the carbon cycle for some amount of time. The amount of limestone deposited in the ocean depends somewhat on the amount of warm, tropical, shallow oceans on the planet because this is where prolific limestone-producing organisms such as corals live. The carbon can be released back to the atmosphere if the limestone melts or is metamorphosed in a subduction zone.

The Nitrogen Cycle

Nitrogen is an element that is found in both the living portion of our planet and the inorganic parts of the Earth system. Nitrogen moves slowly through the cycle and is stored in reservoirs such as the atmosphere, living organisms, soils, and oceans along the way.



Most of the nitrogen on Earth is in the atmosphere. Approximately 80% of the molecules in Earth's atmosphere are made of two nitrogen atoms bonded together (N2). All plants and animals need nitrogen to make amino acids, proteins and DNA, but the nitrogen in the atmosphere is not in a form that they can use. The molecules of nitrogen in the atmosphere can become usable for living things when they are broken apart during lightning strikes or fires, by certain types of bacteria, or by bacteria associated with legume plants. Other plants get the nitrogen they need from the soils or water in which they live mostly in the form of inorganic nitrate (NO3-). Nitrogen is a limiting factor for plant growth. Animals get the nitrogen they need by consuming plants or other animals that contain organic molecules composed partially of nitrogen. When organisms die, their bodies decompose bringing the nitrogen into soil on land or into the oceans. As dead plants and animals decompose, nitrogen is converted into inorganic forms such as ammonium salts (NH4+) by a process called mineralization. The ammonium salts are absorbed onto clay in the soil and then chemically altered by bacteria into nitrite (NO2-) and then nitrate (NO3-). Nitrate is the form commonly used by plants. It is easily dissolved in water and leached from the soil system. Dissolved nitrate can be returned to the atmosphere by certain bacteria through a process called denitrification.

Certain actions of humans are causing changes to the nitrogen cycle and the amount of nitrogen that is stored in reservoirs. The use of nitrogen-rich fertilizers can cause nutrient loading in nearby waterways as nitrates from the fertilizer wash into streams and ponds. The increased nitrate levels cause plants to grow rapidly until they use up the nitrate supply and die. The number of herbivores will increase when the plant supply increases and then the herbivores are left without a food source when the plants die. In this way, changes in nutrient supply will affect the entire food chain. Additionally, humans are altering the nitrogen cycle by burning fossil fuels and forests, which releases various solid forms of nitrogen. Farming also affects the nitrogen cycle. The waste associated with livestock farming releases a large amount of nitrogen into soil and water. In the same way, sewage waste adds nitrogen to soils and water.

Nitrogen and Air Pollution

Nitric oxide (NO) and nitrogen dioxide (NO2) are together known as nitrogen oxides. These nitrogen oxides contribute to the problem of air pollution, playing roles in the formation of both smog and acid rain. They are released into Earth's atmosphere by both natural and human-generated sources.

Nitric oxide is a colorless, flammable gas with a slight odor. Nitrogen dioxide is a deep red-orange gas that is poisonous but not flammable. It, along with aerosols, is responsible for the reddish-brown color of smog. At high concentrations, it is highly toxic and can cause serious

lung damage. Nitrogen dioxide is a strong oxidizing agent, and is thus very reactive with other compounds.

Scientists estimate that between 20 and 90 million tons of nitrogen oxides in produced naturally each year from sources such as volcanoes, oceans, biological decay, and lightning strikes. Human activities add another 24 million tons of nitrogen oxides to our atmosphere annually.

Both NO and NO2 are formed during high-temperature combustion in the atmosphere, when oxygen combines with nitrogen. The exhaust gases of cars and trucks are major sources of nitrogen oxides, as are the emissions from electrical power generation plants. Automobile exhaust has more NO than NO2, but once the NO is released into the atmosphere it quickly combines with oxygen in the air to form NO2.

Nitrogen oxides are at least partially responsible for several types of air pollution. Nitrogen dioxide lends its color to the reddish-brown haze we call smog. Photodissociation of nitrogen dioxide by sunlight produces nitric oxide and ozone in the troposphere, which is another component of smog. A series of chemical reactions transform Volatile Organic Compounds (VOCs) into substances that combine with nitrogen dioxide to produce PAN (Peroxyacytyl nitrate), yet another element in smog. Nitrogen dioxide in the air also reacts with water vapor to form nitric acid, one of the types of acid in acid rain. Nitric oxide concentration in unpolluted air is around 0.01 ppm. In smog, the concentration rises twenty-fold to about 0.2 ppm.

Although nitrogen oxides have gained dubious distinction as pollutants, they are also used beneficially in some industrial processes. Nitric oxide is manufactured on a large scale, and is subsequently used to make nitric acid (HNO3). To create nitric oxide for industrial uses, chemists combine ammonia (NH3) with oxygen (O2), releasing water (H2O) as a byproduct. Nitrogen compounds derived from nitric acid are used to create chemical fertilizers, explosives, and other useful substances.

BACK TO BASICS: How and Why Phosphorus Cycles through a Lake

By Leah Dickenson

https://www.iisd.org/ela/blog/back-to-basics-how-and-why-phosphorus-cycles-through-a-lake/

You may have heard about nutrient cycles, otherwise known as biogeochemical cycles. But what you may not know is that these cycles also occur within a lake. One of the most important nutrient cycles in a lake is the phosphorus cycle due to its role in driving primary productivity (the ability of plants and algae to convert energy and inorganic nutrients into organic matter for the rest of the food web).

So, What Are Biogeochemical Cycles?

First off, biogeochemical cycles represent the movement of elements, such as nutrients, within a natural environment. These elements can be in various phases and exist within different chemical compounds. For example, the element carbon can exist in the carbon cycle as gaseous carbon dioxide (CO_2), as solid calcium carbonate ($CaCO_3$), and as various other compounds. These cycles can also include different compounds and phases depending on the scope, such as the movement of elements throughout terrestrial, freshwater, or oceanic ecosystems. Depending on the environment and magnitude there will be different biological and chemical reactions that each play a role within the cycle.

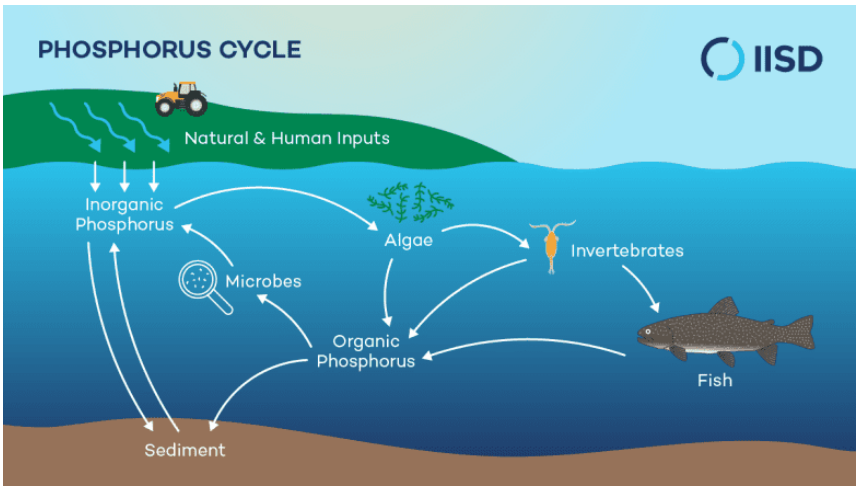
We will just be exploring nutrient cycles within a freshwater lake. Although this is a more focused scope, so many important reactions and processes occur in a lake within these cycles. Additionally, lakes are physically and chemically active daily and can vastly change with each change in season. This dynamic environment can impact when nutrients are available for the aquatic biota. For example, stratification within a lake can prevent the mixing of nutrients from higher to lower depths. Also, nutrients are not actively available at all stages within a nutrient cycle. Therefore, nutrient availability can have an impact on primary productivity within a lake, which can furthermore impact food web dynamics.

To understand nutrient cycles, we first need to know about the different nutrients in a lake. Nutrients are essential for all living components in a lake, however, every nutrient is of varying importance. The three most important nutrients in a lake are carbon, nitrogen, and phosphorus. These nutrients are crucial for metabolic processes and cell structure formation, thus essential components of all living things. Each of these nutrients processes and cycles within a lake are complex and unique. We are only going to focus on the phosphorus cycle.

The Phosphorus Cycle

Phosphorus (P) is an important nutrient for all living things because it is a component of DNA. It has many other essential roles especially related to internal processing of cells and growth. The nutrient phosphorus is the least abundant of carbon, nitrogen, and phosphorus, this means it is the most limiting nutrient. Therefore, the biological productivity of a lake is commonly related

to the amount of available phosphorus. This theory has been famously studied at IISD-ELA since the 1970's.



First, what are the sources of phosphorus? There are both natural and anthropogenic (or 'originating from humans') sources of phosphorus to a lake. The natural source of phosphorus originates from the leaching of minerals. This source will then be supplied to a lake via erosion and runoff from terrestrial landscapes. Additionally, sediment at the bottom of a lake typically acts as a large internal nutrient reserve. The phosphorus retained within the sediment is periodically released, however this release is dependant on multiple factors that can occur at the where the sediment meets the water (described in more detail below).

The input of phosphorus by humans to a lake can be a result of several different sources. If this P loading is high, it can be detrimental to lakes, resulting in harmful algal blooms. The alteration of landscapes to promote increased drainage and runoff results in faster P loading to surface waters. Also, the application of P containing fertilizers onto agricultural lands in excess can result in runoff into waterways and eventually into lakes. Other phosphorus sources include discharge from wastewater facilities, livestock manure runoff, and urban area runoff.

There are two important interfaces that play a role in the biogeochemical cycling of phosphorus. The first is the air-water interface. Interestingly phosphorus does not commonly exist in the gas phase, so this interface may be seen as irrelevant. However, movement of other elements across this interface are important for the phosphorus cycle such as oxygen.

In terms of the phosphorus cycle the sediment-water interface is incredibly important to the loading of phosphorus to a lake. The sedimentation of phosphorus occurs when organic phosphorus is released during either, excretion or decomposition, if this organic phosphorus is not taken up within the water column it will settle to the bottom of the lake. When the sediment is highly oxygenated, the phosphorus is bound to the sediment and unavailable to release—this is called complexation. However, the release of phosphorus at the sediment-water interface can be due to a few different processes. One process is the physical mixing of the water column, this typically occurs during turnover and can release the phosphorus in the sediment. Next, if the sediment is under an anoxic state (little to no dissolved oxygen), this

results in oxidation-reduction reactions to occur that release phosphorus, this is called internal P loading.

There are a variety of forms of phosphorus that can exist within a lake. When phosphorus enters a lake, it is in the inorganic form as orthophosphate (PO_4^{-3}). The dissolved orthophosphate is the main source taken up by algae and aquatic plants. When phosphorus is within living biota such as algae, this is called particulate phosphorus. As grazers feed on the algae, and predators feed on the grazers, and so on, the phosphorus will be mobilized and used within the entire food web. Once contained within living manner in the food web, the inorganic phosphorus is converted to organic phosphorus. Which is then released in the process of either, excretion or death of animal or plant matter. The stage of decomposition within the cycle returns organic phosphorus to inorganic phosphorus. Most of the inorganic phosphorus in the water column is up taken again by algae and plants, then the cycle continues. The remainder will fall to the sediments to be retained. As previously mentioned, once in the sediment depending on the conditions, the phosphorus will either remain or be released.

Nutrient cycles are complex, and their processes vary depending on the chemical, physical, and biological processes that occur within and around a lake. The phosphorus cycle is one of the most important cycles in a lake. This cycle occurs in the lakes around you and depending on the amount of available phosphorus in the cycle, it may result in the formation of algal blooms. However, you play a role in the cycle due to the many sources of P from human activity.

So, next time you are at a lake, think about all the processes that are occurring within and be just beware that your actions can influence that system.

How Stream Order works

ArcGIS Pro 3.6

In this topic

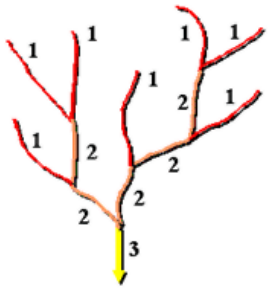
1. Strahler method
2. Shreve method
3. References

Available with Spatial Analyst license.

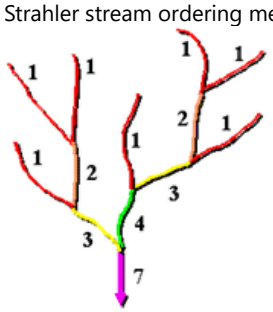
Stream ordering is a method of assigning a numeric order to links in a stream network. This order is a method for identifying and classifying types of streams based on their numbers of tributaries. Some characteristics of streams can be inferred by simply knowing their order.

For example, first-order streams are dominated by overland flow of water; they have no upstream concentrated flow. Because of this, they are most susceptible to non-point source pollution problems and can derive more benefit from wide riparian buffers than other areas of the watershed.

The Stream Order tool has two methods you can use to assign orders. These are the methods proposed by Strahler (1957) and Shreve (1966).



Strahler stream ordering method



Shreve stream ordering method

In both methods, the upstream stream segments, or exterior links, are always assigned an order of 1.

Strahler method

In the Strahler method, all links without any tributaries are assigned an order of 1 and are referred to as first order.

The stream order increases when streams of the same order intersect. Therefore, the intersection of two first-order links will create a second-order link, the intersection of two second-order links will create a third-order link, and so on. The intersection of two links of different orders, however, will not result in an increase in order. For example, the intersection of a first-order and second-order link will not create a third-order link but will retain the order of the highest ordered link.

The Strahler method is the most common stream ordering method. However, because this method only increases in order at intersections of the same order, it does not account for all links and can be sensitive to the addition or removal of links.

Shreve method

The Shreve method accounts for all links in the network. As with the Strahler method, all exterior links are assigned an order of 1. For all interior links in the Shreve method, however, the orders are additive. For example, the intersection of two first-order links creates a second-order link, the intersection of a first-order and second-order link creates a third-order link, and the intersection of a second-order and third-order link creates a fifth-order link.

Because the orders are additive, the numbers from the Shreve method are sometimes referred to as magnitudes instead of orders. The magnitude of a link in the Shreve method is the number of upstream links.

References

Tarboton, D. G., R. L. Bras, and I. Rodriguez-Iturbe. 1991. On the Extraction of Channel Networks from Digital Elevation Data. Hydrological Processes. 5: 81–100.

Related topics

- Stream Order

Stream Order

A Classification of the Rank of Streams and Rivers

Sunset Avenue Productions / Getty Images

By Amanda Briney

Updated on April 29, 2025

Key Takeaways

Stream order helps scientists learn what kinds of plants and animals might live in different waters.

Geographers use stream order in maps to show how streams connect to form bigger rivers.

One of the most important aspects of physical geography is the study of the world's natural environment and resources—one of which is water.

Because this area is so important, geographers, geologists, and hydrologists alike use stream order to study and measure the size of the world's waterways.

A stream is classified as a body of water that flows across the Earth's surface via a current and is contained within a narrow channel and banks.

Based on stream order and local languages, the smallest of these waterways are also sometimes called brooks and/or creeks. Large waterways (at the highest level the stream order) are called rivers and exist as a combination of many tributary streams.

Streams can also have local names such as bayou or burn.

How It Works

When using stream order to classify a stream, the sizes range from a first-order stream to the largest, a 12th-order stream.

A first-order stream is the smallest of the world's streams and consists of small tributaries. These are the streams that flow into and "feed" larger streams but do not normally have any water flowing into them. Also, first- and second-order streams generally form on steep slopes and flow quickly until they slow down and meet the next order waterway.

First- through third-order streams are also called headwater streams and constitute any waterways in the upper reaches of the watershed. Over 80% of the world’s waterways are estimated to be these first- through third-order or headwater streams.

For example, to compare the relative size of these different streams, the Ohio River in the United States is an eighth-order stream while the Mississippi River is a 10th-order stream. The world's largest river, the Amazon in South America, is considered a 12th-order stream.

Unlike the smaller order streams, these medium and large rivers are usually less steep and flow more slowly. They do however tend to have larger volumes of runoff and debris as it collects in them from the smaller waterways flowing into them.

Going Up in Order

If, however, two streams of different order join neither increases in order. For example, if a second-order stream joins a third-order stream, the second-order stream simply ends by flowing its contents into the third-order stream, which then maintains its place in the hierarchy.

Importance

Stream order also helps people like biogeographers and biologists in determining what types of life might be present in the waterway.

This is the idea behind the River Continuum Concept, a model used to determine the number and types of organisms present in a stream of a given size. More types of plants, for example, can live in sediment-filled, slower flowing rivers like the lower Mississippi than can live in a fast-flowing tributary of the same river.

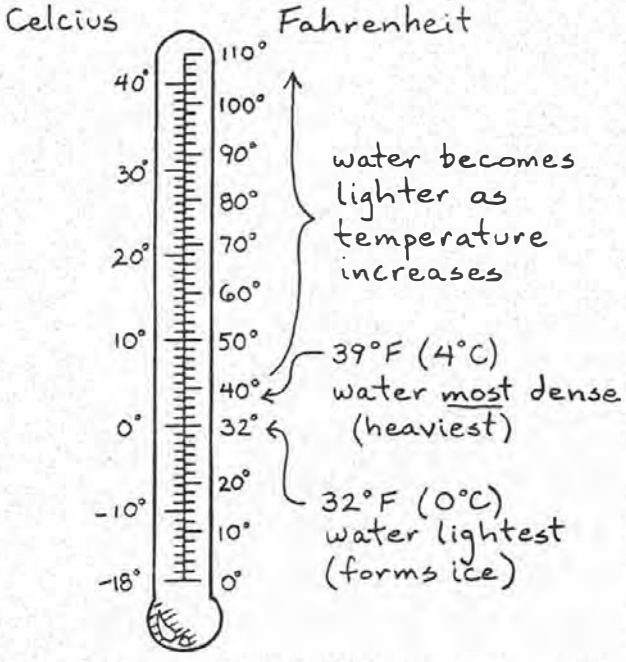
More recently, stream order has also been used in geographic information systems (GIS) to map river networks. The algorithm, developed in 2004, uses vectors (lines) to represent the various streams and connects them using nodes (the place on the map where the two vectors meet.)

By using the different options available in ArcGIS, users can then change the line width or color to show the different stream orders. The result is a topologically correct depiction of the stream network that has a wide variety of applications.

Lake Notes

Lake Stratification and Mixing

Many of our Illinois lakes and reservoirs are deep enough to stratify, or form "layers" of water with different temperatures. Such ***thermal stratification*** occurs because of the large differences in density (weight) between warm and cold waters. Density depends on temperature: water is most dense (heaviest) at about 39°F, and less dense (lighter) at temperatures warmer and colder than 39°F.



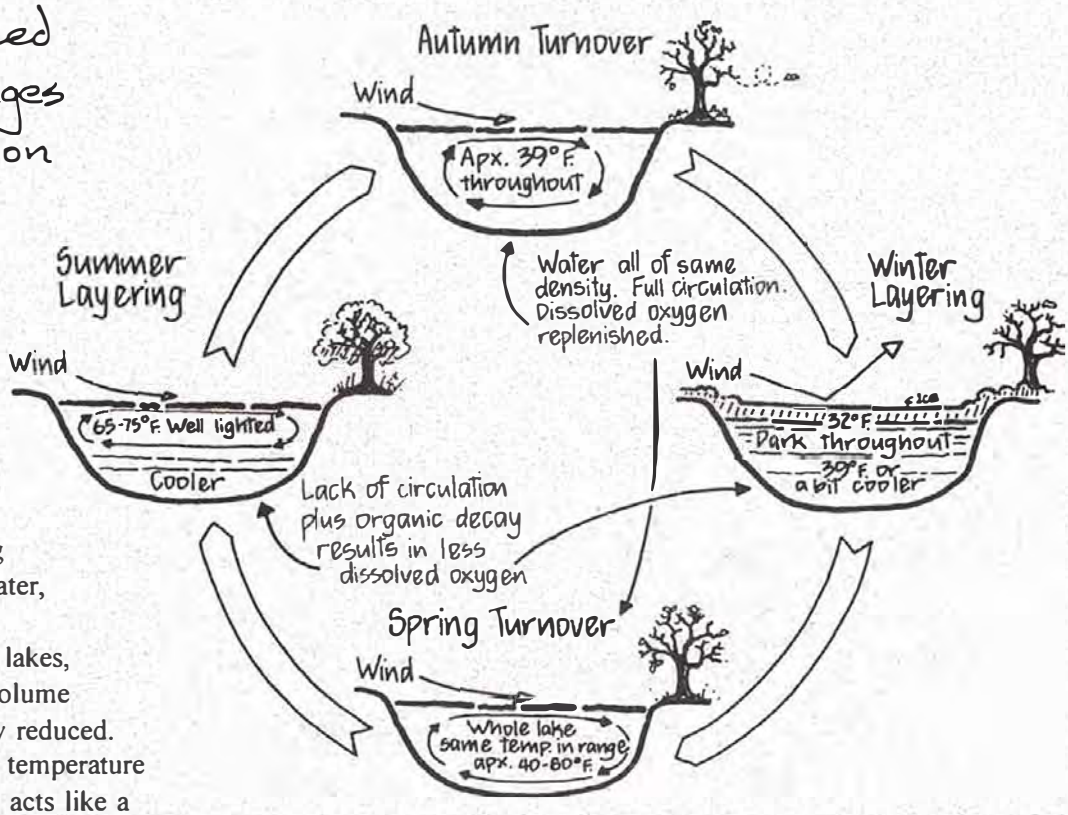
The Stratification Process

In the fall, chilly air temperatures cool the lake's surface. As the surface water cools, it becomes more dense and sinks to the bottom. Eventually the entire lake reaches about 39°F (4°C). As the surface water cools even more, it becomes less dense and "floats" on top of the denser 39°F water, forming ice at 32°F (0°C). The lake water below the ice remains near 39°F. This situation is referred to as ***winter stratification***. Winter stratification remains stable because the ice cover prevents wind from mixing the water.

Come spring, the ice melts and the surface water begins to warm above 32°F. The increasing density of the warming water along with wind action cause this surface water to sink and mix with the deeper water—a process called ***spring turnover***. During this time period, most of the lake water is at the same temperature, and surface and bottom waters mix freely. Lakes with a small surface area, especially if protected from the wind, typically completely mix for only a brief time in the spring—usually just a few days. In comparison, large lakes often circulate for weeks.

As the sun continues to warm the lake surface through late spring and early summer, the temperature differences increase between the surface and deeper waters. In lake areas deeper than about 10 to 12 feet, the temperature differences eventually create a physical force strong enough to resist the wind's mixing forces (it only takes a difference of a few degrees Fahrenheit to prevent mixing). The lake now stratifies into three layers of water—a situation termed ***summer stratification***. The upper layer is a warm (lighter), well-mixed zone called the ***epilimnion***. Below this is a transitional zone where temperatures rapidly change called the ***metalimnion***. The ***thermocline*** is a horizontal plane within the metalimnion through the point of greatest water temperature change. The metalimnion is very resistant to wind mixing. Beneath the metalimnion and extending to the lake bottom is the colder (heavier), usually dark, and relatively undisturbed ***hypolimnion***.

Lakes are influenced by seasonal changes in water circulation patterns



The most important actions causing lake mixing are wind, inflowing water, and outflowing water. While wind influences the surface waters of all lakes, its ability to mix the entire water volume in summer-stratified lakes is greatly reduced. This is because the rapid change in temperature and density within the metalimnion acts like a physical barrier between the epilimnion and hypolimnion. Though not an absolute barrier, it takes a lot of energy to disrupt it.

The stability of a lake's stratification depends on many factors, most importantly the lake's depth, shape, and size. Also playing a role are climate, orientation of the lake to the wind, and inflow/outflow. As noted earlier, in shallow lakes (less than about 10 to 12 feet deep) wind forces are usually strong enough to mix the water from top to bottom and thereby thwart summer stratification. Lakes with a lot of water flowing through them (i.e., a short water residence time) also do not develop persistent thermal stratification. While a temperature gradient from warmer surface to cooler bottom waters may exist in such lakes, a true metalimnion is not typically formed.

Summer stratification continues until fall when surface waters begin to cool and sink. The metalimnion begins to "erode" and weaken, and continues to do so as the lake cools. Wind energy helps mix the lake deeper and deeper. When the whole lake reaches a similar temperature, wind forces are again able to mix the lake from top to bottom in a process called ***fall turnover***. The transition from summer stratification to fall turnover can occur within just a few hours, especially if accompanied by strong winds.

Effects of Stratification

Stratification has important implications for fisheries management, phytoplankton (algae) populations, and water supply quality. A discussion of a few stratification impacts follows.

Dissolved Oxygen

Just after summer stratification is established, the hypolimnion is rich in dissolved oxygen from the early spring mixing of the lake. However, because the metalimnion acts as a barrier between the epilimnion and hypolimnion, the hypolimnion is essentially cut off from oxygen exchange with the atmosphere and is often too dark for plants and algae to grow and produce oxygen by photosynthesis. In a eutrophic (nutrient-rich) lake, the hypolimnion can become ***anoxic*** (without oxygen, or anaerobic) as the summer progresses. This occurs as its supply of oxygen is consumed by bacteria and other bottom-dwelling organisms. A lack of dissolved oxygen can have serious consequences.

Phosphorus and Nitrogen: In anoxic conditions, the nutrients phosphorus and ammonia-nitrogen become more soluble (dissolvable) and are released from the bottom sediments into the hypolimnion. During the summer, stratified lakes can sometimes

partially mix (such as with the passing of a cold front accompanied by strong winds and cold rains), allowing some of these nutrients to "escape" into the epilimnion and potentially stimulate an algal bloom. For similar reasons, algal blooms often are seen at fall turnover as nutrient-rich bottom water is brought to the lake surface where there is ample sunlight to support algae growth. Ammonia-nitrogen also can have an impact on fish. Fish are sensitive to ammonia and are repelled by high levels in the water.

Metals and Other Compounds: Some metals and other elements—notably iron, manganese, and sulfur (as hydrogen sulfide)—also become increasingly soluble and are released from anoxic bottom sediments. These compounds cause taste and odor problems—a potentially serious concern in drinking water supply reservoirs. Additionally, hydrogen sulfide concentrations above 1 mg/L are lethal to many gamefish as well as some zooplankton (microscopic animals that are an important fish food).

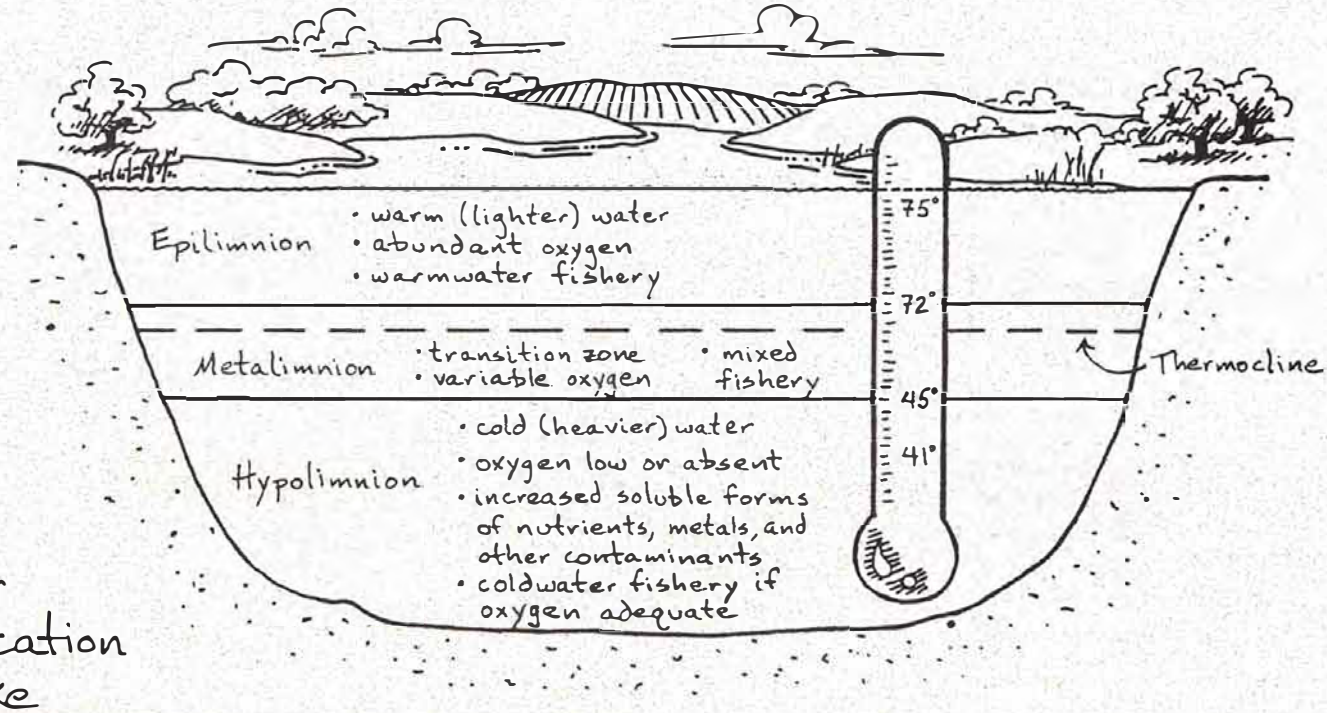
Fish: Low oxygen levels may restrict where fish can go in a lake and limit the types and numbers of fish in the hypolimnion. Warmwater fish (e.g., bass and bluegill) need at least 5 mg/L of dissolved oxygen to survive, while coldwater fish (e.g., trout) require 6-7 mg/L. In eutrophic lakes, as summer progresses and dissolved oxygen levels become too low in the hypolimnion, fish are confined to the epilimnion and a portion of the metalimnion.

As ice covers a lake in early winter, there usually is adequate oxygen in the water to sustain fish and other aquatic organisms. You may be surprised to learn that certain algae and rooted aquatic plants grow right through the winter and photosynthesize, producing oxygen. However, bacterial decomposition of organic matter on the lake bottom can consume more oxygen than photosynthesis can replace, causing a decline in dissolved oxygen levels as the winter season progresses. If enough snow covers the ice or if the ice is opaque, sunlight may be inadequate or unable to penetrate and photosynthesis will stop. If the lake's supply of oxygen falls too low before ice-out, a partial or total fishkill can occur.

Temperature

In summer-stratified lakes, water temperatures decrease from the surface to the bottom. As discussed above, a warm surface layer (the epilimnion) "floats" on a colder layer (the hypolimnion).

Different fish species prefer different water temperatures. Hence, a lake's temperature variations are important in influencing what types and how many fish will live and reproduce in that lake. If the colder, deeper waters of the hypolimnion have enough oxygen, then that area will provide a refuge for fish species that prefer, or require, cold water temperatures. However, if dissolved oxygen levels become too low in the hypolimnion and fish are forced into the warmer surface waters, coldwater fish species may not be able to survive.



Summer stratification in a lake

The Unique Properties of Water

Water is a unique substance. To understand how lakes behave, it is useful to understand water's physical and chemical properties. The molecular structure of water and the way in which water molecules associate with each other dictate these properties:

1. Water is an excellent solvent; many gases, minerals, and organic compounds dissolve readily in it.

2. Water is a liquid at natural environmental temperatures and pressures. Although this property seems rather common and obvious, it is quite important. If water behaved at ordinary temperatures and pressures like other inorganic compounds that are chemically similar to it, water would only be present as a vapor—and lakes would not exist.

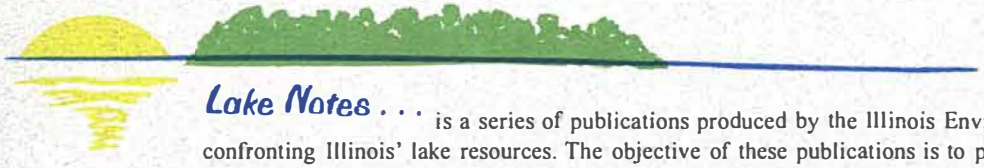
3. The temperature/density relationship of water is also unique. Most liquids become more dense (heavier) as they cool. Water also rapidly becomes more dense as its temperature drops, but only to a certain point. Water reaches its maximum density at 39.2°F (3.94°C), then it decreases slightly in density until it reaches 32°F (0°C), the freezing point. At this point, ice forms and its density decreases sharply. Ice, therefore, is much lighter than liquid water and thus forms at the surface of lakes rather than at the lake bottom.

   A second important consequence of the temperature/density relationship of water is the thermal stratification of lakes. Energy is required to mix fluids of differing densities, and the amount of energy necessary is related to the difference in density. In the case of lakes, this energy is provided primarily by wind. Therefore, the changes in water density that accompany rapidly decreasing water temperatures in the metalimnion during summer stratification are of great importance. The metalimnetic density gradient provides a strong and effective barrier to lake mixing.

4. Water also has an unusually high "specific heat." Specific heat is the amount of energy required to change the temperature of 1 gram of water by 1°C. Water also has a high "latent heat of fusion," which is the energy required to melt 1 gram of ice at 0°C. These properties make lakes slow to thaw and warm in the spring and slow to cool and freeze in the fall, thus providing exceptionally stable thermal environments for aquatic organisms.

   Because water gains and loses heat slowly, the presence of large lakes can exert a significant influence on local and regional climate. A good example is the Great Lakes, which have a dramatic effect on both air temperature and precipitation in the states and provinces surrounding them.

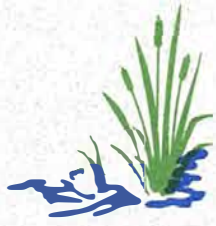
- adapted from *The Lake and Reservoir Restoration Guidance Manual*, 1990



Lake Notes . . . is a series of publications produced by the Illinois Environmental Protection Agency about issues confronting Illinois' lake resources. The objective of these publications is to provide lake and watershed residents with a greater understanding of environmental cause-and-effect relationships, and actions we all can take to protect our lakes.

This *Lake Notes* publication was prepared by Holly Hudson and Bob Kirschner of the Northeastern Illinois Planning Commission, Chicago, Illinois. Illustrations by Holly Hudson and Linda Wallis.

For more information about other publications in this series and to request copies, please contact: Illinois Environmental Protection Agency, DWPC-Lake and Watershed Unit, P.O. Box 19276, Springfield, Illinois, 62794-9276; 217/782-3362.



USGS
science for a changing world

Saline Water and Salinity

COMPLETED

By Water Science School

June 11, 2018

Saline Water and Salinity

Overview Science

In your everyday life you are not involved much with saline water. You are concerned with freshwater to serve your life's every need. But, most of Earth's water, and almost all of the water that people can access, is saline, or salty water. Just look at the oceans and remember that oceans comprise about 97% of all water on, in, and above the Earth.

• Water Science School HOME • Surface Water topics • Water Properties topics • Water Quality topics •

What is saline water?

First, what do we mean by "saline water?" Water that is saline contains significant amounts (referred to as "concentrations") of dissolved salts, the most common being the salt we all know so well—sodium chloride (NaCl). In this case, the concentration is the amount (by weight) of salt in water, as expressed in "parts per million" (ppm). If water has a concentration of 10,000 ppm of dissolved salts, then one percent (10,000 divided by 1,000,000) of the weight of the water comes from dissolved salts.

Here are our parameters for saline water:

- Fresh water - Less than 1,000 ppm
- Slightly saline water - From 1,000 ppm to 3,000 ppm
- Moderately saline water - From 3,000 ppm to 10,000 ppm
- Highly saline water - From 10,000 ppm to 35,000 ppm
- By the way, ocean water contains about 35,000 ppm of salt.

Saline water is not just in the oceans

Naturally, when you think of saline water you think of the **oceans**. But, hundreds of miles from the Pacific Ocean, the residents of states such as Colorado and Arizona can "enjoy a day at the beach" by just walking outside their house, for they may be right next to saline water. There is an extensive amount of very salty water in the ground in the western United States. In New Mexico, approximately 75 percent of **groundwater** is too saline for most uses without treatment (Reynolds, 1962). Water in this area may have been leftover from ancient times when saline seas occupied the western U.S., and, also, as rainfall **infiltrates** downward into the ground, it can encounter rocks that contain highly soluble minerals, which turn the water saline. **Groundwater** can exist and move for thousands of years and can thus become as saline as ocean water.

Mono Lake in California is the saline remnant of a much larger lake (Lake Russel) that filled the Mono basin millions of years ago. The ancient fresh-water lake was once about 130 meters higher than the current water level. Mono Lake is now a highly-saline remnant of Lake Russel, having much of its fresh water drained off to serve the water needs of the city of Los Angeles. Water levels are currently falling about 1 meter per year. This has resulted in salty deposits left onshore as the water recedes.

Sources/Usage: Some content may have restrictions. View Media Details

Why is the ocean salty? Rivers discharge mineral-rich water to the oceans is from outflow from rivers, which drain the landscape, thus causing the oceans to be salty.(July-September 1973) --- A vertical view of the Montevideo, Uruguay area of South America is seen in this Skylab 3 Earth Resources Experiments Package S190-B (five-inch Earth terrain camera) photograph taken from the Skylab space station in Earth orbit. The large body of water is Rio de la Plata which flows into the South Atlantic Ocean at the bottom of the picture. The red plum in the Rio de la Plata is probably sediment moving seaward. The Santa Lucia River enters the Rio de la Plata west of Montevideo and is the major drainage for the region. Note the small Isla del Tigre at the mouth of the Santa Lucia. The white beach and sand dune areas are plainly visible along the coast. A major airport can be seen immediately east of downtown Montevideo. Major thoroughfares and residential areas, such as the bright one in the suburbs, are clearly visible, also. Farm tracts in green and grey rectangular patterns indicate agricultural regions.

Credit: NASA

Can saline water be used for anything?

So, with all of the water available on Earth and all that saline water sitting offshore of our coasts, how come we are worried about water shortages? You can think of it as a water-quality situation rather than water-quantity situation. In its raw state, saline water cannot be used for many of the purposes we need water for, such as drinking, irrigation, and many industrial uses. Slightly saline water is sometimes used for similar purposes as freshwater. For example, in Colorado, water having up to 2,500 ppm of salt is used for irrigating crops. Normally, though, moderate to high saline water has limited uses. After all, you don't drink salt water at home; you don't use it to water your tomatoes or brush your teeth; farmers don't usually irrigate with it; some industries can't use it without damaging their equipment; and, farmer Joe's cows won't drink it.

If nothing else, saline water can be just plain fun. If you happen to be one who has been to the Dead Sea in the Middle East, you could have experienced the unique sensation of floating in the extremely dense (and salty) water that apparently holds you up like a mattress. The water is so dense that you truly do not sink, as you do in normal, even ocean, water. Closer to home, many homeowners who have backyard pools fill them with saline water, rather than have to use freshwater and added chlorine.

So, what else can saline water be used for, and can it be made more usable?

There are two answers—both "yes." Saline water is useful for some **water-use** purposes, and saline water can be turned into freshwater, for which we have many uses.

Saline water use in the United States in 2015

In today's world we are all more aware of the need to conserve **freshwater**. With the ever-growing demand for water by growing populations worldwide, it makes sense to try to find more uses for the abundant saline water supplies that exist, mainly in the **oceans**. As these pie charts of the Nation's water use show, about 16 percent of all water used in the United States in 2015 was saline. The second chart shows that almost all saline withdrawals, over 97 percent, was used by the **thermoelectric-power** industry to cool electricity-generating equipment. About three percent of the Nation's saline water was used for **mining** and **industrial** purposes.

NCF-Envirothon 2026 Mississippi

Aquatic Ecology Study Resources

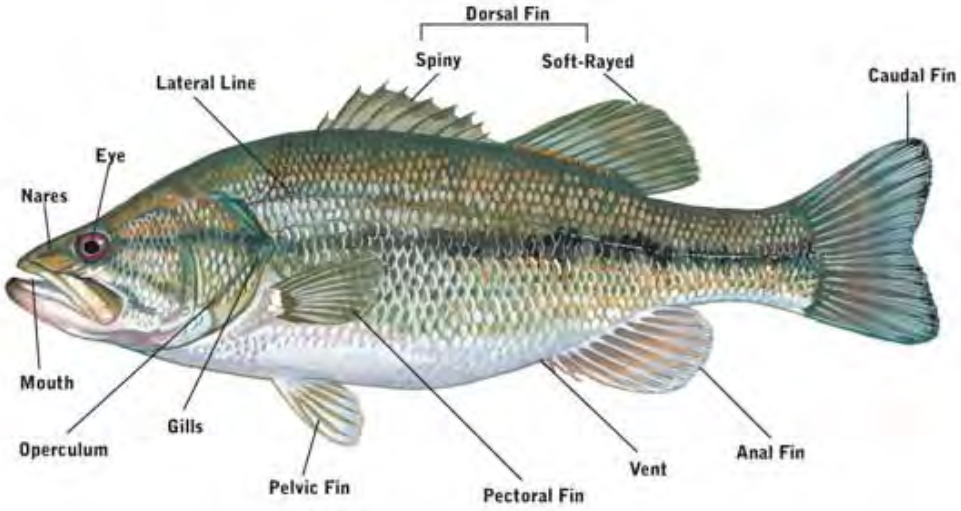
Key Topic #3: Organisms

13. Categorize different types of aquatic plants based on their adaptations.
14. Identify common aquatic animal species including fish, reptiles, amphibians, and mammals and recognize their major characteristics.
15. Identify common aquatic macroinvertebrates and their pollution tolerances.
16. Describe the unique life cycles of aquatic creatures, including adaptations such as anadromy, catadromy, metamorphosis, etc.
17. Analyze the ecological niches of aquatic organisms.

Resource Title	Source	Located on Page
External Anatomy of a Fish	*SCDNR - Fishing information. (n.d.). https://www.dnr.sc.gov/fish/anatomy.html*	53
Fish Identification and Info (MS WFP)	*Fish ID Guide. (n.d.). MS Wildlife, Fisheries, and Parks. https://www.mdwfp.com/sites/default/files/2025-11/Fish%20ID%20Guide%20November%202025.pdf*	55
Catadromous—Diadromous and Anadromous Fishes	*Catadromous—Diadromous and anadromous fishes | Encyclopedia.com. (n.d.). https://www.encyclopedia.com/science/news-wires-white-papers-and-books/catadromous-diadromous-and-anadromous-fishes*	62
MACROINVERTEBRATE IDENTIFICATION	*Macroinvertabrate identification poster. (n.d.). In Adopt-A-Stream Mississippi. Adopt-A-Stream Mississippi.*	65
Key to Macroinvertebrate Life in the River	*University of Wisconsin–Extension, Wisconsin Department of Natural Resources, & Riveredge Nature Center. (n.d.). Key to macroinvertebrate life in the river.*	66
Macroinvertebrates Factsheet	*U.S. Environmental Protection Agency. (n.d.). Macroinvertebrates. FACTSHEET ON WATER QUALITY PARAMETERS.*	67
Life Cycles and Natural History of Aquatic Insects	*Calvert, P. & Stream Team Academy. (n.d.). Stream Team Academy Fact Sheet #13. Stream Team Academy Fact Sheet Series. https://irp.cdn-website.com/2c37d579/files/uploaded/factsheet13p1.pdf*	70
Plant Identification	*Texas A&M AgriLife Extension. (2020, December 14). Plant identification | pond algae, grass, weeds, moss, and more. Texas a&M AgriLife Extension. https://aquaplant.tamu.edu/plant-identification/*	72
Southeastern Aquatic Plants: Alligator Weed, American Lotus, Salvnia, Water Hyacinth, and White Water Lily	*Neal, J.W., G. Turnage, & D. Riecke. 2023. Southeastern aquatic plants: Identification, control, and management. Publication 3735. Mississippi State University Extension Service.*	74

Fish - Anatomy

Fish are vertebrates, meaning they have a backbone. All fish have fins and most have scales (with a few exceptions, like catfish which do not). Fish are cold blooded animals that lay eggs and are well suited for living in water. Learn about the different fish adaptations below that allow a fish to survive in water.



External Anatomy

Eyes: Used for sight, fish can detect colors and see short distance with their eyes. They use their vision to escape predators and find food.

Nares: Similar to nostrils, except nares are used for smelling only (nostrils are used for both smelling and breathing).

Mouth: The mouth is used to consume food.

Operculum: The operculum is the bony flap that protects the gills from harm. It opens and closes to allow water to pass over the gills.

Pectoral Fin: The pectoral fin allows for abrupt changes in side-to-side direction and speed. It also acts as a brake to decrease speed while swimming.

Pelvic Fin: The pelvic fin stabilizes the fish while swimming and allows for up-and-down movement in the water.

Vent: The vent removes waste and extra water. It is also the outlet for eggs or milt (sperm) during spawning.

Anal Fin: The anal fin stabilizes the fish while swimming.

Caudal Fin: The caudal fin moves, propels or pushes the fish through the water.

Adipose Fin: The adipose fin is not pictured; it is not present on a lot of fish species. Its purpose is unknown. Trout, salmon and catfish have an adipose fin. It is the small, thick, fleshy fin located between the dorsal and caudal fins.

Dorsal Fin: The dorsal fin helps maintain balance while swimming.

Scales: Scales protect the fish from injury.

Barbels: Barbels are not pictured. They are the "whiskers" found on the head area of fish such as catfish or bullheads. On the catfish and bullheads, barbels are thought to be a sensory organ to help track down prey or food. Sturgeon also have barbels.

Internal Anatomy

Gills: Gills are the feathery tissue structure that allows fish to breathe in water. Water flows in through their mouth and over their gills where oxygen is extracted and passed into the bloodstream.

Swim Bladder: The swim bladder is a long, skinny organ that can inflate/deflate with air allowing fish to float at different levels in the water column.

Fish Senses

Eyesight: Fish can see in two directions (one eye focusing on an object independent of the other whereas human's eyes can only focus on one object at a time).

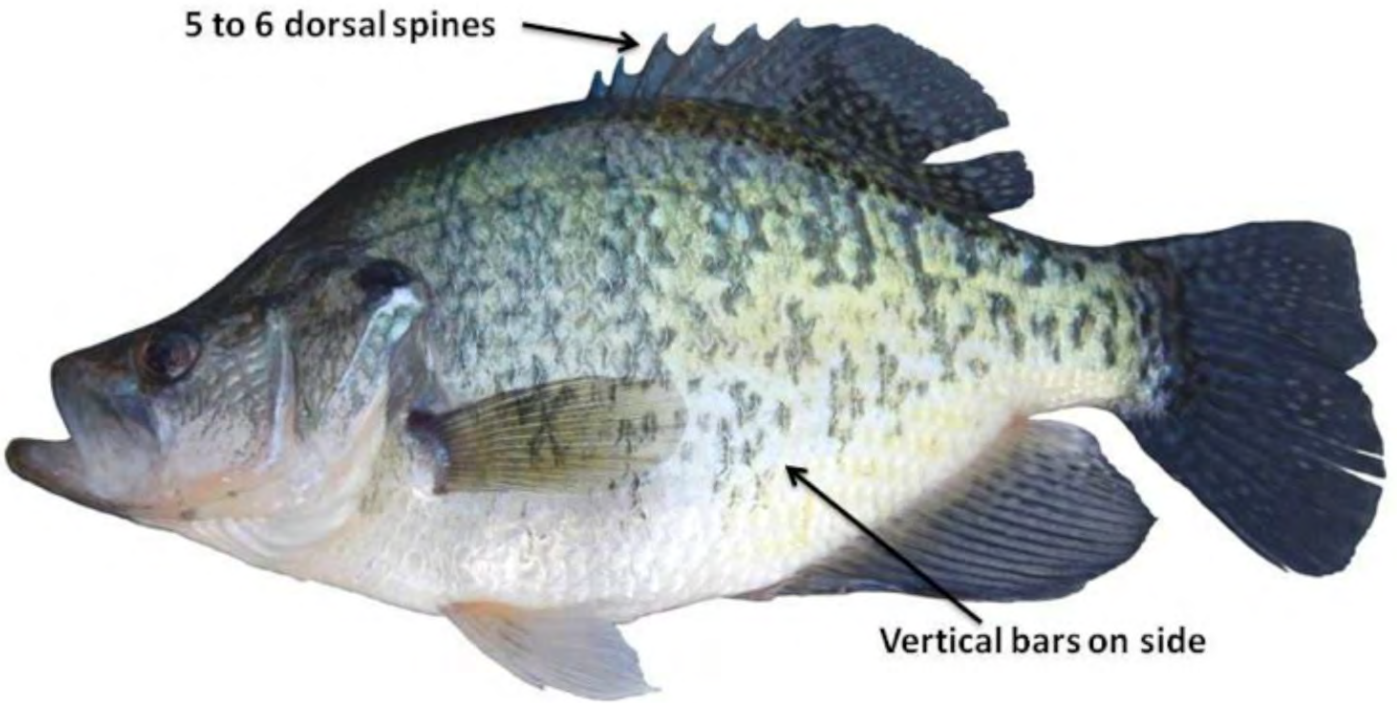
Hearing: Fish have ears but not external ear openings like humans do. Their ears lack a middle and outer ear because sound travels faster in water than in air. Fish have internal ears with pairs of inner ear bones called otoliths. The otoliths allow fish to sense sounds in the water. Fisheries biologists can also use these bones (otoliths) to age fish and determine the health of fish populations.

Smell: Fish use their sense of smell to locate food and to aid in migrating.

Taste: Some fish have taste buds, however, these taste buds are located on the outside of the fish's head and fins in small pores. Some fish like catfish have a very developed sense of taste.

Lateral Line: The lateral line, found alongside a fish's body from the operculum to the tail (caudal fin), senses vibrations or movements in the water. It allows fish to locate predators and find prey. This system is made up of a series of fluid-filled canals just below the skin of the fish's head and alongside the body. The canals are filled with tiny hair-like structures that detect changes in the water pressure via tiny pores connected to the system.

White Crappie *(Pomoxis annularis)*



Other Names
White perch, Sac-a-lait, Slab, and Papermouth.

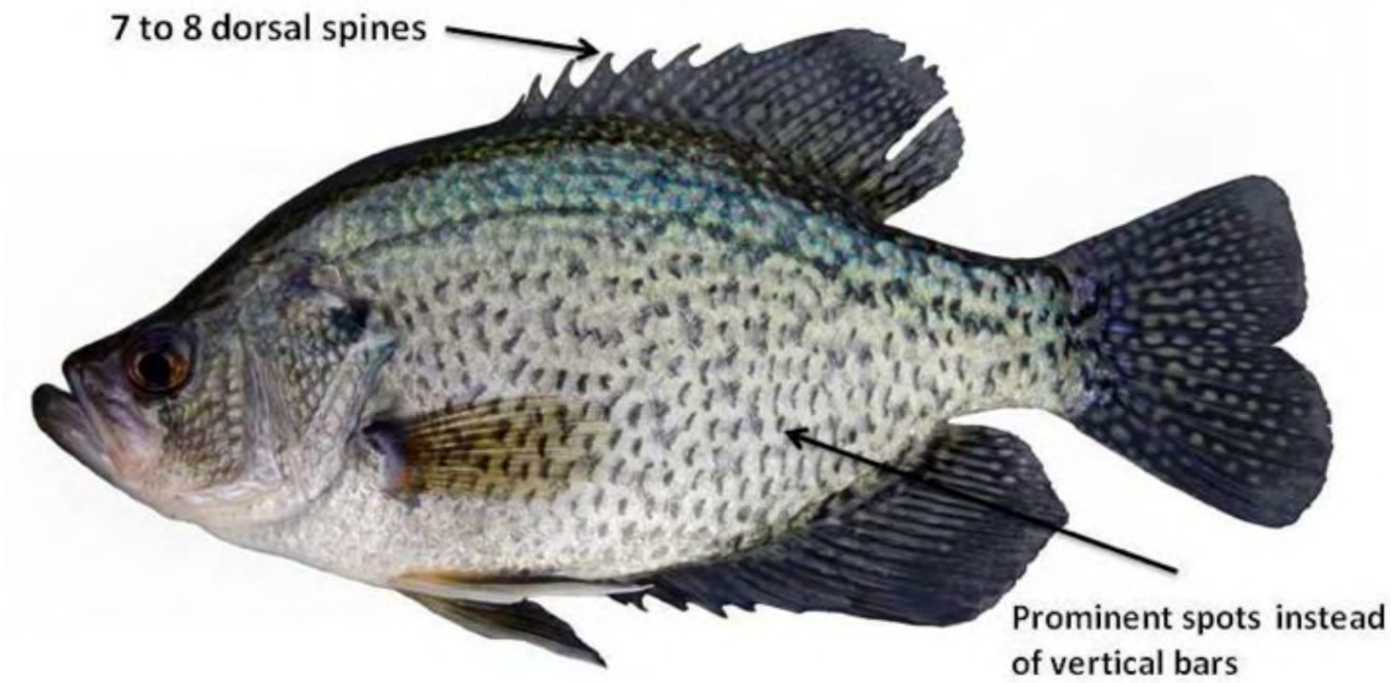
Description
White crappie are deep-bodied and silvery in color, ranging from silvery-white on the belly to a silvery-green or dark green on the back with possible blue reflections. There are several dark vertical bars on the sides. Males develop dark coloration on the throat and head during the spring spawning season, which can cause them to be mistaken for black crappie. White crappie have five or six spines on the dorsal fin, whereas black crappie have seven or eight spines. White crappie typically weigh 1 to 3 pounds, grow to 14 inches or more, and live up to 10 years.

Habits and Habitat
Adults feed on small fish and insects. Crappie prefer deep water near drop offs and areas of cover. White crappie can be found in many different types of habitats, including reservoirs, oxbow lakes, and rivers. Like other members of the sunfish family, white crappie are nest builders. They produce many eggs, which can cause overpopulation, slow growth, and small sizes in small lakes and ponds. White crappie spawn from March through May when water temperatures are between 58°F and 65°F. White crappie can tolerate muddier water than black crappie.

State Record
The current state and world record white crappie was caught by Fred Bright from Memphis, Tennessee in 1957 from Enid Lake; it weighed 5 pounds 3 ounces, and was 21 inches in length.

Fishing Fact
Popular baits for white crappie include jigs, small crank baits, and minnows. These fish are often found around structures, such as logs, brush piles, and cypress trees.

Black Crappie *(Pomoxis nigromaculatus)*



Other Names
White perch, Calico bass, Speck, Strawberry bass, Papermouth, Speckled perch and Slab.

Description
Black crappie are deeper bodied than the white crappie, and bluish green or gray in color on top with white or silver underneath. Irregular black spots are scattered on the body. A small percentage of black crappie in some lakes has a distinctive dark stripe running from the top (dorsal) fin to under the mouth. These "blackstripe" or "blacknose" crappie are a genetic color variation and are not a hybrid or subspecies. Black crappie have seven or eight spines on the dorsal fin, whereas white crappie have five to six spines. The black crappie is most easily confused with the white crappie, especially the white crappie males in breeding season (see White Crappie section). Black crappie weigh 1 to 3 pounds, grow to 12 inches or more, and can live up to 10 years.

Habits and Habitat
Black crappie are most active at night or in the early morning. Adults feed on insects, insect larvae, and fish, such as sunfish and minnows. Black crappie prefer shallow water lakes and sloughs and are more abundant where there is clear water and aquatic vegetation. They spawn in early spring when water temperatures are between 58°F and 65°F.

State Record
Mississippi's Rod and Reel record is 4 pounds 4 ounces, caught in 1991 at Arkabutla Lake by Gerald Conlee.

Fishing Fact
Baits used for white crappie are also used for black crappie.

Largemouth Bass *(Micropterus salmoides)*

Other Names

Green trout, Bigmouth bass, Bucketmouth bass, and Hog.

Description

There are two subspecies of largemouth in Mississippi waters. The northern largemouth bass, Micropterus salmoides salmoides, is native to Mississippi. The Florida largemouth bass, Micropterus salmoides floridanus, has been introduced into many Mississippi lakes. Largemouth bass are usually green with dark blotches that form a horizontal stripe along the middle of the fish on either side. The underside ranges in color from light green to almost white. Their upper jaw extends far beyond the rear margin of the eye. Largemouth bass can reach weights greater than 10 to 15 pounds, with females growing larger and faster than males. Largemouth bass can reach lengths greater than 26 inches. Largemouth females can live up to 10 to 12 years with males living between five and seven years.

Habits and Habitat

Adults feed almost exclusively on other fish, insects, and large invertebrates such as crayfish. Largemouth bass seek protective cover such as logs, vegetation, rocks, and even man-made structures. They prefer slow moving water but will survive in a variety of habitats including streams, rivers, lakes, and reservoirs. Spawning occurs in spring when water temperatures are from 60°F to 75°F. Males build the nests next to areas having brush piles, near underwater logs, or in areas under overhanging tree limbs. The male cares for the nest, protecting it from predators and keeping the eggs fanned until the eggs hatch. He also guards the young for a week or more after the hatch.

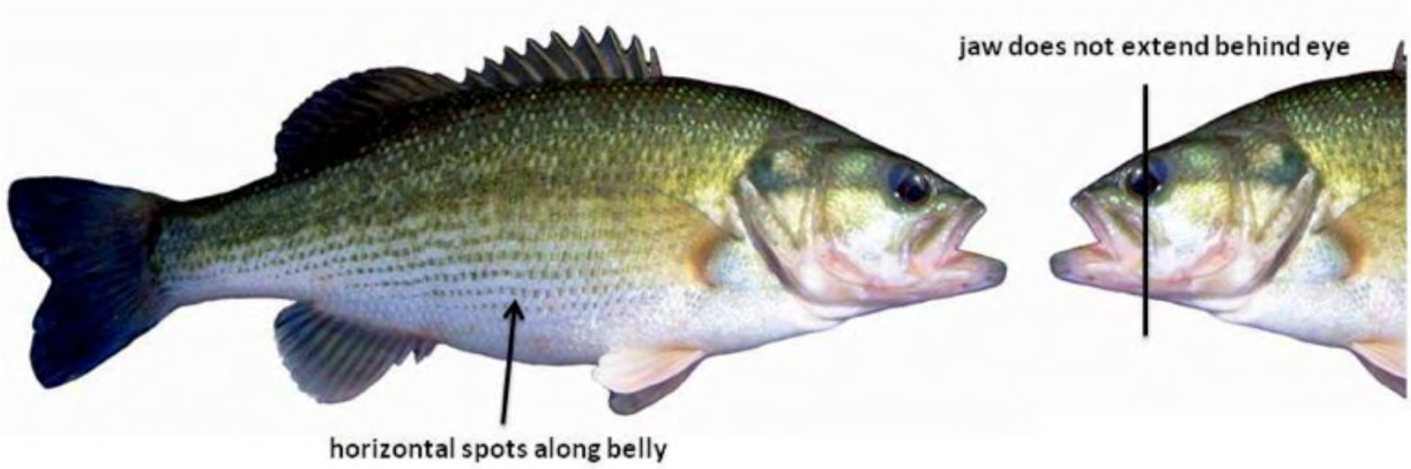
State Record

Mississippi's Rod and Reel record is 18.15 pounds, caught in 1992 in Natchez State Park Lake by Anthony Denny.

Fishing Fact

Spring through fall is a great time to fish for largemouth bass with best success usually occurring during the evenings or mornings using minnows, artificial baits, and even frogs. The largemouth bass is also Mississippi's state fish.

Spotted Bass *(Micropterus punctulatus)*



Other Names
Kentucky bass, Diamond bass, Creek bass, Red-eye bass, and Spot

Description
Spotted bass are slender with rows of dark spots on the lower sides. These spots form horizontal streaks. Spotted bass also have a stripe along the middle of each side that form diamond-shaped blotches. The back of these fish is a dark mottling against an olive green color. The top and sides of these fish are dark, but the underside of the body is white. Spotted bass can reach lengths of 24 inches but are usually smaller with maximum size less than either largemouth or smallmouth bass. These fish usually live no more than six years. Females tend to live longer and grow faster than males.

Habits and Habitat
The diet of spotted bass changes as the fish grow, changing from plankton, small aquatic insects, and small crustaceans to larger aquatic and terrestrial insects, crayfish, and small fish. Spotted bass live in streams and rivers, preferring faster waters than largemouth bass. They have adapted very well to reservoirs, and are often found around rocks or rip-rap. These fish spawn in mid-April through June. Spawning occurs in water temperatures of about 63°F to 78°F. Female and male spotted bass are mature at the age of two years. Spotted bass like other bass are nest spawners. The males build nests and guard the nests until the eggs hatch.

State Record
Mississippi's Rod and Reel record is 8 pounds 2 ounces, caught in a farm pond in 1975 by S. R. Grantham.

Fishing Fact
Spinner baits, jigs, crank baits, plastic worms, and live worms are popular for landing a spotted bass.

Bluegill *(Lepomis macrochirus)*

Other Names
Bream (Brim), Coppernose, Copperhead, Bull bream, Blue sunfish, and Blue joe.

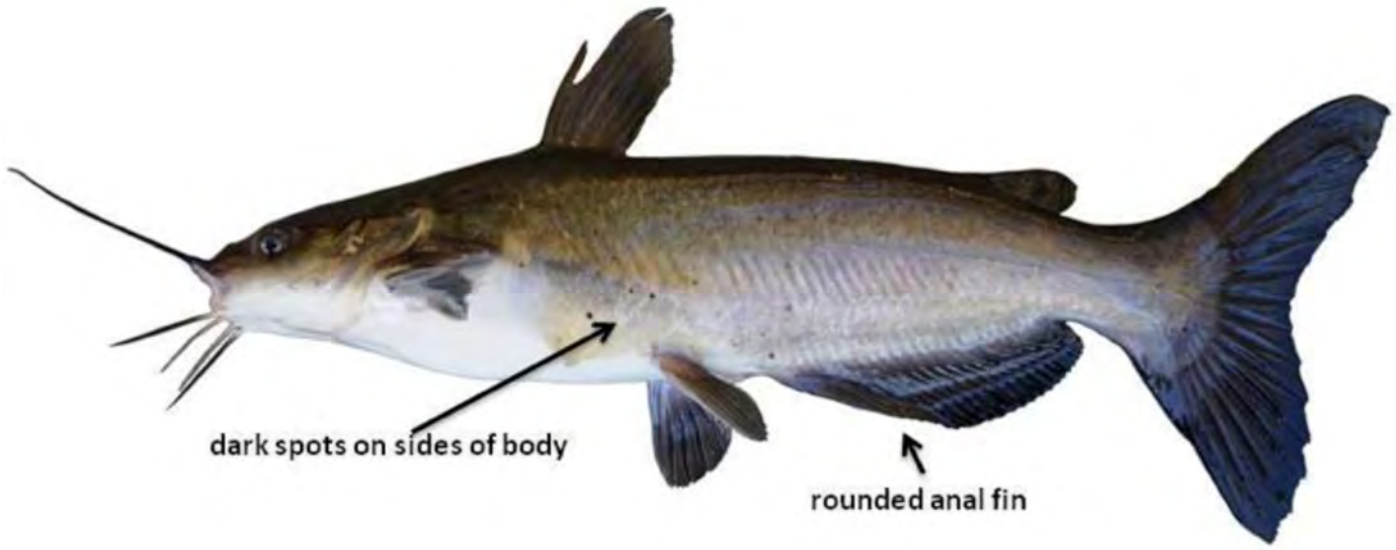
Description
Bluegill are deep bodied. They are dark olive green with a distinctive black spot on the dorsal fin and intense colors on breeding males. The sides are a blue or silver color with vertical bars and the belly is yellow, silver, or white. The coppernose bluegill is a Florida subspecies whose fins have whitish margins and whose head displays a copper patch. These bluegill are stocked in smaller impoundments in the southern and central portions of the state. Bluegill usually weigh between 1/2 to 1 pound but some catches have been over 3 pounds. Bluegill can live up to seven years.

Habits and Habitat
These fish prefer vegetated waters of shallow lakes and ponds, feeding on insect larvae. Spawning begins when water temperatures reach around 65°F and these fish often spawn multiple times during the summer. Bluegill are community spawners with nests located close together. Nests are not located in heavily vegetated areas. Males will compete for a site, sweeping away sand and exposing coarse gravel.

State Record
Mississippi's Rod and Reel record is 3.45 pounds, caught by Gerald E. Thurmond in a farm pond in 1995.

Fishing Fact
Even small bluegill can put up a scrappy fight. Crickets, earthworms, and small artificials (spinners and flies) are excellent baits for bluegill.

Channel Catfish *(Ictalurus punctatus)*



Other Names
Fiddler, Willow cat, Speckled cat, Spotted cat, Government cat, and River cat.

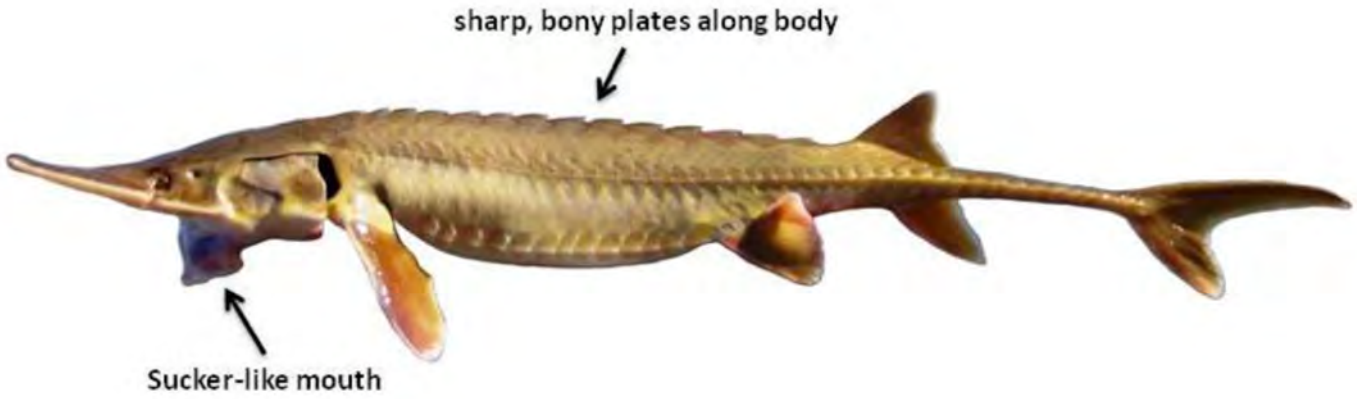
Description
Channel catfish have elongated bodies with a whitish belly and olive or brown body. They have a deeply forked tail, barbels, and black spots on the sides and tail. Channel catfish can be distinguished from blue catfish by their rounded anal fin (versus straight in blue catfish) and the presences of dark spots on the body. These spots are often not present in large fish. Channel catfish typically weigh between 5 and 10 pounds but can reach weights of over 50 pounds. These fish can reach lengths of up to 50 inches. Channel catfish normally live at least 6 to 10 years but can live longer.

Habits and Habitat
Channel catfish feed on insect larvae, crustaceans, crayfish, and small fish such as gizzard shad and minnows. These fish are active at night in streams, rivers, oxbow lakes, and ponds. Channel catfish spawn in late spring to early summer when water temperatures are between 60°F and 75°F. Channel catfish are raised commercially in the Delta and other areas in the state. Channel catfish are often stocked in small lakes and ponds. If too many are stocked in bass-bream ponds, the result is poor growth of all fish and muddy water from the feeding action of overabundant catfish.

State Record
Mississippi's Rod and Reel record is 51 pounds 12 ounces, caught by Tom Edwards at Lake Tom Bailey in 1997.

Fishing Fact
These fish can be caught in a variety of ways including hand grabbing, jugs, limblines, rod and reels, and trotlines. Best baits to use are liver, stink baits, cut fishes, and worms; they are rarely caught on artificials.

Shovelnose Sturgeon *(Scaphirhynchus platorynchus)*



Other Names
Hackleback sturgeon.

Description
Shovelnose sturgeon are primitive, odd-looking fish. They have several rows of sharp, bony plates along their elongated body, a strongly forked tail, spade-shaped snout, sucker-like mouth, and four barbels. Shovelnose sturgeon are normally brown or olive colored with a cream-colored belly. Average lengths of adults range from 22 to 26 inches in length. These fish are long-lived, reach sexual maturity at age 5 to 10 years, and do not spawn every year.

Habits and Habitat
Shovelnose sturgeon inhabit the Mississippi River and are normally found in deep water with moderately strong current. These fish feed on the bottom and primarily eat aquatic insects. Spawning normally occurs in the spring when water temperatures reach 63°F to 70°F over gravel or sand substrate.

State Record
No record is possible because harvest of shovelnose sturgeon is illegal.

Fishing Fact
Shovelnose sturgeon are sometimes caught by anglers running trotlines for catfish on the Mississippi River. Though shovelnose sturgeon are abundant in the Mississippi River, and they have historically been harvested for their roe for caviar, they are currently listed by the U.S. Fish and Wildlife Service as threatened due to their similarity of appearance with the endangered pallid sturgeon. Harvest of all sturgeon species is prohibited.

Catadromous—Diadromous and Anadromous Fishes

Diadromous fishes describe species that spend part of their lives in freshwater and part in saltwater. There are two categories of diadromous fishes, **catadromous** and **anadromous**.

Catadromous fishes hatch or are born in marine habitats, but migrate to freshwater areas where they spend the majority of their lives growing and maturing. As adults they return to the sea to spawn. The word "catadromous" means "downward-running," and refers to the seaward migration of adults. The best-known group of catadromous fishes are the true eels. In these species, females spend their lives largely in freshwater, while males live primarily in the brackish water of estuarine areas. Individuals breed in the seas and die after spawning once.

Anadromous fishes are the opposite of catadromous fishes in that hatching and a juvenile period occur in freshwater. This is followed by migration to and maturation in the ocean. Adult fish then migrate back up rivers - "anadromous" means "upward-running" - in order to reproduce in freshwater habitats. The length of the initial freshwater period and of the oceanic period vary greatly by species. Similarly, the length of the migration can vary tremendously. Some species travel hundreds of kilometers between their marine habitat and their breeding grounds, while others migrate only a short distance upstream from brackish water to reach freshwater spawning grounds.

There are approximately 100 known species of anadromous fishes. Several of these are well-known and of great commercial value, including many species of salmon along with striped bass, steelhead trout, sturgeon, smelt, shad, and herring. Salmon in particular have long been admired for their lengthy, arduous migrations up rivers to their original spawning grounds, as well as for the unusual homing ability that allows them to accomplish this. Their ability to navigate back to appropriate breeding areas is particularly impressive since migration often follows a lengthy period at sea, often as long as four or five years. Chemical cues are believed to guide them in this journey.

In some anadromous species, the majority of individuals die immediately after spawning, with only a few returning downstream and surviving to spawn again. In other species, multiple migrations and spawning bouts are common.

The Rigors of Making Freshwater-Saltwater Transitions

Diadromous fishes are of particular interest to physiologists because of the great challenges posed by freshwater-saltwater transitions. In particular, freshwater and saltwater environments make strikingly different demands on water-balance systems, so these fishes must make the necessary **physiological** adjustments whenever they pass from one type of **aquatic** habitat to the other. Every diadromous species migrates at least twice, once from freshwater to saltwater,

and once in the other direction. Because of their ability to tolerate a variety of salinity regimes, diadromous species are also described as **euryhaline**, meaning "broadly salty."

Freshwater fish are in an environment in which they are hyperosmotic. That is, the concentration of salts and ions in their bodies is greater than that in the external aquatic environment. As a result, they have a tendency to lose important ions through **diffusion** across the skin and **gills**, and simultaneously to gain water from the environment. To maintain **homeostasis**, freshwater species have special adaptations for retaining ions and getting rid of excess water. First, they actively take in ions across their gills and skin, a process that requires energy. Second, to get rid of excess water they excrete nitrogenous waste products in great quantities, in the form of a highly diluted urine.

In marine environments the challenges are the opposite. Saltwater species must deal with an environment in which their salt and ionic concentrations are significantly lower than that of the surrounding aquatic environment. Saltwater species tend to lose water to the ocean and to gain ions from it. To obtain and conserve water, saltwater species increase their drinking rate, and excrete smaller amounts of a highly concentrated urine. In addition, they eliminate excess ions through specialized salt-excretion cells in the gills and in the lining of the mouth.

Euryhaline species must adopt the tactics of freshwater species while in freshwater environments, and those of marine species in saltwater environments. Frequently, physiological adjustments are made while organisms are in the intermediate, brackish waters of estuaries. These include changing their drinking rate, the degree of concentration of their urine, and the direction of ion-pumping in the gills and **integument**.

In addition to these physiological changes, associated with osmoregulation, other changes are made by diadromous species during transitions between freshwater and saltwater habitats. In some diadromous species, external features such as coloration change. For example, in some salmon species, individuals lose their typical red coloration before migrating to sea, where they take on a more silver-colored form. They regain their freshwater coloration when they reenter the freshwater environment.

Considering both the rigors of the long migratory journey and the serious physiological challenges faced by diadromous species, it makes sense to ask why these species have evolved a complex life cycle that requires multiple transitions between salt and freshwater environments. The likely answer is that species are able to take advantage of the benefits offered by each habitat, and that these benefits overshadow the burdens of the repeated migrations. For anadromous species such as salmon, for example, there appears to be a significantly greater safety for eggs in freshwater habitats yet the possibility for much faster growth in the ocean, where the food supply is more plentiful. The increase in growth rate that salmon exhibit once they have migrated to the ocean is dramatic.

The Benefits of Transitions

The rigors of the journey from saltwater to freshwater habitats, or vice versa, including the stresses related to physiological adjustment, is likely linked to the observation that many diadromous species are **semelparous**, that is, they reproduce in one large reproductive bout and then die. This is also known as "big-bang" reproduction. Semelparity is contrasted with the reproductive strategy of **iteroparous** species, which reproduce multiple times. Iteroparity characterizes numerous species, including humans.

Some formerly anadromous species have lost anadromy, having evolved to remain in freshwater habitats throughout the entire life cycle. For example, some species of salmon use lakes rather than oceans for the period of growth and maturation. However, they continue to migrate up rivers in order to find appropriate spawning grounds.

In other species, such as the steelhead trout, anadromy appears to be optional. Individuals that are spawned farther from the ocean have a tendency to remain in freshwater habitats during maturation, while those closer to river mouths have a tendency to retain the anadromous condition. This probably relates to differences in the costs of migration.

Perils to Diadromous Fishes

Diadromous fishes are particularly dependent on estuarine areas, the brackish areas linking freshwater rivers and saltwater environments. It is within the estuaries that diadromous species make the physiological adjustments necessary for transitioning between fresh and salt water. Unfortunately, many of these estuarine habitats are under threat. This is only one factor responsible for the dangerous declines in the **populations** of many anadromous species. Others include increasing river pollution that damages critical spawning habitats, the building of dams and other man-made barriers that make the upward migration difficult, and the overfishing of commercially important species. However, the release of young salmon into reclaimed rivers has met with some success, and in some areas special passages for migrating salmon allow individuals to get upstream to the spawning grounds.

Jennifer Yeh

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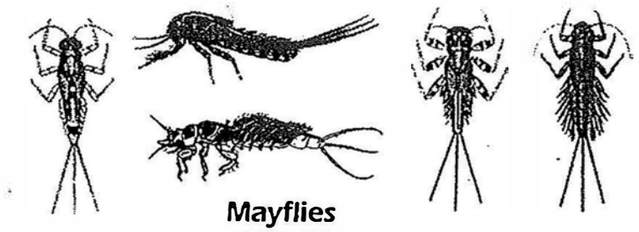
Internet Resources

Oregon Coast Aquarium.
<http://www.aquarium.org/education/spotlight/anadromy/anadromy.htm>.

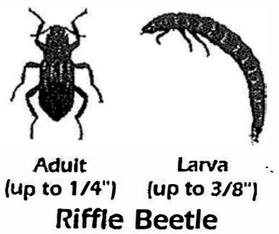
MACROINVERTEBRATE IDENTIFICATION

Mississippi Department of Environmental Quality and Mississippi Wildlife Federation

GOOD WATER QUALITY



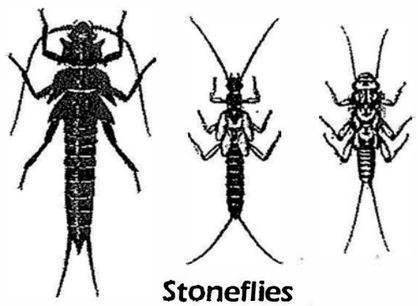
Mayflies
(1/4" - 1")



Adult
(up to 1/4")

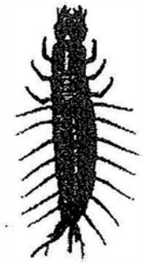
Larva
(up to 3/8")

Riffle Beetle



Stoneflies
(1/4" to 1 1/2")

Snail
(Right
Opening)



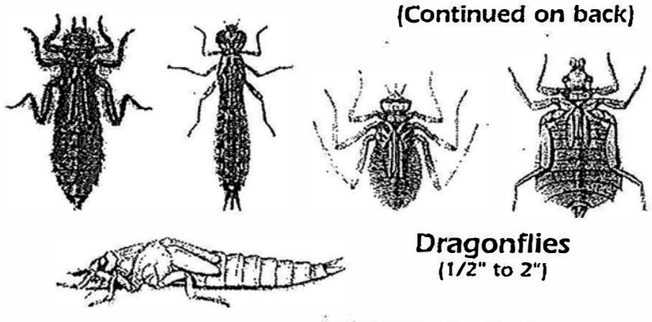
Hellgrammite
(3/4" to 4")

Water
Penny
(up to 1/4")

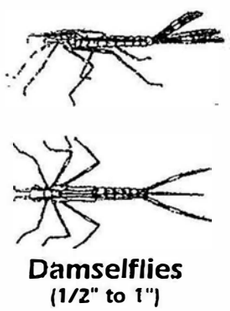
Caddisflies
(1/8" to 1 1/2")

FAIR WATER QUALITY

(Continued on back)



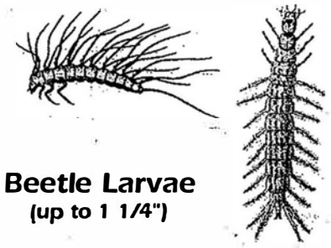
Dragonflies
(1/2" to 2")



Damselflies
(1/2" to 1")

FAIR WATER QUALITY

(Continued)

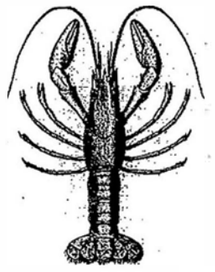


Beetle Larvae
(up to 1 1/4")

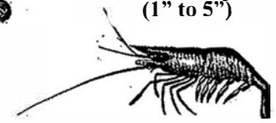
Scud
(1/4"to 3/4")

Clam

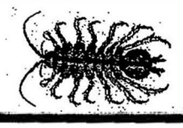
Cranefly
Larva
(1/2" to
3 1/2")



Crayfish
(1/2" to 6")



Freshwater
Shrimp
(1" to 5")

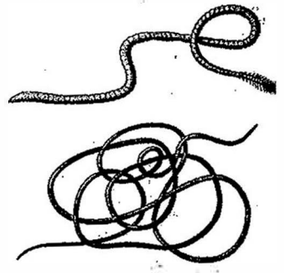


Sowbug
(1/4" to
3/4")

POOR WATER QUALITY

Blackfly Larva
(up to 1/4")

Midge Larvae
(up to 3/4")

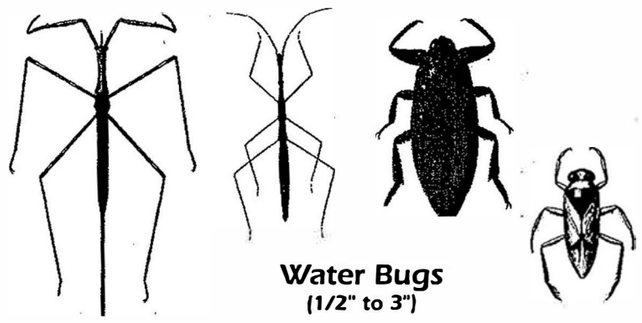


Aquatic Worms

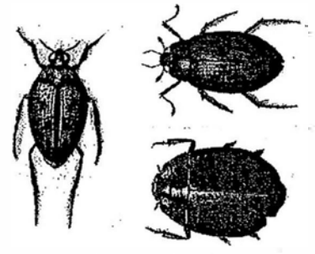
Snail
(Left
Opening)

Leech
(1/4" to
2 1/2")

COMMON MACROINVERTEBRATES WITH NO INDEX VALUE



Water Bugs
(1/2" to 3")



Water Beetles
(up to 1 1/4")

Adopt-A-Stream Mississippi

FOR MORE INFORMATION CONTACT: Mississippi Department of Environmental Quality, P.O. Box 2261, Jackson, MS 39201, (601) 961-5171 or Mississippi Wildlife Federation, 517 Cobblestone Court, Suite 2, Madison, MS 39110, (601)605-1790

Key to Macroinvertebrate Life in the River

(Sizes of illustrations are not proportional.)

Shells

Single Shell

spiral, opening on left

Pouch Snail

spiral, opening on right

Gilled Snail

coiled

Orb Snail

conical

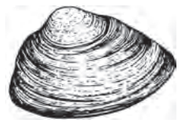
Limpet

Double Shell

small, whitish, tan or brown

Pill or Fingernail Clam

large, 2 to 8 inches, dark-colored



Freshwater Mussel

Legs

10+ Legs

lobster-like

Crayfish

shrimp-like, swims on side

Scud or Amphipod

walks on bottom

Aquatic Sowbug or Isopod

Four Pairs of Legs

tiny, often brightly colored

Water Mite

runs on top of water

Fishing Spider

Three Pairs of Legs

No Wings

No Obvious "Tails"

brown, leatherlike, six legs, usually "C"-shaped

Riffle Beetle Larva

six legs and prolegs on abdomen

Pyralid Caterpillar

suction cup-like

Water Penny

large body, hinged mouth

Dragonfly Larva

green, tan, orange or white body

Caddisfly Larva

lives in stone case

Caddisfly Larva

lives in stick house

Caddisfly Larva

One or Two "Tails"

dark head, green or tan body, two brush-like tails

Caddisfly Larva

small, "spines" on side

Alderfly Larva

large mouth parts, "spines" on side

Dobsonfly Larva

"tails" long and stiff, long antennas

Stonefly Larva

flat gills on abdomen

Mayfly Larva

hangs from surface, large mouth parts

Predaceous Diving Beetle Larva

Three "Tails"

long "tails," gills on abdomen

Mayfly Larva

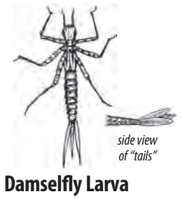
long "tails," gills on abdomen

Mayfly Larva

large legs, feathery gills

Mayfly Larva

plate-like "tails," no gills on abdomen



side view of "tails"

Damselfly Larva

With Wings

Beetle-Like, Wings Hard

small, crawls on bottom

Riffle Beetle

swims moving hind legs alternating

Water Scavenger Beetle

back legs move at same time

Predaceous Diving Beetle

swims on surface

Whirligig Beetle

"Crawls" through water, spotted

Crawling Water Beetle

Leathery Wings

tan, lives on surface

Marsh Treader

dark, lives on surface

Water Strider

grasping front legs, up to three inches

Giant Water Bug

swims on back, back white

Backswimmer

swims right-side-up, back black

Water Boatman

long breathing tube, grasping front legs

Water Scorpion 'Nepa'

long, stick-like

Water Scorpion 'Ranatra'

Worm-Like

Suckers, expands and contracts, body segmented

Leech

reddish brown, segmented body

Tubifex Worm

glides along bottom, body not segmented

Flatworm or Planaria

tan to brown, long

Horsehair Worm

body with bristles, no suckers

Bristle Worm

distinct head, red, green or tan, twists

Midge Larva

small, hair-like, swims in "S" shape

Nematode or Threadworm

Microscopic

apostrophe-shaped

Cyclops or Copepod

round

Seed and Clam Shrimp

swims with a jerk, using antennas

Water Flea or Daphnia

No Legs

With Tentacles, Brushes or "Tails"

long breathing tube

Rat tailed Maggot Larva

two fringed "tails"

Water Snipe Fly Larva

smooth, "stiff," small head

Horse Fly Larva

large, grey with tentacles

Crane Fly Larva

white or grey with tentacles

Crane Fly Larva

big "head," active

Midge Pupa

black, attaches to hard surfaces

Black Fly Larva

Developed by the University of Wisconsin–Extension in cooperation with the Wisconsin Department of Natural Resources. Based on a key developed by Riveredge Nature Center, Newburg, WI. May be reproduced with this credit for educational, non-profit purposes. For information, contact UWEX Environmental Resources Center, 608/262-2634. University of Wisconsin-Extension is an EEO/Affirmative Action employer and provides equal opportunities in employment and programming, including Title IX and ADA requirements.

Macroinvertebrates

Macroinvertebrates are small organisms without a backbone that are visible to the naked eye and large enough to be easily collected. Analyzing the macroinvertebrates in a waterbody can help recognize signs of ecosystem health.

Why do we measure macroinvertebrate communities?

Insects are the most common macroinvertebrates in aquatic systems, living in water as nymphs or larvae at least until they reach their adult stages. Common insects in aquatic systems include dragonflies, caddisflies, stoneflies, beetles, midges, and mayflies. Others, such as aquatic worms, leeches, and small crustaceans (crayfish and fairy shrimp), live entirely in water. Most species live in the bottom sediments of the waterbody or attached to rocks, vegetation, logs, and sticks. Lifespans range from a few weeks to several years. Macroinvertebrates are most frequently used for biological monitoring, or "biomonitoring," because of their prevalence in aquatic habitats and their differing sensitivities to chemical pollution and physical disturbances. Biomonitoring is the use of organisms to assess the overall quality of their environment or habitat. Because they generally have limited mobility and cannot escape pollution, macroinvertebrates better reflect the long-term water quality of a site compared to a single sample of chemical constituents that only provides a snapshot in time. Table 1 shows examples of generalized pollution sensitivity (tolerant or intolerant of pollution) for several common macroinvertebrates.

Table 1. Examples of macroinvertebrates and their pollution sensitivity levels.

Macroinvertebrate	Pollution Sensitivity
Stonefly	Intolerant
Mayfly	Intolerant
Crayfish	Moderately Tolerant
Leech	Tolerant
Aquatic worm	Tolerant

Source: Maine Department of Education (Nd)

Knowing the typical variety and abundance of macroinvertebrates in a healthy waterbody in a region can help indicate signs of poor ecosystem health. Generally, healthy waterbodies support a diverse population of macroinvertebrates. Samples yielding only pollution tolerant species, a low abundance of organisms, or very little diversity (primarily one or two species) might indicate a degraded waterbody. Figure 1 shows an example of a mayfly, a type of pollution sensitive macroinvertebrate.

Figure 1. The mayfly, a type of insect, under the view of a microscope. Credit: Photo courtesy of USGS

An assessment of macroinvertebrates helps to determine whether a stream's designated uses related to aquatic life are supported (protection and propagation of fish, shellfish, and wildlife). Unlike other parameters, macroinvertebrates offer a direct measurement of the condition of the biological community within a waterbody.

For factsheets on other water quality parameters, visit: epa.gov/awma/factsheets-water-quality-parameters.

For more information about the CWA Section 106 Grants Program, visit: epa.gov/water-pollution-control-section-106-grants.

What affects macroinvertebrate communities?

Several factors, including streamflow, geology, elevation, temperature, dissolved oxygen, seasonal life cycle patterns, substrate, and riparian habitat influence the abundance and diversity of macroinvertebrates in a waterbody. Human-induced changes to aquatic ecosystems can include increased pollution (from urban runoff and point source discharges) and land use changes that alter natural streamflow patterns, modify the channel structure, or contribute to nonpoint source loadings to the waterbody.

Below are some examples of the effects of human-induced changes on macroinvertebrate communities:

Increased turbidity and sedimentation in the waterbody from reduced riparian vegetation or other causes of erosion can eliminate food sources and habitat for macroinvertebrates.	Excess nutrients can promote algal blooms. The eventual death and decomposition of the excessive algae depletes dissolved oxygen, reducing macroinvertebrate survival.	Increased concentrations of metals, pesticides, or other toxic pollutants can shift the relative abundances of macroinvertebrates toward more pollution tolerant species.	Altered pH affects macroinvertebrate survival by weakening shells and exoskeletons (if pH is decreased) or reducing the survival of alkaline-intolerant species (if pH is increased).

What are EPA's recommended criteria for macroinvertebrates?

There are no published EPA recommended water quality criteria for macroinvertebrates. However, guidance materials are available to help develop biological criteria that define specific characteristics of healthy macroinvertebrate, fish, or algal communities. A useful example of an approach to setting targets is EPA's *A Practitioner's Guide to the Biological Condition Gradient: A Framework to Describe Incremental Change in Aquatic Ecosystems* (2016).

A multimetric index approach can be used to set targets for biological criteria. A macroinvertebrate multimetric index (MMI) is a numerical value calculated by combining individual measurements (metrics) of the macroinvertebrate community in a sample into an overall index score. This score is intended to reflect the overall condition of the macroinvertebrate community. There are often different indices and thresholds for different regions and waterbody types.

How do we measure macroinvertebrate communities?

Macroinvertebrate samples are collected in the field and identified in the laboratory (Figure 2 and Figure 3). An MMI used to characterize samples may include abundance, richness (number of species present), composition (proportions of species), number of pollution-sensitive species, or other measurements appropriate for the program's data analysis and assessment methods. There are many examples of the development and use of macroinvertebrate indices by states, tribes and other agencies including EPA's National Aquatic Resource Surveys. This work can be leveraged as ecoregional indices/MMIs to be used along with their protocols.

Sampling locations and times

Sampling locations can be selected using a targeted design or random design. For example, river or stream sampling sites may be located in riffles (shallow, turbulent sections of a river) or runs (smooth-flowing sections of a river) to represent the range of macroinvertebrate habitats. Samples are typically collected by moving upstream to prevent disturbance. Sampling times, seasons, and frequencies should be determined by the life cycles of the macroinvertebrate species as appropriate.

Figure 2. Using a net to collect macroinvertebrates. Credit: Photo courtesy of USEPA

Equipment and methods

Macroinvertebrate sampling requires little equipment, with methods depending on the waterbody being sampled. For example, nets (Figure 2) are typically used in streams. After sampling, samples are sorted and identification is done visually. A microscope can be connected to a screen to provide higher quality lighting and magnification (Figure 3). Unless the data are for educational purposes, it is strongly encouraged that the samples be reviewed by a trained taxonomist, which may be a staff member or an outside expert.

Other parameters measured at the same time

Macroinvertebrates are the most commonly measured organism group for biological assessments, followed by fish and periphyton (organisms such as algae that attach to objects in waterbodies). Measurements of basic water quality parameters (pH, temperature, turbidity, dissolved oxygen [DO], nutrients) taken during sampling will give a more complete picture of the overall status of the waterbody.

Figure 3. Using a microscope to identify macroinvertebrates. Credit: Photo courtesy of USGS

What are the challenges of using macroinvertebrates as a water quality parameter?

Some of the general challenges in macroinvertebrate sampling include ensuring consistency among staff when collecting samples, taking appropriate sample sizes, and conducting adequate research to understand and interpret results. Specific considerations include the following:

- Because some macroinvertebrates are small and fast-moving, adequate training is needed to collect them.
- Findings can vary based on the method used, sample size collected, and taxonomic level used. Thus, it may not be appropriate to average or otherwise combine data from multiple macroinvertebrate samples when assessing waterbody health.
- Because macroinvertebrates are affected by multiple pollutants, using them to identify or track a specific pollutant of concern is challenging. Also, macroinvertebrates do not respond to all types of pollutants. For more information, see EPA's *Stressor Identification Guidance Document* (2000).
- Because macroinvertebrates are affected by multiple natural factors such as temperature and streamflow, the absence or presence of certain macroinvertebrates does not necessarily indicate poor or healthy water quality. This information should be considered along with other indicators of long-term water quality characteristics.

EPA 841F21007E | July 2021

Life Cycles & Natural History of Aquatic Insects

Part 1 – Introduction

An Educational Series For Stream Teams To Learn and Collect

By Paul Calvert, Streams Services Program Supervisor

The world around us is full of natural and living wonders and, as you study them, new revelations occur almost daily. Many Stream Teams become fascinated with the invertebrates in our streams, wanting more and more information on how they live, interact with each other, and function within the world around them. This new series of fact sheets will provide you more information to help you better understand aquatic macroinvertebrates and make good sound decisions concerning your adopted stream. We will look at the general life cycle (including adult forms), habitat, feeding, and respiration of seven Insect Orders:

1. Ephemeroptera
2. Plecoptera
3. Trichoptera
4. Coleoptera
5. Odonata
6. Megaloptera
7. Diptera

Stoneflies (Order Plecoptera) experience incomplete metamorphosis with larval development taking three months to one year. Larvae utilize oxygen dissolved in the water for external respiration via membranes and/or gills.

Life Cycles

Not all life cycle stages of aquatic insects are aquatic. In fact, most only have aquatic larvae or nymphs and adults are terrestrial. However, there are some that have both aquatic and terrestrial adults, and there is even one Order containing Families that have terrestrial larvae and aquatic adults. Needless to say, there are many different roads to travel to become classified as an aquatic insect.

There are two types of life cycles or metamorphoses in aquatic insects. The first is ***hemimetabolous***, or incomplete metamorphosis. Orders that undergo incomplete metamorphosis include Ephemeroptera, Plecoptera, and Odonata. These Orders go from egg to larva (nymph) to adult with no pupal stage and the nymphs look very similar to the adults. The Orders Trichoptera, Coleoptera, Megaloptera, and Diptera are ***holometabolous***, that is, they go through a complete metamorphosis that includes a pupal stage. They go from egg to larva to pupa to adult and the larvae look very different than the adults.

Habitat

Aquatic insects are found in every conceivable aquatic habitat, from mud puddles to hot springs and tidal pools to streams, even the open ocean. Although all of these habitats are really fascinating, let's concentrate on where we can find them in the streams of Missouri. There are primarily five types of aquatic insect habitats in stream systems: riffles,

(continued on back)

MISSOURI STREAM TEAM

Stream Team Academy Fact Sheet Series:

#1: Tree Planting Guide
#2: Spotlight on Big Muddy
#3: Lewis & Clark
#4: Missouri Is Number One?
#5: Responsible ATV Use
#6: Headwater Streams
#7: Whatology?
#8 Exotic Does Not Mean Beauty
#9 Wetlands
#10 Stream Sedimentation
#11 Emerald Ash Borer Found in Missouri
#12 Protecting Prairies = Protecting Streams
#13 Life Cycle & Natural History of Aquatic Insects (Part 1)

Watch for more Stream Team Academy Fact Sheets coming your way soon. Plan to collect the entire educational series for future reference! Contact us at 1-800-781-1989 if you'd like a copy of previous Fact Sheets or a binder to store them in.

pools, substrate (benthic sediment), vascular plants, and woody debris.

Feeding

Aquatic insects can be herbivorous (plant eaters), detritivorous (scavengers or detritus eaters), carnivorous (predacious on other animals), or omnivorous (feed on anything). Although many experts try to place them into these categories and then into particular feeding groups or guilds, this may be carrying classifications too far. Many insects change throughout their life cycles from one guild to another.

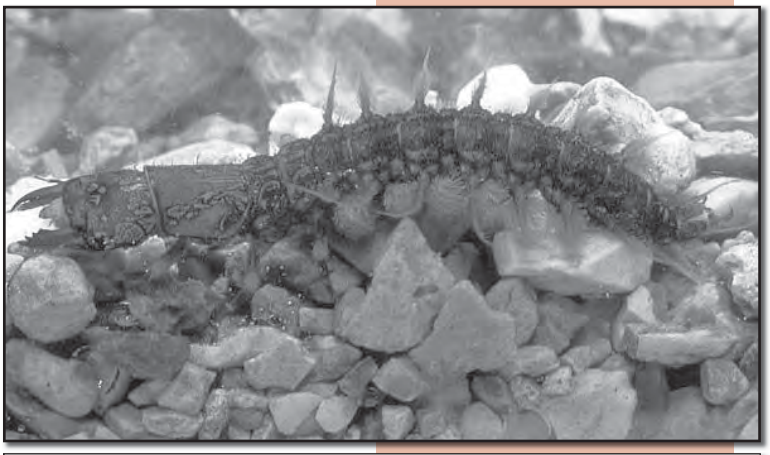
Respiration

Respiration is a fascinating and essential function for all living organisms. This is no exception in the insect world. Having originated from terrestrial ancestors, all insects obtained their oxygen from the air through tubes known as tracheae. The tracheae take oxygen through openings in the cuticle (protective covering) known as spiracles, and carry it directly to the body tissue.

Once insects invaded the aquatic world, they needed a way to resupply their oxygen. The efficient tracheal system of tubing for transport of gases was retained to use as an adult, but adaptations were needed to obtain oxygen in a new environment. Aquatic insects either resurface and refresh their air supply or pull dissolved oxygen directly from the water around them. Insects that have adapted to aquatic systems that aren't moving or still (lentic) like ponds, lakes, and wetlands, typically pull their oxygen from the atmosphere. Those in moving systems (lotic) like streams and rivers, typically pull their oxygen from the dissolved oxygen in the water around them.

These fact sheets will concentrate on those found in streams and rivers. These insects typically have what are known as closed tracheal systems. This means there are no openings (spiracles) present in the cuticle and some areas of the cuticle are thinner. Under these thin areas there are rich networks of tracheae for the gas exchange to occur by diffusion. In other cases the cuticle is modified into thin extensions called tracheal gills. These gills may be of various forms. Tracheae may be present or absent and they can be located on different parts of the body, but their function is the same. Although it is still being debated how important tracheal gills are in the actual gas exchange, it is not debated that they are important for ventilation. Movement of gills ventilates the cuticle with water containing dissolved oxygen, allowing for gas exchange to occur. This movement can come in many forms: abdominal contractions, gill beating, swimming, positioning one's body in the stream flow, or a combination of any of these activities.

Now with some general information under our belts, we will delve into more specifics for each of the Orders mentioned earlier. Our first Insect Order to be covered in the next fact sheet will be the mayflies, Order Ephemeroptera. More will follow. Don't hesitate to send questions to streamteam@mdc.mo.gov or call 1-800-781-1989.



Dobsonflies (also called Hellgrammites) go through 10–12 instars (stages between molts) during incomplete metamorphosis before crawling out onto shore to pupate. They have spiracles which help them respire when they leave the water.

Sources:

Freshwater Macroinvertebrates of Northeastern North America. Barbara L Peckarsky et al. 1990.

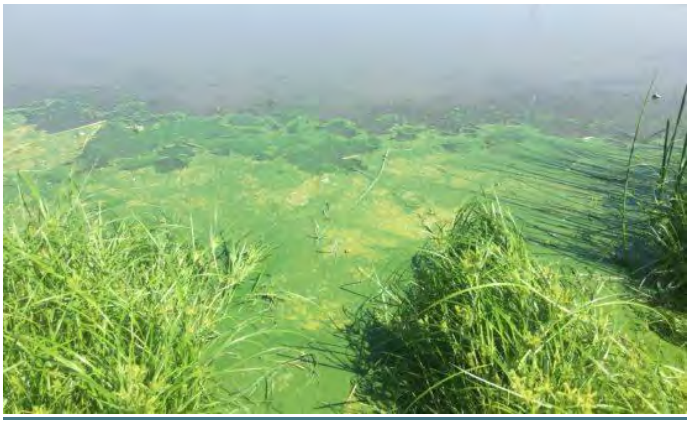
Aquatic Entomology–the Fishermen's and Ecologists' Illustrated Guide to Insects and Their Relatives. W. Patrick McCafferty. 1998.

Plant Identification

(Texas A & M AgriLife Extension https://aquaplant.tamu.edu/plant-identification/ and Southeastern Aquatic Plants https://www.mdwfp.com/sites/default/files/2024-06/P3735%20Southeastern%20Aquatic%20Plants.pdf)

Aquatic plants are generally divided into four groups for management purposes. These groups are:

Algae and Other Plankton



Algae are very primitive plants. Some algae are microscopic (planktonic algae). Others are thin and stringy or hair-like (filamentous algae). While still others are large and resemble higher plants but without true roots (chara).

Floating Plants

True floating plants are not attached to the bottom. Floating plants come in sizes from very small (duckweed) to over a foot in diameter (water hyacinth). Most, but not all, have roots that hang in the water from the floating green portions.

Submerged Plants

Submerged plants are rooted plants with most of their vegetative mass below the water surface, although some portions may stick above the water. One discerning characteristic of submerged plants is their flaccid or soft stems, which is why they do not usually rise above the water's surface.

Emergent Plants

Emergent plants are rooted plants often along the shoreline that stand above the surface of the water (cattails). The stems of emergent plants are somewhat stiff or firm.

Mississippi is home to extensive surface water resources. There are 81,316 miles of rivers and streams ranging in size from small, intermittent headwater streams to the Mississippi River. There are natural lakes, reservoirs, and more than 190,000 acres of ponds, most of which are privately owned. These resources support numerous uses, including water withdrawal for municipal, industrial, and agricultural purposes, electric power generation, and recreation.

Plants fulfill many natural functions and are vital in aquatic and wetland environments. They provide food, shelter, and reproductive habitat for fish and other aquatic and terrestrial species and help regulate water quality and produce oxygen. However, they can become overabundant and interfere with fishing, swimming, and boating in public and private waters. They also can disrupt ecosystem dynamics and interfere with fish management. This is particularly true with non-native (or exotic) species, which can be especially invasive and lack natural controls to limit their populations.

Alligator Weed | *Alternanthera philoxeroides*

Alligator weed profile showing opposite leaves and pink stems.

Clover-like flower with leaves.

Close-up of alligator weed flower.

Alligator weed is a non-native species originally from South America. It was first reported in Alabama in the late 1800s. Thick mats of alligator weed form at the shoreline and can extend many feet across the water's surface.

Alligator weed has elliptical to lanceolate (sword-shaped) leaves that are paired opposite of each other on the stem. The stem is pale green to pink. Alligator weed can be mistaken for water primrose; however, **the stems of alligator weed are hollow, while primrose stems are solid.**

Flowers are small, round, white, and **similar in appearance to terrestrial clover flowers.** The petals are thin, and the flower is on a stem that is 3–5 inches in length.

This species outcompetes most native species with a similar growth form, and can reduce or eliminate shoreline access to anglers and wildlife. Alligator weed can also form floating islands that block sunlight from the water and phytoplankton. It is invasive and can spread easily from plant fragments left during control efforts.

Management Value

Alligator weed is highly invasive and not recommended for any application. This species should be eradicated on first appearance. Alligator weed is listed as a Class C noxious weed in Alabama.

American Lotus | *Nelumbo lutea*

Mixed stand of American lotus, water lily, and other species. Round American lotus leaves are floating on the surface and emergent.

American lotus seed pod.

Round American lotus leaf showing the central stem insert, radiating veins, and lack of notch.

American lotus is found throughout Mississippi and is easily recognizable by its large, round leaves with central stem insertion, large, yellow single flower, and unmistakable seed pod.

Leaf stems extend to the pond or lake bottom, where the plant is rooted in the sediment and has rhizomes that store nutrients.

Leaves can reach diameters of 2.5 feet or more and may float on the water surface. Some leaves may emerge several feet above the water; these are referred to as umbrella pads. Flowers can be as wide as 10 inches.

The seed pod, or receptacle, is **shaped like an inverted cone and contains acorn-like seeds** within individual cavities.

Management Value

American lotus is a native plant, and its seeds are eaten by some species of waterfowl and possibly other wildlife. The rhizomes are eaten by beavers and muskrats, while the leaves and stalks provide habitat for fish. In small quantities, it is part of a healthy pond ecosystem, although it is highly invasive and usually takes over shallow ponds. American lotus is not recommended for pond management.

American lotus roots, leaves, and seeds are edible. Native Americans were known to eat the starchy rhizomes, and young leaves can be cooked and eaten like spinach. Immature seeds can be eaten raw, and the seed pods are commonly used in floral arrangements.

Salvinia | *Salvinia* spp.

Common salvinia.

Giant salvinia.

Heavy coverage of salvinia.

Common salvinia (*Salvinia minima*) and giant salvinia (*Salvinia molesta)* are non-native invasive plant species that are problematic in Mississippi. Salvinia are **aquatic ferns that float** on the water's surface in calm areas.

The leaves of common salvinia are relatively small, ranging from one-fourth of an inch to no more than 1 inch. Giant salvinia is roughly twice as large. **Leaves are hairy** and may be flat, slightly bent, or heavily folded. The "roots" are modified leaves.

Both species are invasive and should be eliminated. Giant salvinia is one of the worst invasive plants worldwide. Under ideal conditions, it can form mats up to 3 feet thick that negatively impact aquatic biota and human uses of aquatic resources.

Management Value

This plant is non-native and highly invasive. Eradicate on sight.

Water Hyacinth | *Pontederia crassipes*

Water hyacinth plant with vegetative new plant forming on the right.

Enlarged, hollow stems allow water hyacinth to float.

Floating water hyacinth plants.

Water hyacinth is a non-native, highly invasive species from Brazil. It has both free-floating and rooted forms. The floating growth form is particularly aggressive and can rapidly cover the water's surface in a thick, heavy mat that can stand 3 feet tall.

This species is easily identified by its leathery, **spongy, spoon-like leaves that feature parallel striations** (wrinkles or ridges) along their length. Stems are spongy and buoyant, and smaller plants often have enlarged bulbous areas on stems that provide buoyancy. Young colonies can be misidentified as frog's-bit; however, major veins will be evident in frog's-bit leaves and will be absent in water hyacinth leaves.

The roots are purple to black and feathery. During the summer, the plant produces very **showy, light-purple flowers with darker purple and yellow highlights**.

The species can reproduce by seed but more commonly uses vegetative reproduction. Stolons (runners) extend horizontally and form new plants. This mode of reproduction is rapid and quickly produces mats that obstruct both human and wildlife use of water resources.

Management Value

Water hyacinth is extremely invasive and should never be introduced. It is not known to provide wildlife or fisheries benefits and can quickly cover the water's surface and eliminate nearly all light penetration. Eradicate at first sight. Luckily, although it is very aggressive, it is also easily controlled in small ponds.

Water Lily | *Nymphae* spp.

Water lily compared to smaller frog's-bit and water shield leaves.

Mixed stand including water lily taking over a shallow lake.

Water lily flower.

Water lily is a common calm-water plant that has been extensively added to water gardens and ponds for aesthetics. Some species are native, while others are cultivars or introduced from elsewhere.

The leaves are **round to oval and have a deep notch** where the leaf stalk inserts. Leaves and stems are spongy, green on the upper surface, and purple or red underneath. The plants grow from rhizomes on the lakebed, with the leaves forming a mat on the surface or emerging just above.

The flowers are very showy. Many are white or yellow, but cultivars and non-natives can be many colors. There are three common types: yellow flowers (*N. mexicana*), light purple and yellow flowers (*N. elegans*), and white and yellow flowers (*N. odorata*).

Management Value

Water lily makes excellent habitat for fish and other aquatic animals in moderate densities. The flowers attract pollinators, and some mammals, turtles, and birds eat parts of the plant.

People have used the rhizomes to make medicine for gastrointestinal issues, sore throats, or dressings for burns. The flowers, seeds, and rhizomes are edible raw or cooked.

Water lily can be used to provide fish habitat and to give ponds a more natural appearance. It can take over shallow lakes, so this plant should be considered for deeper ponds with an understanding that a management plan is necessary. Planting in large containers or on isolated shallow islands is a good approach, with spot treatment of unwanted plants on first appearance.

NCF-Envirothon 2026 Mississippi

Aquatic Ecology Study Resources

Key Topic #4: Field Skills

18. Identify and utilize common water monitoring tools to determine local water quality (such as Secchi disk, dip net, pH meter, etc.)
19. Interpret results of water quality monitoring measures and provide best management practices.
20. Delineate a watershed on a topographic map. Analyze how water/pollution flows through the watershed.
21. Know the ten Mississippi drainage basins and where they flow to.

Resource Title	Source	Located on Page
What is a Secchi Disk?	North American Lake Management Society (NALMS). (n.d.). North American Lake Management Society (NALMS). https://www.nalms.org/secchidipin/monitoring-methods/the-secchi-disk/what-is-a-secchi-disk/	80
Wetland Sampling Steps to Success: Collecting Macroinvertebrates Using a Dip Net Measured Sweep	Biomonitoring Homepage. (n.d.). Wetland sampling steps to success: Collecting macroinvertebrates using a dip net measured sweep. https://www.maine.gov/dep/water/monitoring/biomonitoring/materials/wetland_sampling_handout.pdf	81
How to Read a Topographic Map and Delineate a Watershed	USDA Natural Resources Conservation Service. (n.d.). How to read a topographic map and delineate a watershed. https://bwsr.state.mn.us/sites/default/files/2020-05/MN_Watershed_Delineation.pdf	82
Dissolved Oxygen	US EPA. (2021). Factsheet On Water Quality Parameters [Report]. https://www.epa.gov/system/files/documents/2021-07/parameter-factsheet_do.pdf	86
Turbidity	EPA. (2021). Factsheet On Water Quality Parameters. https://www.epa.gov/system/files/documents/2021-07/parameter-factsheet_turbidity.pdf	86
MS watershed basins large (map)	Basin Management Approach – MDEQ. (n.d.). MDEQ - Mississippi Department of Environmental Quality. https://www.mdeq.ms.gov/water/surface-water/watershed-management/basin-management-approach/	93
pH	US EPA. (2021). Factsheet On Water Quality Parameters. https://www.epa.gov/system/files/documents/2021-07/parameter-factsheet_ph.pdf	95
Temperature	USGS. (2021). Temperature. Factsheet On Water Quality Parameters. https://www.epa.gov/system/files/documents/2021-07/parameter-factsheet_temperature.pdf	98

What is a Secchi Disk?

(https://www.nalms.org/wp-content/uploads/2015/04/disk6.gif)A Secchi disk is an 8-inch (20 cm) disk with alternating black and white quadrants. It is lowered into the water of a lake until it can no longer be seen by the observer. This depth of disappearance, called the Secchi depth, is a measure of the **transparency** of the water.

Transparency can be affected by the color of the water, algae, and suspended sediments. Transparency decreases as color, suspended sediments, or algal abundance increases. Water is often stained yellow or brown by decaying plant matter. In bogs and some lakes the brown stain can make the water the color of strong tea. Algae are small, green aquatic plants whose abundance is related to the amount of plant nutrients, especially phosphorus and nitrogen. Transparency can therefore be affected by the amount of plant nutrients coming into the lake from sources such as sewage treatment plants, septic tanks, and lawn and agricultural fertilizer. Suspended sediments often come from sources such as resuspension from the lake bottom, construction sites, agricultural fields, and urban storm runoff.

Transparency is an indicator of the impact of human activity on the land surrounding the lake. If transparency is measured through the season and from year to year, trends in transparency may be observed. Transparency can serve as an early warning that activities on the land are having an effect on a lake.

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Wetland Sampling Steps to Success: Collecting Macroinvertebrates Using a Dip Net Measured Sweep

Standard Sampling Season: June and July

Other information collected at each site:

- Physical/chemical water characteristics using hand-held meters
- Water grab samples for analysis at the lab
- Algae samples (phytoplanktonic and epiphytic)
- Description of the site and its surrounding habitat and land uses

Macroinvertebrates

- Collect from areas not disturbed by other sampling
- Complete all sweeps in areas of emergent vegetation or macrophyte beds having similar habitat representative of the overall site.

Dip Net Measured Sweep:

- Using a 600 micron D– frame net, sweep through the water for 1 meter– measured using a yard stick held above the water's surface
- Bump net against bottom substrate 3 times (beginning, middle, end), to dislodge and collect organisms from the sediment
- Keep the net submerged during the entire sweep
- Complete sweep in approximately 3 seconds
- At the end of the sweep, turn net so the opening is facing the surface of the water and lift the net quickly out of the water - so no organisms are lost out of the opening
- If net becomes clogged or if it was prevented from thoroughly contacting the bottom substrate - discard the sample and start again in an undisturbed location
- Transfer all material collected in the net into a 600 micron sieve bucket by placing the bucket halfway into the water and turning the net inside out into the bucket
- Place material in and on the net into the water in the bucket
- Visually inspect the net and remove any clinging organisms
- Examine, wash, and discard any large pieces of vegetation, woody debris, and stones– remove and retain any aquatic macroinvertebrates observed
- Retain fine plant material and detritus
- Drain water out of sieve bucket and transfer all material collected into 1 quart wide mouth canning jar - none of the jars should be more than half full
- Preserve samples in 95% ethyl alcohol for later sorting and taxonomic analysis in the laboratory
- Repeat process to collect a total of three replicate samples

For further information, please refer to the Biomonitoring Homepage

United States Department of Agriculture

How to Read a Topographic Map and Delineate a Watershed

Interpreting Topographic Maps

In order to successfully delineate a watershed boundary, the evaluator will need to visualize the landscape as represented by a topographic map. This is not difficult once the following basic concepts of the topographic maps are understood.

Each contour line on a topographic map represents a ground elevation or vertical distance above a reference point such as sea level. A contour line is level with respect to the earth's surface just like the top of a building foundation. All points along any one contour line are at the same elevation.

The difference in elevation between two adjacent contours is called the contour interval. This is typically given in the map legend. It represents the vertical distance you would need to climb or descend from one contour elevation to the next.

The horizontal distance between contours, on the other hand, is determined by the steepness of the landscape and can vary greatly on a given map. On relatively flat ground, two 20 foot contours can be far apart horizontally.

On a steep cliff face two 20 foot contours might be directly above and below each other. In each case the vertical distance between the contour lines would still be twenty feet.

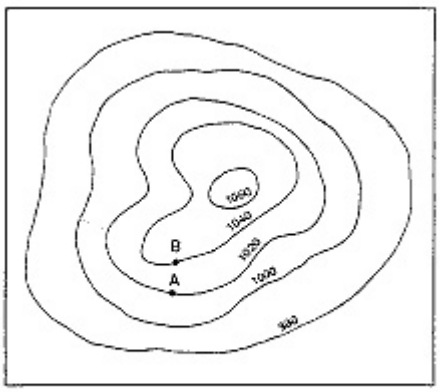

Figure E-1: Isolated Hill

One of the easiest landscapes to visualize on a topographic map is an isolated hill. If this hill is more or less circular the map will show it as a series of more or less concentric circles (Figure E-1). Imagine that a surveyor actually marks these contour lines onto the ground. If two people start walking in opposite directions on the same contour line, beginning at point A, they will eventually meet face to face.

If these same two people start out in opposite directions on different contours, beginning at points A and B respectively, they will pass each other somewhere on the hill and their vertical distance apart would remain 20 feet. Their horizontal distance apart could be great or small depending on the steepness of the hillside where they pass.

A rather more complicated situation is one where two hills are connected by a saddle (Figure E-2). Here each hill is circled by contours but at some point toward the base of the hills, contours begin to circle both hills.

How do contours relate to water flow? A general rule of thumb is that water flow is perpendicular to contour lines. In the case of the isolated hill, water flows down on all sides of the hill. Water flows from the top of the saddle or ridge, down each side in the same way water flows down each side of a garden wall (See arrow on Figure E-2).

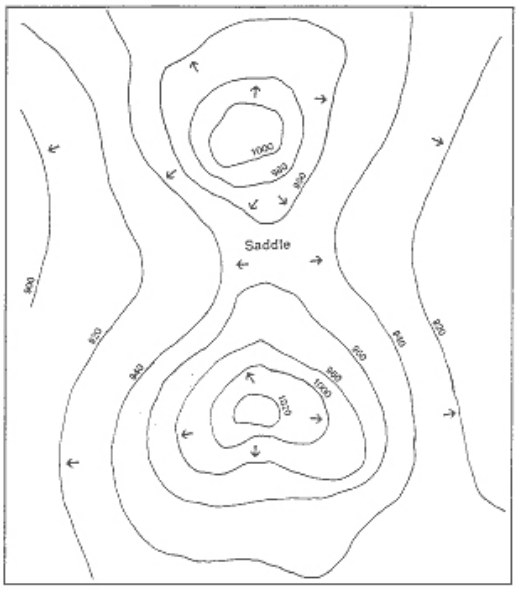

Figure E-2: Saddle

As the water continues downhill it flows into progressively larger watercourses and ultimately into the ocean. Any point on a watercourse can be used to define a watershed. That is, the entire drainage area of a major river like the Mississippi can be considered a watershed, but the drainage areas of each of its tributaries are also watersheds.

Each tributary in turn has tributaries, and each one of these tributaries has a watershed. This process of subdivision can continue until very small, local watersheds are defined which might only drain a few acres, and might not contain a defined watercourse.

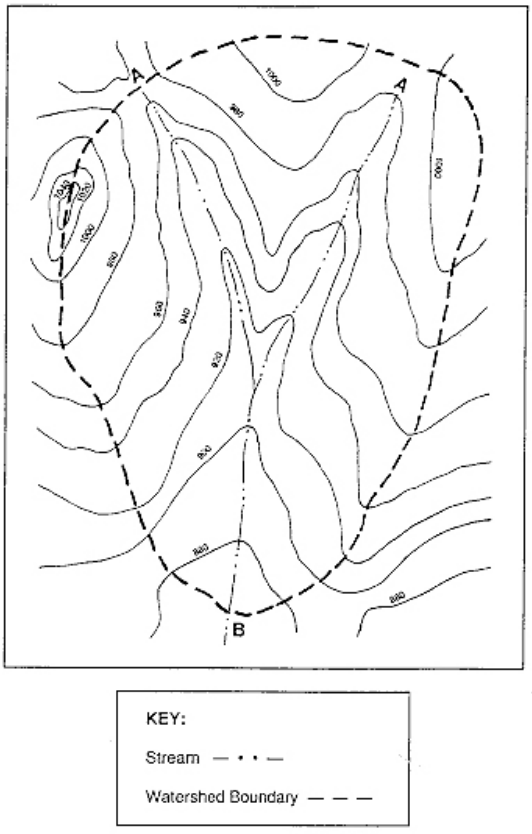

Figure E-3: Idealized Watershed Boundary

Figure E-3 shows an idealized watershed of a small stream. Water always flows downhill perpendicular to the contour lines. As one proceeds upstream, successively higher and higher contour lines first parallel then cross the stream. This is because the floor of a river valley rises as you go upstream. Likewise the valley slopes upward on each side of the stream. A general rule of thumb is that topographic lines always point upstream. With that in mind, it is not difficult to make out drainage patterns and the direction of flow on the landscape even when there is no stream depicted on the map. In Figure E-3, for example, the direction of streamflow is from point A to point B.

Ultimately, you must reach the highest point upstream. This is the head of the watershed, beyond which the land slopes away into another watershed. At each point on the stream the land slopes up on each side to some high point then down into another watershed. If you were to join all of these high points around the stream you would have the watershed boundary. (High points are generally hill tops, ridge lines, or saddles).

Delineating a Watershed

The following procedure and example will help you locate and connect all of the high points around a watershed on a topographic map shown in Figure F-4 below. Visualizing the landscape represented by the topographic map will make the process much easier than simply trying to follow a method by rote.

1. Draw a circle at the outlet or downstream point of the wetland in question (the wetland is the hatched area shown in Figure E-4 to the right)
2. Put small "X's" at the high points along both sides of the watercourse, working your way upstream towards the headwaters of the watershed.
3. Starting at the circle that was made in step one, draw a line connecting the "X's" along one side of the watercourse (Figure E-5, below left). This line should always cross the contours at right angles (i.e. it should be perpendicular to each contour line it crosses).
4. Continue the line until it passes around the head of the watershed and down the opposite side of the watercourse. Eventually it will connect with the circle from which you started.

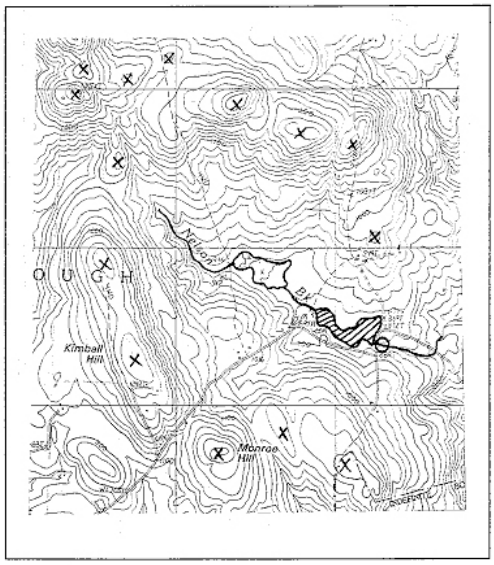

Figure E-4: Delineating a Watershed Boundary - Step 1

At this point you have delineated the watershed of the wetland being evaluated.

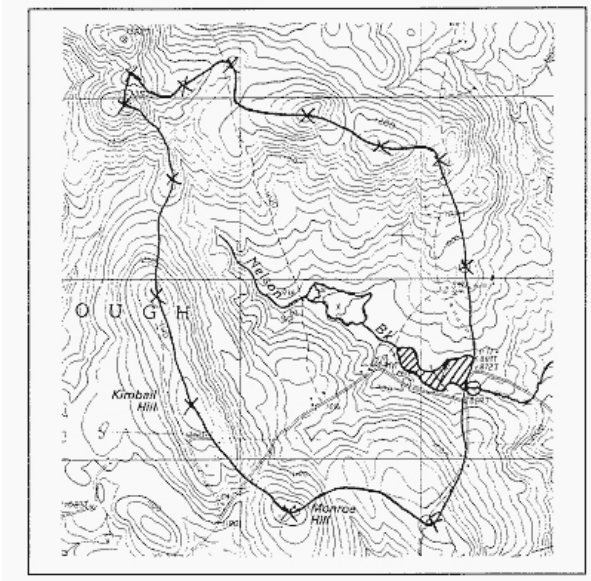

Figure E-5: Delineating a Watershed Boundary - Step 2

The delineation appears as a solid line around the watercourse. Generally, surface water runoff from rain falling anywhere in this area flows into and out of the wetland being evaluated. This means that the wetland has the potential to modify and attenuate sediment and nutrient loads from this watershed as well as to store runoff which might otherwise result in downstream flooding.

Measuring Watershed Areas

There are several available methods for measuring the area of a watershed: a) Dot Grid Method, b) Planimeter, and c) Computer programs such as ArcGIS.

a) The dot grid method is a simple technique which does not require any expensive equipment. In this method the user places a sheet of acetate or mylar, which has a series of dots about the size of the period at the end of this sentence printed on it, over the map area to be measured. The user counts the dots which fall within the area to be

measured and multiplies by a factor to determine the area. A hand held, mechanical counting device is available to speed up this procedure.

b) Another method involves using a planimeter, which is a small device having a hinged mechanical arm. One end of the arm is fixed to a weighted base while the other end has an attached magnifying lens with a cross hair or other pointer. The user spreads the map with the delineated area on a flat surface. After placing the base of the planimeter in a convenient location the user traces around the area to be measured with the pointer. A dial or other readout registers the area being measured.

c) Computer programs such as ArcGIS have measure tools that can be used to determine the area of the watershed.

For more information on Minnesota NRCS conservation planning and other technical references, visit https://www.nrcs.usda.gov/.

Dissolved Oxygen

Dissolved oxygen (DO) is the amount of oxygen in water that is available to aquatic organisms. DO is necessary to support fish spawning, growth, and activity.

Why do we measure dissolved oxygen?

DO is an important indicator of the overall biological health of a waterbody and is required for a waterbody to support aquatic life. It is generally measured in the field along with water temperature, turbidity (clarity), specific conductance, and pH. This information is then assessed against water quality standards to determine whether the water is fit for aquatic life.

Figure 1 is a generalized illustration of how DO affects fish health – sensitivities vary by species. In the range labeled as "too low", DO is too low to support fish. In the "stressful" range, DO conditions impede spawning and reproduction, and limit growth and activity. A higher DO is needed to be "supportive" of fish spawning, growth, and activity. Different levels of DO are required to support aquatic life depending on the species present and their stages of life (spawning, larvae, etc.). Trout, for example, require higher DO, while carp can survive in lower DO conditions. Among the macroinvertebrates, many immature insects require a high DO content, while other species such as aquatic worms and snails can tolerate lower DO concentrations. Hypoxic (low DO concentration) or anoxic (virtually no DO) conditions do not support fish or macroinvertebrate populations.

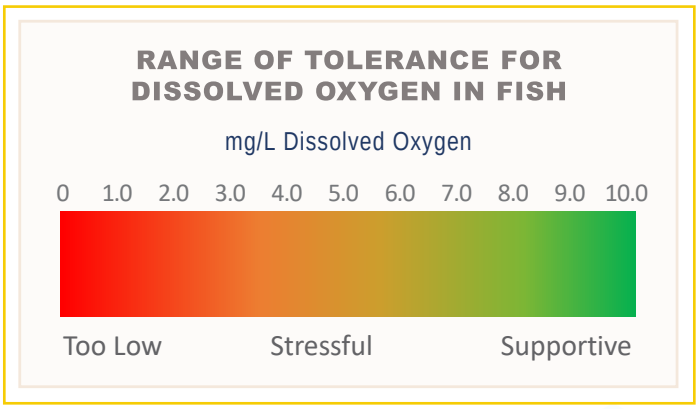

Figure 1. General freshwater fish tolerance for dissolved oxygen concentrations – tolerances vary by species.

What affects dissolved oxygen?

The primary sources of oxygen in surface waters are transfer of oxygen from the air and by plants and algae in the water due to photosynthesis. When the water is in equilibrium with the atmosphere and is holding as much DO as expected for the temperature, barometric pressure, and salinity conditions, it is said to be saturated. Aeration or photosynthesis can cause DO concentrations to become even higher and exceed saturation (the water becomes supersaturated).

For factsheets on other water quality parameters, visit: epa.gov/awma/factsheets-water-quality-parameters.

For more information about the CWA Section 106 Grants Program, visit: epa.gov/water-pollution-control-section-106-grants.

Seasonal cycles

Seasonal changes in water temperature (T) of lakes affect DO concentrations. Figure 2 shows these seasonal changes in a eutrophic (nutrient rich) lake.

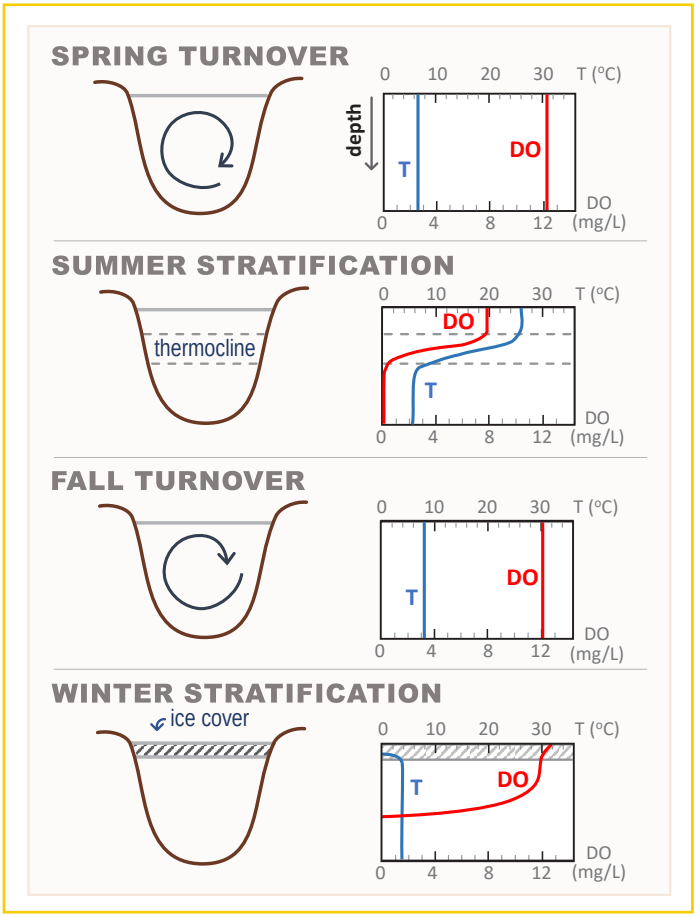

Figure 2. DO and temperature trends in eutrophic (nutrient rich) lakes by season. Adapted from Wetzel (1975)

After spring turnover occurs, the lake water is evenly mixed, so the temperature and DO are generally the same throughout the lake. During summer stratification, the top layer of the lake is warm and DO is high from the transfer of oxygen in the air and from algae due to photosynthesis. As depth increases, temperature decreases and DO also decreases as there is less photosynthesis and more organisms are consuming DO. After fall turnover occurs, the lake water is evenly mixed, so the temperature and DO are generally the same throughout the lake. During winter stratification, when the top of the lake freezes, the cold water just beneath the ice can hold the most DO, and the sunlight shining through the ice allows algae to photosynthesize. DO then decreases with depth as there is less photosynthesis and more organisms consume DO deeper in the water.

These seasonal factors combine to amplify the daily DO cycles described next. Warmer water and high nutrient concentrations (eutrophication) can result in excess algal growth. The eventual die-off of algae in an algal bloom and the increased rate of decomposition of organic matter in warmer temperatures ultimately reduce DO.

Other factors that can affect DO concentrations include:

Salinity – Increased salinity reduces the ability for water to absorb DO.

Altitude – Lower barometric pressure at higher elevations reduces the ability for water to absorb DO.

Daily cycles

DO levels in surface waters usually follow a daily cycle (Figure 3). During the day, oxygen is added to the water through photosynthesis by aquatic plants and algae and can create saturated, or even supersaturated surface waters. At night, photosynthesis stops, and DO levels drop as oxygen is consumed through respiration by aquatic plants and animals. Therefore, DO levels in surface water will likely be lowest early in the morning, and aquatic organisms are most vulnerable at that time (assuming all other conditions are the same). DO levels rise again during the day as photosynthesis resumes.

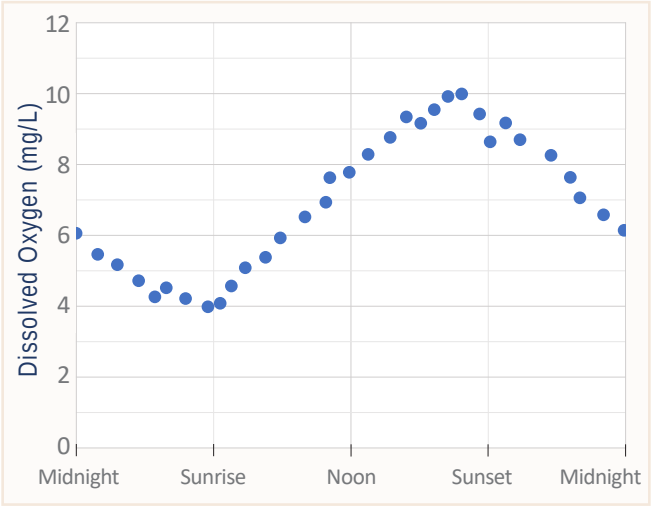

Figure 3. Generalized depiction of daily variation in dissolved oxygen concentrations.

Other water quality parameters

Changes in DO levels may be associated with changes in other water quality parameters. For example:

- **Chlorophyll *a*** – Chlorophyll *a* can be a useful indicator of an emerging algal bloom. During a bloom, DO can increase due to photosynthesis by the algae. Later, DO concentrations may decline because of oxygen consumption by consuming dead algae.
- **pH** – pH may change throughout the day along with DO fluctuations. As algae and aquatic plants draw carbon dioxide (CO_2) out of the water during photosynthesis, pH may increase throughout the day. At night, when aquatic plants, algae, and decomposers respire, they return CO_2 to the water, and pH decreases again.
- **Minerals** – Under anoxic conditions, minerals (such as iron oxide) in the sediment can dissolve, largely due to microbial activity. Any phosphorus associated with these minerals will also be released into the water further exacerbating nutrient rich (eutrophic) conditions.

What are EPA's recommended criteria for dissolved oxygen?

EPA's *Quality Criteria for Water* (1986) establishes recommended criteria for DO concentrations to protect aquatic life. Water quality criteria provide guidance for setting region-specific standards and can be adopted or adjusted as appropriate.

Criteria are based on the lowest DO concentrations needed by freshwater fish. Freshwater criteria are broken down into warmwater fish and coldwater fish because certain species such as trout and salmon require higher DO levels than others (such as pike). Table 1 shows the freshwater criteria.

Table 1. Recommended criteria for the protection of aquatic life in freshwaters (mg/L of DO).

	Coldwater Criteria		Warmwater Criteria	
	Early Life Stages[1,2]	Other Life Stages	Early Life Stages	Other Life Stages
30 Day Mean	NA[3]	6.5	NA	5.5
7 Day Mean	9.5 (6.5)	NA	6.0	NA
7 Day Mean Minimum	NA	5.0	NA	4.0
1 Day Minimum[4,5]	8.0 (5.0)	4.0	5.0	3.0

1 *These are water column concentrations recommended to achieve the required intergravel DO concentrations shown in parentheses. The 3 mg/L differential is discussed in the criteria document. For species that have early life stages exposed directly to the water column, the figures in parentheses apply.*

2 *Includes all embryonic and larval stages and all juvenile forms to 30-days following hatching.*

3 *NA (not applicable).*

4 *For highly manipulatable discharges, further restrictions apply.*

5 *All minima should be considered as instantaneous concentrations to be achieved at all times.*

Source: USEPA (1986)

How do we measure dissolved oxygen?

DO can be measured at discrete points in time or continuously. Monitoring sensors (continuous monitoring) allow assessment of DO changes throughout the day and are a cost-effective option for collecting DO data. DO can be measured using water quality probes, which often report DO measurements in both mg/L (milligrams of oxygen in a liter of water) and percent saturation. Concentrations can vary greatly, ranging from 0 mg/L to as high as 12 mg/L or more. Low DO concentrations are considered hypoxic. Concentrations below 0.2 mg/L are often considered anoxic (virtually no oxygen).

DO can vary both horizontally and vertically in a waterbody. Water samples should, therefore, be taken at regular increments across a waterbody and at various depths (or depth integrated, which is a sample that represents the entire water column). Also, because DO levels vary throughout the day, an hourly profile can be informative. If a single sample is to be taken, consider sampling as early in the morning as possible, when the DO levels are likely to be at a minimum.

What are the challenges of using dissolved oxygen as a water quality parameter?

Because DO varies naturally throughout the day and throughout the waterbody, it can be difficult to determine if low DO measurements are a true reflection of the overall DO levels of the waterbody. This can make it challenging to assess whether the waterbody is attaining water quality criteria.

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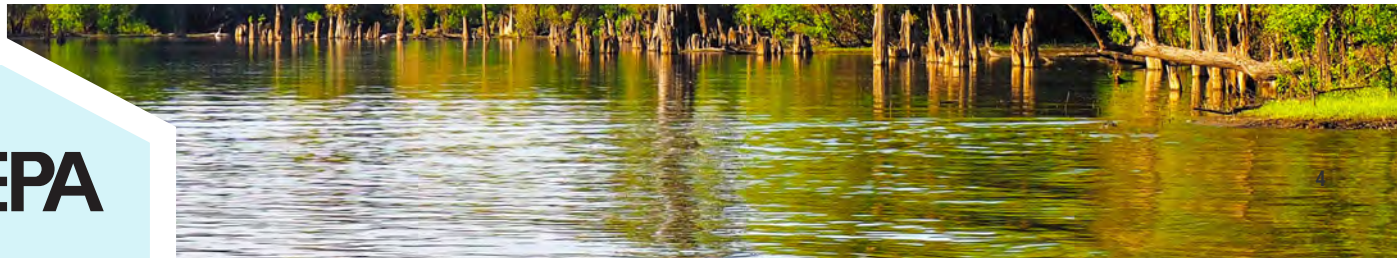

Turbidity

Turbidity is a measure of water clarity. High turbidity makes water appear cloudy or muddy.

Why do we measure turbidity?

Turbidity and total suspended solids (TSS) are different ways to measure similar water quality characteristics. TSS is the concentration of suspended particles, which include soil particles (clay, silt, organic matter), algae, and microscopic organisms.

An increase in turbidity (Figure 1) or suspended solids can also negatively affect aquatic health by:

- Clogging fish gills or the filter-feeding systems of other aquatic animals.
- Hindering visibility, making it difficult for predators to find prey.
- Decreasing light penetration into water and thereby the ability of submerged aquatic plants to photosynthesize, reducing biomass and growth rates of aquatic plants.
- Reducing fish resistance to disease.
- Altering egg and larval development.

Changes in turbidity can also affect other water quality parameters; increased turbidity is likely to be accompanied by the following:

- Higher temperature and reduced dissolved oxygen due to increased heat absorption of the water.
- Reduced dissolved oxygen due to decreased light penetration into the water and an associated decrease in photosynthesis by aquatic plants.
- Increased nutrient concentrations and chlorophyll *a* if the turbidity is caused by excess algal growth.

Figure 1. Fish in turbid water (left), and fish in clear water (right). Credit: Photo courtesy of Credit Valley Conservation

The suspended solids contributing to turbidity can affect water chemistry and microbiology. The particles can adsorb (take up on their surfaces) pollutants, including nutrients, metals, and organic compounds. If the particles settle on the bottom of the waterbody, then the pollutants settle with them. If bottom sediments are subsequently disturbed and resuspended, the aquatic community can be exposed to any adsorbed toxins or nutrients.

In drinking water, particles can interfere with disinfection by physically blocking UV rays from reaching microorganisms. Some microorganisms can make people sick if they occur in drinking water.

What affects turbidity?

Natural factors that increase turbidity include:

- Runoff caused by precipitation and/or severe weather.
- Disruption of bottom sediments (resuspension) due to water turbulence from windstorms or rain events.
- Bottom-feeding animals moving sediments around.
- Small floating organisms suspended in the water column (plankton, algae, cyanobacteria).
- Dead organic matter in the water column.
- Wood ash from wildfires that reaches surface water.
- Spring snowmelt and precipitation.
- Summer algal growth in lakes and slower moving rivers.

Human-induced factors that increase turbidity include:

- Stream bank erosion contributing soil to water (Figure 2).
- Erosion in other areas of the watershed caused by changes in land use (construction, farming, forestry, and urban development) that cause soil to be carried in runoff to surface water.
- Urban runoff carrying particles from impervious surfaces to surface water.
- Untreated wastewater discharges.
- Disturbance and resuspension of bottom sediments during dredging or boating activity.
- Algal growth due to fertilizer use and resulting increases in nutrients in the water, especially in lakes or slower moving rivers.

Figure 2. Example of streambank erosion. Credit: Photo courtesy of Cuyahoga SWCD

What are EPA's recommended criteria for turbidity?

EPA's *Quality Criteria for Water* (1986) contains the following general narrative criterion for turbidity: "Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life."

States and tribes have the discretion to set quantitative or qualitative water quality criteria for turbidity. For example, narrative criteria may require no increases above naturally occurring conditions.

How do we measure turbidity?

Turbidity is measured directly using a turbidity meter or sensor (nephelometry). Turbidity can also be measured indirectly through water clarity, which is measured in deeper rivers or lakes using a Secchi disk.

Figure 3. Water sample taken to assess turbidity. Credit: Photo courtesy of USEPA

Turbidity is reported in nephelometric turbidity units (NTUs) or Secchi depths (in meters) depending on the method used for measurement. Figure 3 shows a water sample that was taken to assess turbidity in murky water.

Turbidity can vary both horizontally and vertically in a waterbody. Water samples should, therefore, be taken at regular increments across a waterbody and at various depths (or depth integrated, which is a sample that represents the entire water column).

Basic field data collected by a water quality monitoring program should include turbidity along with other parameters that may influence turbidity, such as temperature, streamflow, dissolved oxygen, specific conductance, and pH.

What are the challenges of using turbidity as a water quality parameter?

Turbidity is an optical property of water rather than a chemical or biological measurement. Caution should be exercised when using turbidity as a water quality parameter because high turbidity levels do not necessarily indicate poor water quality, and low turbidity levels do not necessarily indicate good water quality. Values should, therefore, be evaluated alongside other parameters. Measurements made using a Secchi disk as shown in Figure 4 are qualitative and subject to the accuracy of the measurer. A related parameter, total suspended solids (TSS), is the concentration of particles suspended in the water column that are larger than two microns in size. Although turbidity is not a direct measure of TSS, changes in turbidity often correspond with changes in TSS. In general, higher turbidity values and greater TSS concentrations are both observed at higher flows. TSS is reported in units of mg/L.

Figure 4. Secchi disk measuring the Secchi depth in water with extensive algal growth. Credit: Photo courtesy of USGS

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Basin Management Approach

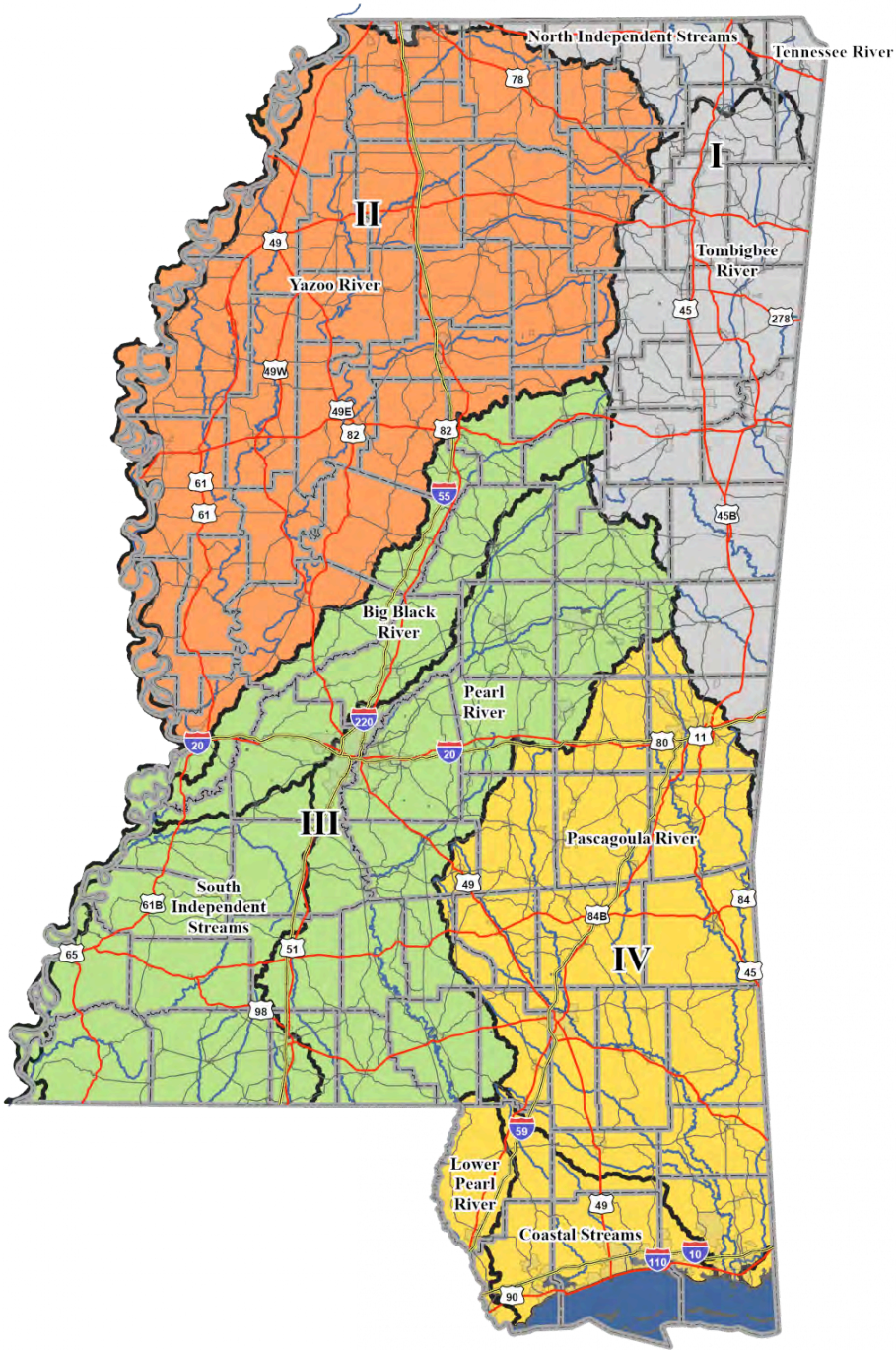
Water Quality: It's Not Just Our Goal — It's Our Future! Join Us in Protecting the Quality of Your Water!

The purpose of Mississippi's Basin Management Approach is to protect and restore the quality of Mississippi's water resources. This is done by developing and implementing effective management strategies that address water quality issues.

Many agencies, organizations, businesses and citizens are coming together to help implement the Basin Management Approach. By working together and collaborating with one another, we are protecting and improving our water resources.

MS's Aquatic Resources | What is a Watershed? | About | Cooperating Stakeholders | Be the Solution | Find Your Basin

Click the map to learn more about your basin.



pH

pH is the concentration of hydrogen ions (H^+) in a sample. pH is measured to determine the acidity of the water.

Why do we measure pH?

pH is an important indicator of chemical, physical, and biological changes in a waterbody and plays a critical role in chemical processes in natural waters. pH values are on a scale from 0 to 14, with 7.0 considered neutral. Figure 1 shows typical pH values of common liquids. Solutions with a pH below 7.0 are considered acidic, and those with a pH above 7.0 are considered basic. The pH scale is logarithmic, meaning that every one-unit change in pH represents a ten-fold change in acidity. In other words, pH 6.0 is ten times more acidic than pH 7.0; pH 5.0 is one hundred times mores acidic than pH 7.0.

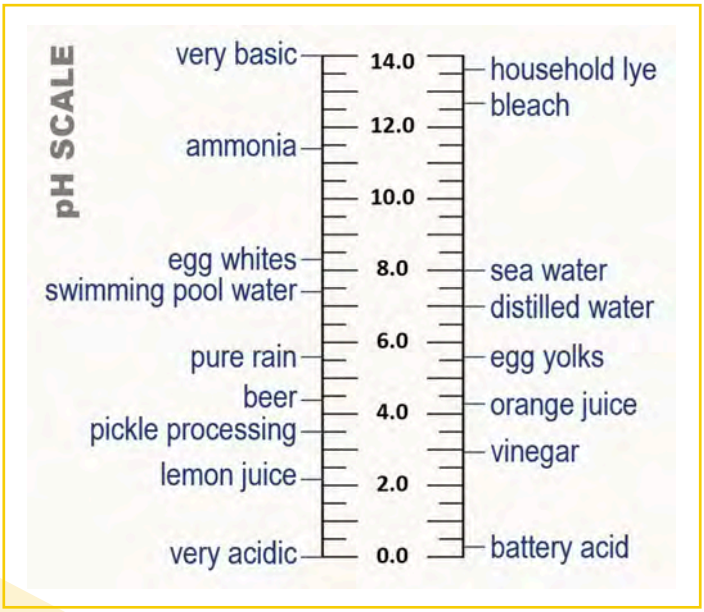


Figure 1. Typical pH values of common liquids. Adapted from Water on the Web (2008)

pH is a key factor in water chemistry and toxicity. A change in pH can alter the concentrations and forms of toxic chemicals in water. Metals such as aluminum, lead, mercury, copper, and arsenic are generally more soluble at a lower pH. Therefore, higher concentrations can be absorbed into the tissues of organisms, rendering these metals more toxic to aquatic life. In more basic waters (pH > 8.5), the conversion of the nontoxic form of ammonia to the toxic form is increased.

pH also plays a key role in aquatic health by affecting biochemical processes and the metabolism of aquatic organisms. Generally, if water is too acidic or too basic, damage can occur to an organism's gills, exoskeleton, fins, and other critical components. Of particular concern are pH-sensitive macroinvertebrates (small organisms without a backbone), fish eggs (most fish eggs cannot hatch at a pH less than 5), and juvenile fish.

Figure 2. Critical pH values below which key aquatic organisms may be lost. Source: USEPA (2020)

Organisms vary in the pH ranges they can tolerate. Figure 2 illustrates the pH values at which key organisms may experience die-off or avoidance. Furthermore, even though an organism itself may tolerate a more extreme pH, its food source may not.

For factsheets on other water quality parameters, visit: epa.gov/awma/factsheets-water-quality-parameters.

For more information about the CWA Section 106 Grants Program, visit: epa.gov/water-pollution-control-section-106-grants.

What affects pH?

pH in a lake or river often fluctuates daily, with a higher pH (more basic) during the daytime due to consumption of CO_2 by aquatic plants and algae during photosynthesis. At night, aquatic plants and algae respire, giving off CO_2 and lowering pH (more acidic). Therefore, pH tends to be highest in late afternoon and lowest before sunrise. The pH of a well buffered pond may fluctuate between 7.0 and 8.4 (Figure 3). Buffering capacity refers to the ability for water to neutralize acids and bases and maintain a fairly stable pH level.

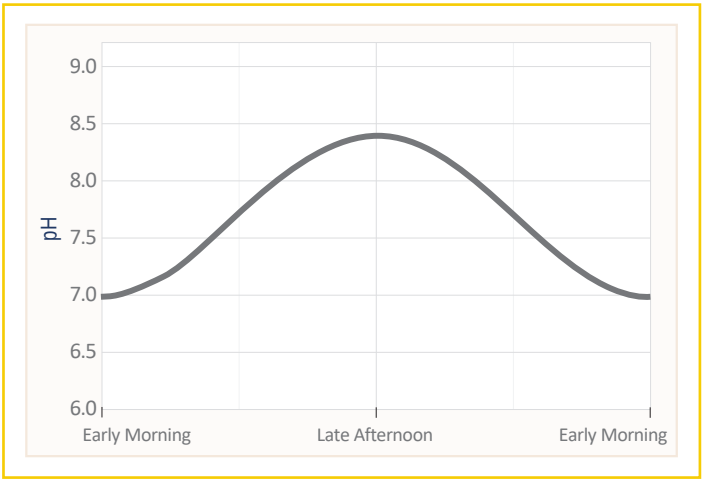


Figure 3. Daily fluctuations in pH in a hypothetical well buffered pond. Adapted from Wurts and Durborow (1992)

There are also seasonal changes in pH. Values are lower during seasons with high rainfall and snowmelt. When excess water runs directly into lakes or rivers without passing through soil, the slight acidity naturally present in precipitation does not get buffered. Additionally, pH in streams or at the surface of lakes is higher during the growing season (spring and summer) when there is more photosynthetic activity by aquatic plants.

pH can also vary with depth in the water column. Near the surface of lakes, pH is higher because light is available for algae to photosynthesize. In thermally stratified lakes, pH in the deeper water is often lower due to the lack of photosynthesis as well as respiration by organisms decomposing organic matter.

Both natural and human-induced factors can affect pH. For example, pH near the surface of lakes can increase with nutrient inputs and the growth of algae during algal blooms which consume CO_2. In addition, pH at the bottom of lakes may decrease due to decomposition of excess algae, plants, and other organic material.

pH can also decrease due to:

- Acid rain, which is typically caused by nitrogen oxides and sulfur dioxide from emissions of cars and coal-fired power plants. Regulations imposed in the last few decades to control acid rain have resulted in lake recovery in some heavily affected areas.
- Acid mine drainage from coal or sulfide mines, which can reach streams.

Local geology helps control pH, with certain types of bedrock such as limestone buffering the water against acid inputs.

What are EPA's recommended ambient water quality criteria for pH?

In EPA's *Quality Criteria for Water* (1986), the recommended water criteria for pH ranges from 6.5 to 9.0 depending on what is protective of aquatic life and the particular system (fresh vs saltwater).

How do we measure pH?

pH can be measured in the field using a water quality probe, indicator tests or strips, or from grab samples. Most commonly pH is measured in the field along with other water quality parameter measurements including temperature, dissolved oxygen, and specific conductance using a single or multi-parameter probe. pH should also be measured along with alkalinity, which is a measure of the capacity of water to neutralize acids. Alkalinity is also known as buffering capacity. Other parameters that may inform pH results include nutrients and metals because pH can indicate nutrient enrichment or impacts from metals.

pH can be measured at discrete times or continuously. Optimally, monitoring should take place at the same time every day if discrete measurements are being taken. Monitoring sensors (continuous monitoring) allow assessment of changes in pH throughout the day that cannot be captured with a single sample.

pH can vary both horizontally and vertically in a waterbody. Water samples should, therefore, be taken at regular increments across a waterbody and at various depths (or depth integrated, which is a sample that represents the entire water column).

What are the challenges of using pH as a water quality parameter?

pH can be highly variable due to its sensitivity to natural and human-induced factors. This sensitivity can make it challenging to pinpoint the sources of long-term trends or water quality exceedances; evaluation of trends in other water quality parameters may help in identifying possible causes.

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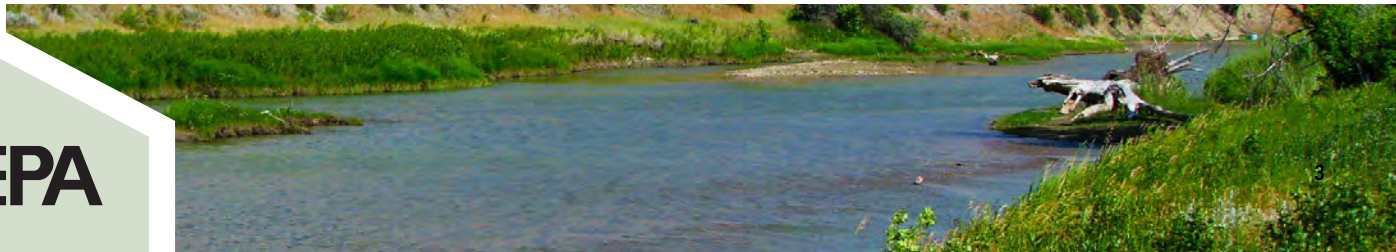

Temperature

Water temperature expresses how warm or cold the water is. It is defined as the amount of average kinetic energy in water molecules and is measured in degrees Fahrenheit (F) or Celsius (C).

Why do we measure temperature?

Water temperature influences the majority of physical, biological, chemical, and ecosystem processes in aquatic environments. Altered stream temperature is a significant cause of water quality impairment in the U.S. and influences other water quality parameters. Measuring temperature helps to understand the magnitude and variability of temperature fluctuations and anticipate the consequences for water quality and ecosystem health (Figure 1).

Figure 1. Measuring temperature in the field. Credit: Photo courtesy of USGS

In general, increased water temperature can result in:

- Decreased dissolved oxygen (DO) available to aquatic life.
- Increased solubility of metals and other toxins in water.
- Possible increased toxicity of some substances to aquatic organisms.
- Algal blooms, which typically occur during the summer season or periods of unusually warm temperatures.

Short- and long-term increases in temperature can negatively impact aquatic health in different ways (Table 1).

Table 1. Potential effects of short- and long-term increases in temperature on aquatic life.

Short-term summer heat stress	Long-term temperature increases
• Reduced or blocked sexual maturation • Inhibited or blocked critical stages of larval development • Reduced feeding and reduced growth of juveniles and adults • Increased susceptibility to predation • Reduced productivity of macroalgae and seagrasses • Increased death, organisms forced to leave, and increased incidence of disease or parasitism	• Loss of aquatic species whose survival and breeding are temperature dependent • Change in the abundance and spatial distribution of aquatic species and reduced populations of some species • Increase in rates of evaporation from surface water, causing increased salinity and waterbody shrinkage, resulting in a loss of habitat

For factsheets on other water quality parameters, visit: epa.gov/awma/factsheets-water-quality-parameters.

For more information about the CWA Section 106 Grants Program, visit: epa.gov/water-pollution-control-section-106-grants.

Decreased water temperature can also harm aquatic life. Specifically, decreased water temperature can alter the timing of migration, decrease spawning for some fish species (pallid sturgeon, salmonids), and change the timing of egg hatching. Other potential effects of decreased water temperature include reduced rate of photosynthesis (resulting in a decrease in aquatic plants) and a decreased metabolic rate of aquatic organisms.

What affects water temperature?

The transfer of heat between a waterbody and the atmosphere, sunlight, or other water source (groundwater, wastewater discharges, etc.) affects the temperature of water. Water temperature depends on many factors, including:

- Weather (air temperature, wind speed and direction, cloud coverage, and precipitation)
- Stormwater runoff from impervious surfaces (highways, roads, large roofs, parking lots)
- Loss of shading when streambank vegetation is lost
- Cooling water discharges (from power plants and other facilities)
- Impoundments (dams)
- Groundwater inflow
- Evaporation rate
- Streamflow
- Turbidity

Both rivers and lakes undergo daily temperature changes. Lake waters also exhibit seasonal temperature changes, typically stratifying (forming temperature layers) in the summer and winter. During the fall and spring, temperature changes lead to turnover and mixing of the water column (Figure 2).

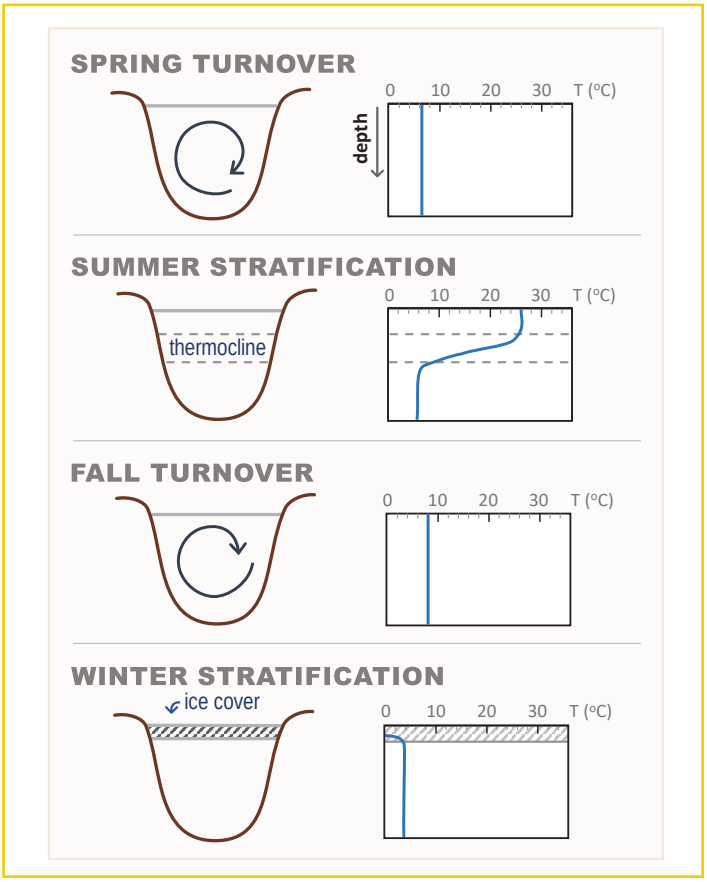

Figure 2. Temperature layers and turnover in lakes by season. Adapted from Wetzel (1975)

What are EPA's recommended criteria for temperature?

EPA's *Quality Criteria for Water* (1986) recommends the temperature criteria below for aquatic organisms. Two types of limiting temperature exist for each **freshwater location** based on important sensitive species:

- The **maximum temperature for short-term exposure** is time-dependent and calculated using a species-specific mathematical equation.

Temperature

- The **maximum weekly average temperature** must do one of the following: protect against mortality in cooler months; protect for physiologically optimum temperature in warmer months; protect for successful migration, spawning, egg incubation, fry rearing, and other reproductive functions in reproductive seasons; or preserve normal species diversity.

Table 2 lists examples of the two types of limiting temperature metrics (the maximum weekly average temperatures and the maximum short-term temperature) for four example fish species. These are examples only and do not necessarily indicate protective values in every location.

Table 2. Maximum average temperatures for growth and short-term maximum temperatures for selected fish (°C and °F).

Species	Max. weekly avg. T for growth (juveniles)	Max. T for survival of short exposure (juveniles)	Max. weekly avg. T for spawning	Max. T for embryo spawning
Common carp	---	---	21 °C (70 °F)	33 °C (91 °F)
Channel catfish	32 °C (90 °F)	35 °C (95 °F)	27 °C (81 °F)	29 °C (84 °F)
Largemouth bass	32 °C (90 °F)	34 °C (93 °F)	21 °C (70 °F)	27 °C (81 °F)
Rainbow trout	19 °C (66 °F)	24 °C (75 °F)	9 °C (48 °F)	13 °C (55 °F)

Source: USEPA (2012)

How do we measure temperature?

Temperature can be measured at discrete points in time or continuously. Monitoring sensors (continuous monitoring) allow assessment of temperature changes throughout the day and are a cost-effective option for collecting temperature data as compared to individual readings using thermometers.

Temperature is generally measured in the field along with other water quality parameters including pH, DO, specific conductance (SC), turbidity, and is generally measured along with any water samples being collected.

Temperature can vary both horizontally and vertically in a waterbody. Measurement locations should be well mixed (not substantially warmer or cooler than the rest of the segment of the waterbody). If a goal is to look for trends, measurements should be taken at the same time of day. Measurements at different depths at each location (depth integrated) will provide information on vertical variability. Measurements should capture spatial variability, stratification, and seasonal trends to the degree feasible.

What are the challenges of using temperature as a water quality parameter?

Temperature varies naturally throughout the day, throughout seasons, and throughout the depth of a single waterbody. Additionally, aquatic species in a single waterbody can have different optimal water temperature ranges. It is, therefore, challenging to set water quality criteria for water temperature.

It can be logistically challenging to collect the data needed to fully characterize seasonal and spatial variability. Furthermore, because many factors can affect temperature, it can be difficult to determine the source(s) of alterations to temperature patterns.

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