MANITOBA ENVIROTHON
AQUATIC ECOLOGY
REGIONAL RESOURCES

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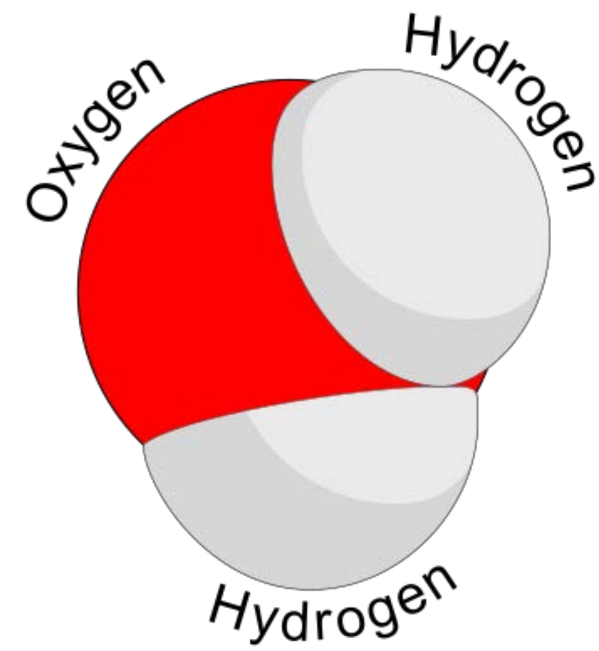
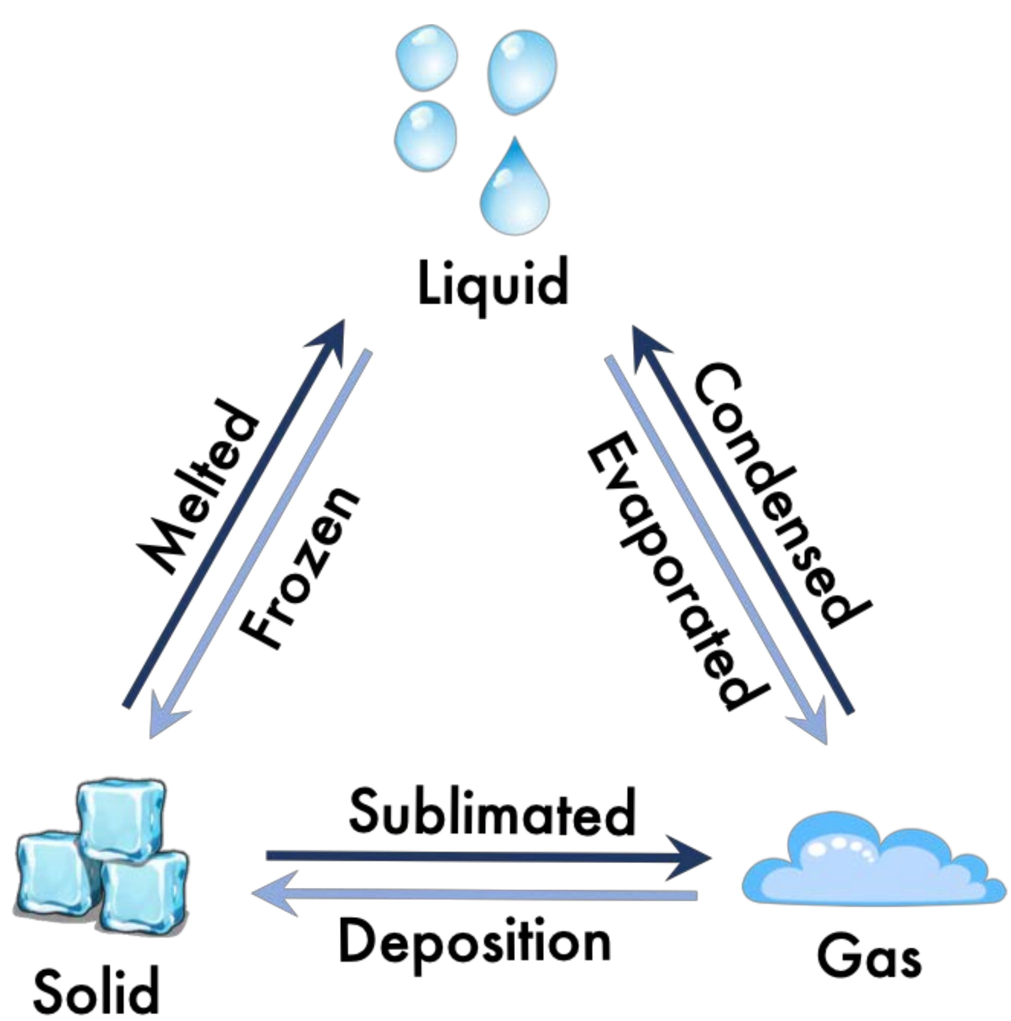
PHYSICAL AND CHEMICAL PROPERTIES OF WATER

All life on Earth depends on water. An animal can live without food for long periods of time, but many animals, including humans, can only live for a few days without water. Water molecules contain two atoms of hydrogen and one atom of oxygen (H_20) which are connected with hydrogen bonds. These very strong bonds determine the physical and chemical properties of water.



Water is present on Earth as a liquid, a solid (ice), or a gas (water vapour). Water can be frozen (liquid to solid), melted (solid to liquid), evaporated (liquid to gas), sublimated (solid to gas), and condensed (gas to liquid). Water can be mixed with other substances to create solutions, and water is a very powerful solvent that can be used to dissolve many things.



Boiling and freezing

Pure water at sea level boils at 100°C and freezes at 0°C. At higher elevations where there is less atmospheric pressure, the boiling temperature of water is lower (e.g., it will boil at 95.46°C in Banff, Alberta, Canada at 1383 m above sea level). For example, boiling an egg takes longer at a higher altitude because the temperature does not get high enough to cook the egg normally. When it comes to freezing, the freezing point of water can be changed by dissolving a substance in it. For example, salt is spread on the streets in winter to prevent ice formation, as salty water will freeze at a lower temperature than fresh water.

Unlike most other substances, which are the densest in their solid state, water is most dense at about 4°C. This means that solid water (ice) is less dense and floats on liquid water. If this was not true, lakes and rivers would freeze from the bottom up, yielding water bodies that are completely frozen in winter. Under these conditions fish and other animals could not survive over winter, and it is unlikely that rivers and lakes in very northern and very southern countries would ever thaw completely.

Thermal properties

Water has a very high capacity to absorb heat without changing temperature dramatically. In fact, if you measure the amount of energy a volume of water can absorb or release for each degree it changes temperature (up or down), you will find that not many other substances in the world have a higher capacity for energy than water. Due to this property, water is often used for cooling and transferring heat in thermal or chemical processes.

Differences in the temperature between water bodies (e.g., lakes and rivers) and the surrounding air can have a variety of effects. In the fall, water bodies cool down more slowly than the land. During cold fall nights, air that has cooled over the land may drift over a water body (warmer). The air immediately above the water body will warm, and some of the water from the water body will evaporate into this layer of air. As this thin layer of warmer, moist air mixes with the cooler air from the land, the water vapour in the layer condenses (water vapour liquid water) and consequently small water droplets are suspended in the air creating a fog or mist. Conversely, if water is colder than the air above it, it can cause condensation in the air which may lead to thick fog above the water body (more common in summer months).

Typically, when water is colder than air there is less precipitation, winds are reduced, and fog banks may be formed. In conditions where water is warmer than air, there will be more precipitation, stronger winds, and fog/mist just above the surface of the water.

Large bodies of water like oceans or the Laurentian Great Lakes (Ontario) have a major influence on global climate, with effects reaching much farther than the land immediately around them. They act as heat reservoirs, heat exchangers, and the source of a lot of the moisture that falls as rain or snow over adjacent land masses. Precipitation that falls adjacent to a lake will often be called "lake effect" precipitation because it is the lake, in conjunction with the air masses moving through the area, that causes it.

Surface tension

Surface tension of any liquid refers to the strength of its surface film (i.e., how much pressure it takes to break through the surface of the liquid). The strength of attraction between the molecules in a substance dictates how much pressure is needed, and thus the surface tension. The hydrogen bonds that connect the water molecules are very strong, so the surface tension of water is very high. Compared to other common liquids, only mercury's surface tension is higher. The surface tension of liquid water permits it to hold up substances heavier and denser than itself. For example, a steel needle carefully placed on the surface of a glass of water will float. Some aquatic insects, such as the water strider, rely on this surface tension to walk on water. Further, surface tension is essential for the transfer of energy from wind to water to create waves, and waves are necessary for rapid oxygen diffusion in lakes and seas.

Molecules in motion

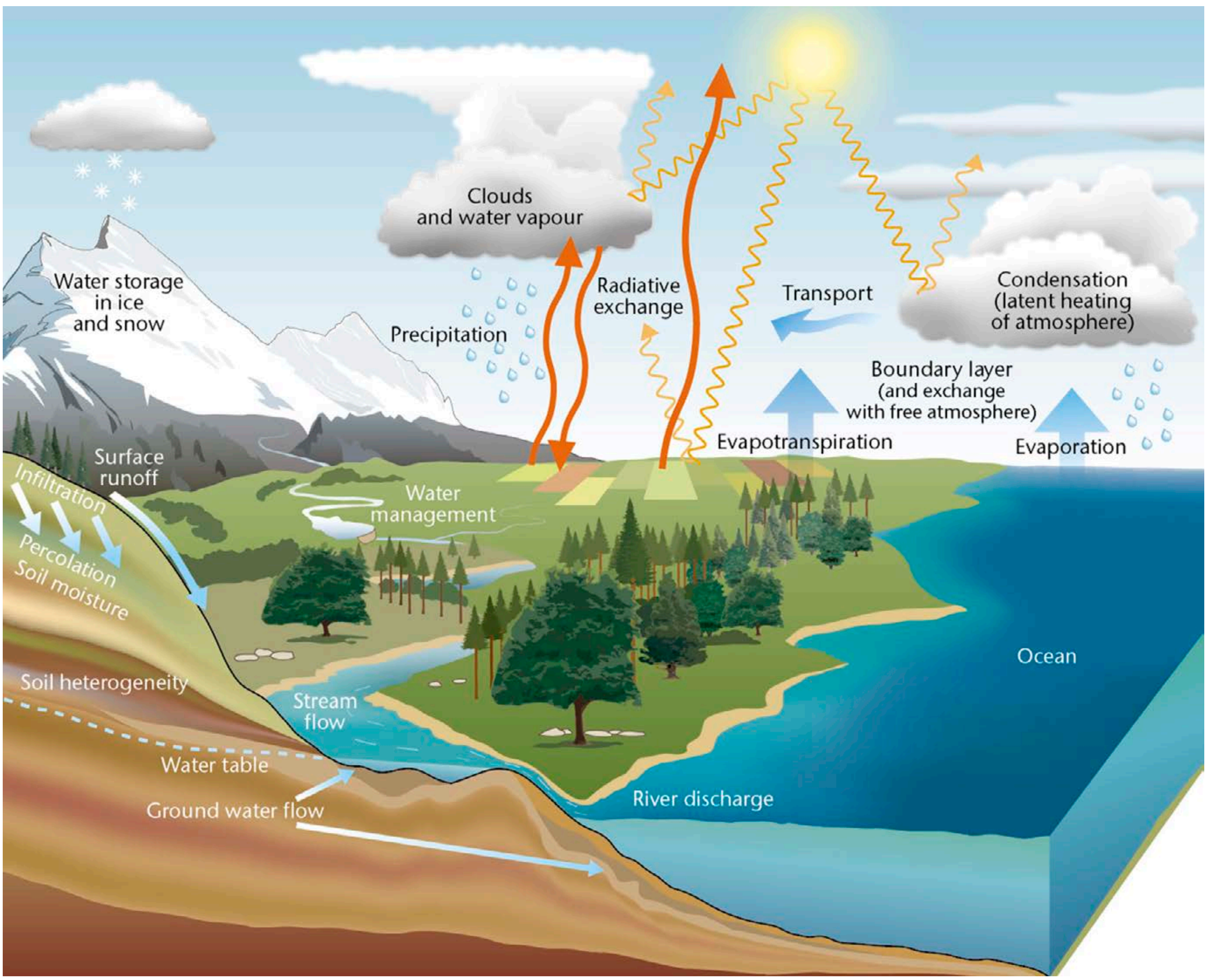
Water molecules bind to themselves through an interaction called **cohesion**, and to other substances through a process called **adhesion**. In the case of adhesion, the water molecules "stick to" the other substance, but do not change the molecular structure of the substance. For example, a droplet of water can defy gravity and stick to a vertical window without falling due to cohesion (molecules of water sticking together), surface tension (a strong film surrounding the droplet), and adhesion (the water molecules sticking to the glass). When if more water molecules are added to the droplet, it may become so large that the molecular forces can no longer overcome the downward force of gravity and the water droplet runs down the window.

Cohesion and adhesion also produce a process called **capillary action**, in which molecules of water move upwards through very small tubes against gravity. In this case, the water molecules want to stick to the tube (adhesion), and also want to stick together (cohesion), which forces water up through the tube continuously. Without this property, the nutrients needed by plants and trees would remain in the soil.

Universal solvent

An extraordinary property of water is its ability to dissolve other substances. We know of very few substances that have not been identified in solution in water. Were it not for the solvent property of water, life could not exist, as water transfers vital nutrients in animals and plants.

HYDROLOGIC CYCLE



The total amount of water on earth has been constant in quantity – little water has been added or lost over time. The same molecules of water have been transferred over and over again from water bodies to atmosphere to land and back to the water bodies for millennia. This continuous cycle is known as the '*hydrologic cycle*'. The sun acts as the "engine" for the hydrologic cycle, causing evaporation.

Evaporation (liquid to gas)

When heated, molecules on the surface of liquid water become sufficiently energized to break their bonds with the other water molecules and rise as an invisible vapour in the atmosphere.

Transpiration (liquid to gas from plants)

Plant leaves emit water vapour formed during respiration from their pores (stomata). An actively growing plant will transpire 5-10 times as much water as it can hold every day. Transpiration is sort of the equivalent of sweating in animals.

Condensation (vapour to liquid)

Condensation occurs when air saturated with water vapour cools so much that these particles then come together and form clouds.

Precipitation (liquid or solid)

Precipitation occurs when small droplets (liquid) or crystals (solid) water fall from the atmosphere to the land. Tiny ice pellets form in the clouds when water condenses and freezes around dust particles (water adsorbs to the dust particle). If the air is above freezing at ground level, the precipitation will fall as rain (or, occasionally, hail), and if it's below freezing, the precipitation will fall as snow or another type of icy precipitation.

Precipitation may also occur when a warm air mass is forced to a higher elevation due to landscape features. When it cools it is not able to hold as much water vapour and the excess moisture "falls out" of the air mass as precipitation. For example, when air masses rise over mountains they cool, which results in condensation and precipitation at the base and slopes of the mountains.

Runoff

Snowmelt or excessive rain can travel across the surface of the land in the form of overland flow until the water reaches a water body. This "runoff" water travels from the place it was deposited on the landscape into larger and larger streams. As the water in an area drains, runoff is the visible flow of water in rivers, creeks, and lakes.

Percolation

Percolation occurs when water moves from the surface of the land into deeper layers, infiltrating the ground through cracks, joints, and pores in the soil and rocks. When the water reaches the water table, it becomes groundwater.

Groundwater

Water held underground in soil or in pores and crevices in rock is called groundwater. In some areas, if the geology is correct, the groundwater can flow to support streams (under- and above-ground) and can be tapped by wells. Groundwater can last for long periods of time underground without evaporating (> 1000 years).

Water table

The upper level of an underground surface in which the soil or rocks are permanently saturated with water.

WATER-CLIMATE RELATIONSHIP

Water is intimately related to climate through the hydrologic cycle. The climate of a region will strongly impact the water supply within that region through precipitation and evaporative loss. Large water bodies (e.g., ocean, Lake Winnipeg, Great Lakes, Lake Baikal, etc.), have a moderating effect on local climatic conditions as they can serve as large sources and sinks for heat. Regions close to large water bodies will often have milder winters and cooler summers.

An enormous amount of solar energy is required to evaporate water into the atmosphere due to the high heat capacity of water. Heat from the sun becomes trapped in the atmosphere by greenhouse gases, with water vapor being the most plentiful. Energy (heat) is released into the atmosphere as water vapour condenses to precipitation. As such, water acts as an energy transfer and storage medium for the climate system.

SNOW, ICE, AND GLACIERS

SNOW

Snow only occurs in parts of the world but has extensive effects on regional weather patterns. The study of snow, its formation, its locations, and how a snowpack changes over time, improves our ability to predict storms and learn about the relationships between snow and weather.

In Canada, an average of 36% of the total annual precipitation is in the form of snow, with wide variability across the country. In the North, 50% of precipitation is snow, in the Prairies it's 25%, and in southern Ontario it's as little as 5%.

Snow impacts the distribution of streamflow year-round. Water is stored on the landscape as snow during winter months instead of immediately infiltrating the soil or running off into stream channels like rainfall. Snow melt in the spring introduces a large amount of water to local streams. If lots of snow falls in the winter, there may be large floods in the spring, but if a winter is relatively dry there will not be as much potential for flooding.

Physical properties of snow

Snow is precipitation in the form of ice crystals. When it falls to the ground and accumulates, it may be considered water in storage and is part of the **cryosphere** (the portion of the earth's surface where water is in solid form). On the ground, it is an accumulation of packed ice crystals, and the conditions of this "snowpack" are determined by several qualities, including colour, temperature, and water equivalent. With the fluctuation of weather, the snowpack may vary as well.

Snow falls in several forms:

- Snow flakes are 6-sided clusters of ice crystals that form in a cloud and fall to earth directly.
- Snow pellets, or **graupel**, form when supercooled water droplets are collected and freeze on falling snowflakes.
- Sleet is drops of rain or drizzle that freeze into ice.

Most snow and ice appear white because visible light is white, and most visible light is reflected back by the snow or ice surface. Snow may also appear blue if light is scattered multiple times through the ice crystals. Particles or organisms present in the snow may also affect the colour of the snow. Watermelon snow, which appears red or pink in colour, occurs because of a freshwater algae that contains a bright red pigment. Watermelon snow is commonly seen in high alpine areas and coastal polar regions during the summertime. Iron rich water, as seen in some glaciers, can cause the ice to have a deep red colour.

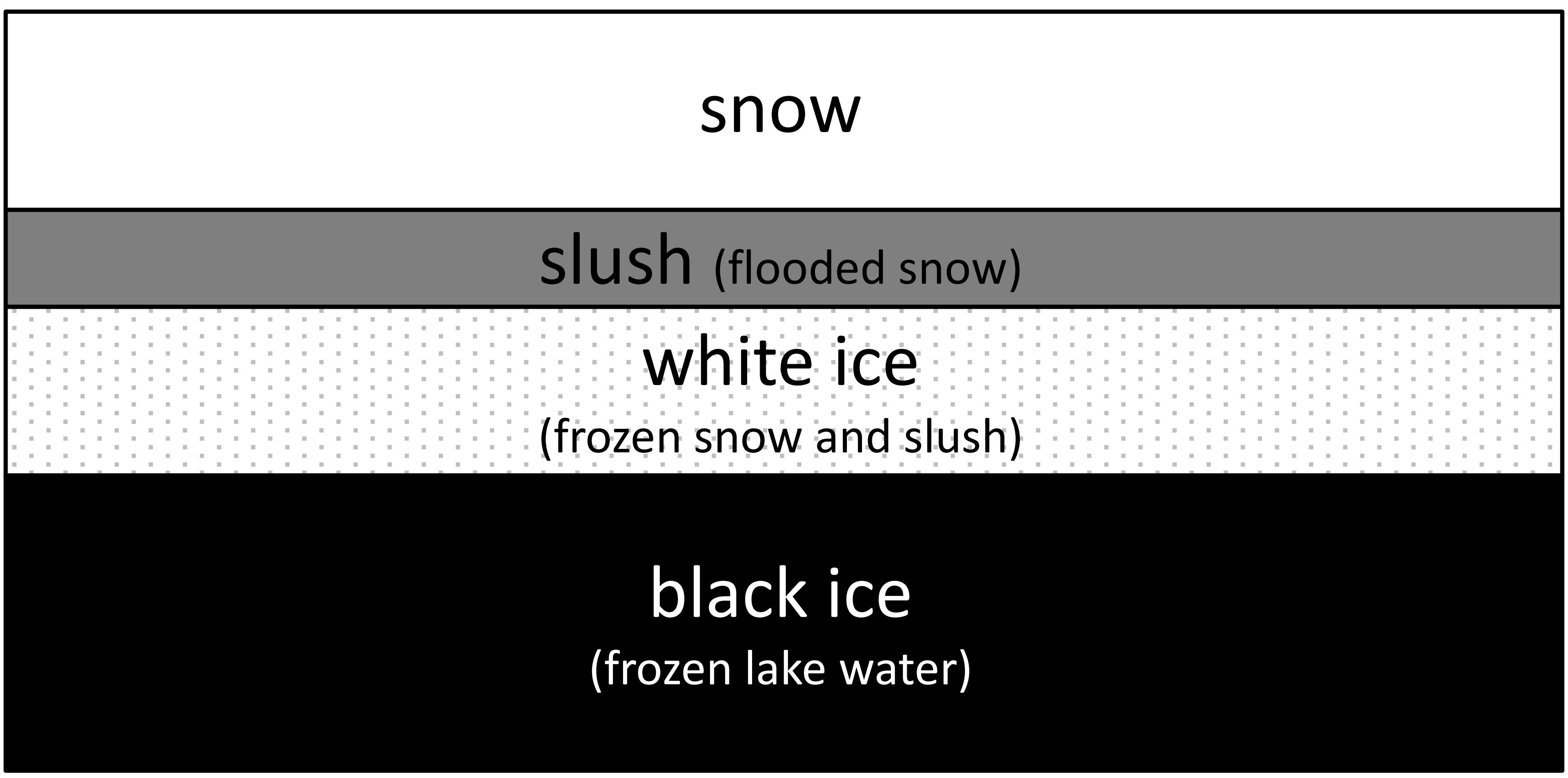
Antarctic glacier stream iron
© Lee Hrenchuk

Snow is an excellent insulator. New snow contains a high percentage of air trapped within its crystals. Uncompacted, fresh snow is up to 90-95% trapped air. Since the air is trapped, the transfer of heat is reduced.

ICE

Ice forms on the surface of water bodies when the temperature drops below freezing. The nature of these ice formations may be simple as a floating layer that thickens gradually, or it may be very complex, especially when water if fast flowing.

Still water bodies, such as lakes and ponds, may freeze over completely in a short period of time (hours to days). Once the first layer of ice forms on the surface of a water body, further growth proceeds both downwards (as water freezes to the underside of the ice layer), and upwards (as snow and slush accumulate on the frozen surface). The presence of snow on top of the ice offers insulation and slows the process of ice formation.



Lake ice diagram. Ice grows downward as lake water freezes to the underside of the ice, creating black ice. Ice grows upward when snow and slush accumulate and freeze on the surface, creating white ice. Slush is flooded snow, and the snow cover is dry (non-flooded) snow. Additional layers may be present between or within black and white layers.

When ice forms across the surface of a still water body it seals off the water from the atmosphere, preventing exchange of gases such as oxygen and carbon dioxide. It also blocks out much of the light, making it difficult for aquatic plants and algae to produce oxygen. During the winter oxygen levels in the lake slowly decline, with a large anoxic zone (no oxygen) building up at the bottom of the lake. This can present a serious challenge to organisms that require oxygen, because if the lake stays frozen for too long, oxygen levels can become low enough to kill them.

Flowing water bodies such as rivers take longer to freeze than still ones because the motion of the water prevents ice from forming. However, once temperatures are cold enough even the motion of the water is not enough to keep the surface from freezing. Ice formed on flowing water may be flat and smooth or may be uneven and broken, depending on conditions during freeze-up. During spring melt, broken ice can accumulate on rivers at obstructed sections (such as a dam). These deposits may block large portions of the river's flow and cause local flooding. Additionally, the chunks of ice may collide with structures (e.g., bridges) and cause major damage.

Sea Ice

Sea ice is made up of frozen sea water and snow, and is found in the polar oceans, covering, on average, about 25 million km^2. Sea ice is formed, grows, and melts within the ocean, unlike icebergs, glaciers, ice sheets, and ice shelves that begin on land. Sea ice grows during winter months and melts through the summer months. However, some ice remains year-round (called multi-year ice).

Sea ice is a critical component of our planet as it influences global climate, polar ecosystem ecology, and people who live in the Arctic. The surface of sea ice appears white, meaning that a lot of the sunlight that strikes the surface bounces off and is not absorbed by the surface, allowing ice-covered areas to remain cool. If the amount of sea ice present on earth is reduced, more solar energy will be absorbed by the ocean, and global temperatures will increase (which, in turn, will cause more sea ice to melt, which will lead to more warming. This scenario is known as a positive-feedback loop).

GLACIERS

A large quantity of the fresh water on earth is frozen in high mountain glaciers. Snow deposited at high altitudes over many years settles and compacts so much over time (millennia) that it turns into glacial ice. This ice slowly proceeds downslope under the pull of gravity like a frozen river and eventually melts to become part of streamflow at lower (warmer) elevations. If the rate of melting is greater than the rate of accumulation, the glacier recedes (appears to retreat uphill). If the rate of melting is less, the glacier advances (appears to move downhill). Unlike rivers fed by snowmelt that experience peak flow in spring, glacier-fed rivers reach their peak during hot summer weather.

Glaciers slow the movement of water through they hydrologic cycle by "trapping" water for thousands of years. In this way, glaciers are excellent fresh water storehouses, releasing water slowly over time. Glaciers, however, can also release water suddenly with great force. Glacier-outburst floods, called jökulhlaups (Icelandic, "glacial run"), can be devastating to flooded areas.

TYPES OF WATER BODIES

Lake – a lake is a sizeable water body formed when water fills a depression in the landscape. Lakes are surrounded by land and fed by rivers, streams, and local precipitation. Lakes may freeze over partially or fully in winter, but liquid water will always remain present below the ice. Lakes are often classified based on a variety of conditions, such as their chemical or biological condition.

Lake Mapourika
© Richard Palmer

Pond – a pond is similar to a lake, but tends to be smaller and shallower. Ponds are typically formed in natural hollows such as limestone sinks, holes created by beaver work, or even human led digging. Ponds may exist seasonally or from year to year, and may freeze solid in winter.

Waikato River

River/Stream – rivers and streams are bodies of fresh, flowing water. The water will either run permanently or seasonally into another body of water such as a pond, lake, or ocean. The difference between rivers, streams, and creeks is based on size of the water body.

Ocean - a very large expanse of salt water surrounding the continents and covering a large proportion of the surface of the globe. The ocean is divided up into several "oceans" geographically, but in fact all oceans on earth are connected.

Estuary
© Nathan Anderson

Estuary – an estuary is a partially enclosed coastal body of brackish water (mix of salt and freshwater), with one or more rivers or streams flowing into it and a free connection to the open sea.

Wetland – a wetland is a nutrient-rich ecosystem formed when water is trapped on the landscape due to poor drainage, occasional flooding, or coastal barriers. Wetlands are lands that are permanently or temporarily submerged or permeated by water and characterized by plants adapted to saturated soil-conditions.

Wetland
© U.S. Fish and Wildlife Service

STREAMS AND WATERSHEDS

Streams of all sizes, from tiny brooks to large rivers, are of immense importance to the geology, biology, and history of most ecosystems. Although they contain only a small portion of the total amount of water present in an area at a given time, streams play a crucial role in the hydrologic cycle. They act as drainage conduits for surface water, provide habitat, nourishment, and means of transport to countless species, leave valuable deposits of sediments, and provide power to produce electrical energy, among many other things.

The existence, flow, and size of a stream are influenced by:

- availability of surface water
- channel geometry
- slope of land

DRAINAGE PATTERNS AND WATERSHEDS

The area of land drained by a stream is called the stream's **watershed** or **drainage basin**. All precipitation and groundwater in this area will eventually flow into the stream and be carried elsewhere. Since water will always flow downhill, a stream's watershed is separated from the watersheds of neighbouring streams by higher lands called **drainage divides**. All water that falls on one side of a drainage divide will end up in one watershed, while water that falls on the other side will end up in another one. If you were to stand by a stream at the bottom of a valley, you might look up and see hills all around you. All the land that slopes down toward your stream is part of the stream's watershed. See the mapping/topography section later in this document for additional information about watersheds.

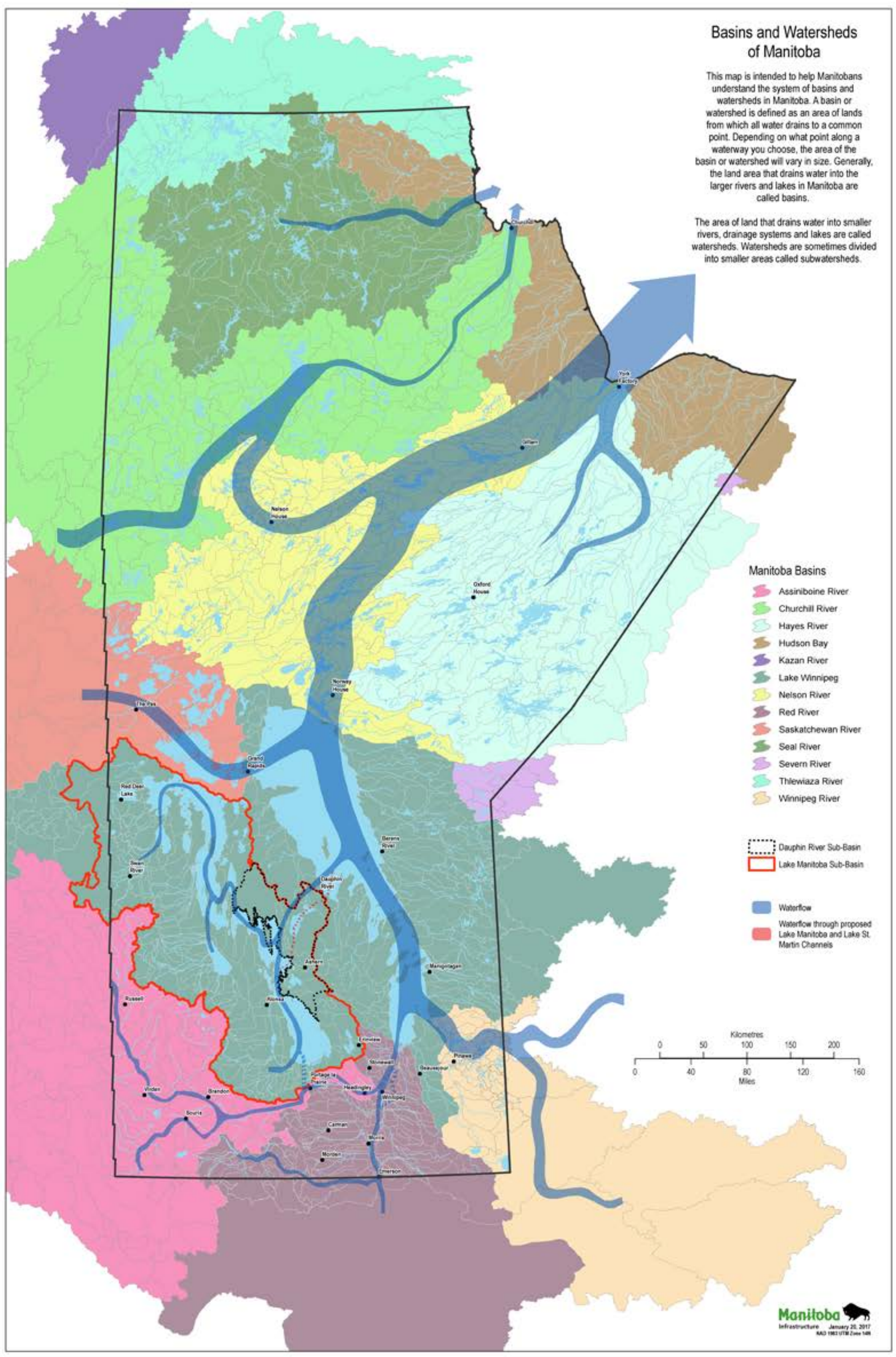
You can look at the watersheds on a landscape at many scales, from locally to continentally. The watershed of a tiny stream will be much smaller than that of a river; the river's watershed is made up of all the watersheds of its tributaries (streams that feed the river) combined. Canada has five continental watersheds. Water in each of these watersheds will end up in: Pacific Ocean, Arctic Ocean, Atlantic Ocean, Hudson Bay, and Gulf of Mexico.

Canada continental watersheds. The water that falls in each area will eventually end up in the water bodies noted. All water in Manitoba will eventually end up in Hudson Bay.

Modified from © 2018 Canadian Geographic

Watersheds in Manitoba

The figure below illustrates the major watersheds of Manitoba, which can be further subdivided into many smaller and smaller watersheds, or sub-basins, depending on the spatial scale in which one is interested. Note that most of these watersheds extend beyond provincial borders, including reaching all the way to the continental divide in the Rocky Mountains. Most of Manitoba lies at a lower average elevation than its neighbouring provinces and states, meaning that much of the runoff from these neighbouring regions flows into, and through, Manitoba. All water in Manitoba eventually makes its way north to Hudson Bay.



Manitoba Watersheds

SHAPING THE LANDSCAPE

Flowing water changes the landscape it travels through. Given enough time, a stream can carve deep canyons through solid rock. For example, the Grand Canyon (as seen below) was initially formed by erosion from the river.

The volume of water and the speed and timing of the flows governs how a river shapes the surrounding landscape and the species found within it. Rainfall, snowmelt, and groundwater all contribute to the volume of flow, varying by season and year. Most high flows are caused by spring snowmelt in Canada. Rainstorms can also cause high flows and floods, especially on small streams. In Canada, the lowest flows for streams generally occur in late summer, when precipitation is low and evaporation and consumption by plants is high, and in late winter, when rivers are ice-covered, and the precipitation is stored until spring in the form of ice and snow.

In steep, narrow areas such as at the “top” (highest points) of the watershed, water flows quickly and may cut down deeply into the substrate (soil and rock of the stream bed). In gently-sloping, wide areas such as those found “lower down” in the watershed, water flows slowly and may deposit some of the materials it carries in the flow (e.g., sand particles). Over time, slow-flowing rivers will meander back and forth across the landscape instead of cutting a straight line. The Red and Assiniboine Rivers are good examples of relatively slow-flowing, gently-sloped rivers, and as a result they both have many bends and sand deposits in them.

Erosion and Sedimentation

Rivers can move large amounts of material across the landscape. Any material that can be dislodged can be transported, such as silt, sand, and soil. Collectively, this material is called **sediment**. Material present in the water column is called **suspended sediment**, while materials deposited on the bottom of a water body are simply called **sediment**. Sediment is picked up from the landscape (**erosion**), **transported** by the stream, and ultimately deposited in an area with slower flow where the sediment is no longer able to stay in suspension (**sedimentation**), such as a lake or ocean. Sediment may also be deposited in a slower-flowing section of the stream. **Fluvial sediments** are those which have been eroded, transported, and deposited by flowing water.

Natural erosion takes place slowly, over centuries to millennia. Streams may also experience accelerated erosion due to human activity, such as digging along banks, removal of riparian vegetation, etc.

Transportation of sediment across the landscape begins at a very small scale at the top of the watershed where falling raindrops cause a phenomenon called **sheet erosion**. As water droplets run downhill, they pick up sediment and carry it to small streams, which carry it further down the watershed. The greater the discharge of a stream, the higher the capability there is for sediment transport.

Sediment comes to rest when there is not enough energy to transport it further, and the process of deposition is called **sedimentation**. **Depositional areas** occur as newly deposited material on a flood plain, sand/silt bars and islands in stream channels, and deltas in places where streams enter lakes and oceans. Substantial deposits may or may not be visible, depending on the amount of sediment transported.

The presence of suspended sediment directly affects stream communities in a variety of ways:

- decreases light penetration into water
- erodes the protective mucous covering the eyes and scales of fish, making them more susceptible to infection and disease
- particles absorb warmth from the sun and increase water temperature.

- high concentrations of suspended sediment can dislodge plants and sedentary organisms
- toxic chemicals can become attached (adsorbed) to sediment particles and transported to/deposited in other areas.
- settling sediments can bury and suffocate fish eggs.

AQUATIC ECOLOGY AND ECOSYSTEMS

Ecology is the study of how organisms interact with each other and with their environment (**habitat**), including relationships between individuals of the same species, between different species, and between organisms and their physical and chemical (**abiotic**, or non-living) environments. **Aquatic ecology** includes the study of these relationships in aquatic environments.

An **ecosystem** is a community of living organisms and their abiotic environment (water, land, and air), linked by the flow of energy. Aquatic ecosystems may be permanent (e.g., oceans, lakes, rivers), or ephemeral (e.g., some streams, wetlands, floodplains). Aquatic ecosystems can also be present in areas that may appear to be inhospitable to life, such as thermal springs, glaciers, and polluted waters.

Aquatic ecosystems often contain a variety of species, including (but not limited to), bacteria, viruses, fungi, protozoans, algae - microscopic plants, a variety of invertebrates (insect larvae, molluscs, worms, zooplankton (microscopic animals), etc.), macrophytes (plants), and animals (fish, amphibians, mammals, reptiles, birds, etc.). The species found in each system vary depending on both **biotic** and **abiotic** conditions. Habitat conditions are unique to each type of ecosystem, leading unique assemblages of species. For example, many rivers are relatively oxygen-rich and fast-flowing compared to lake habitats. The species adapted to flowing water are often rare or absent in the still waters of lakes and ponds.

Abiotic (chemical, physical) characteristics of aquatic habitats influence which species may be found in an area. For an animal or plant to be found within a habitat, it needs to be able to survive the conditions, find shelter and space, and have nutrients available. The species within an area can also impact aspects of their environment (for example, beaver dams change water flows on the landscape).

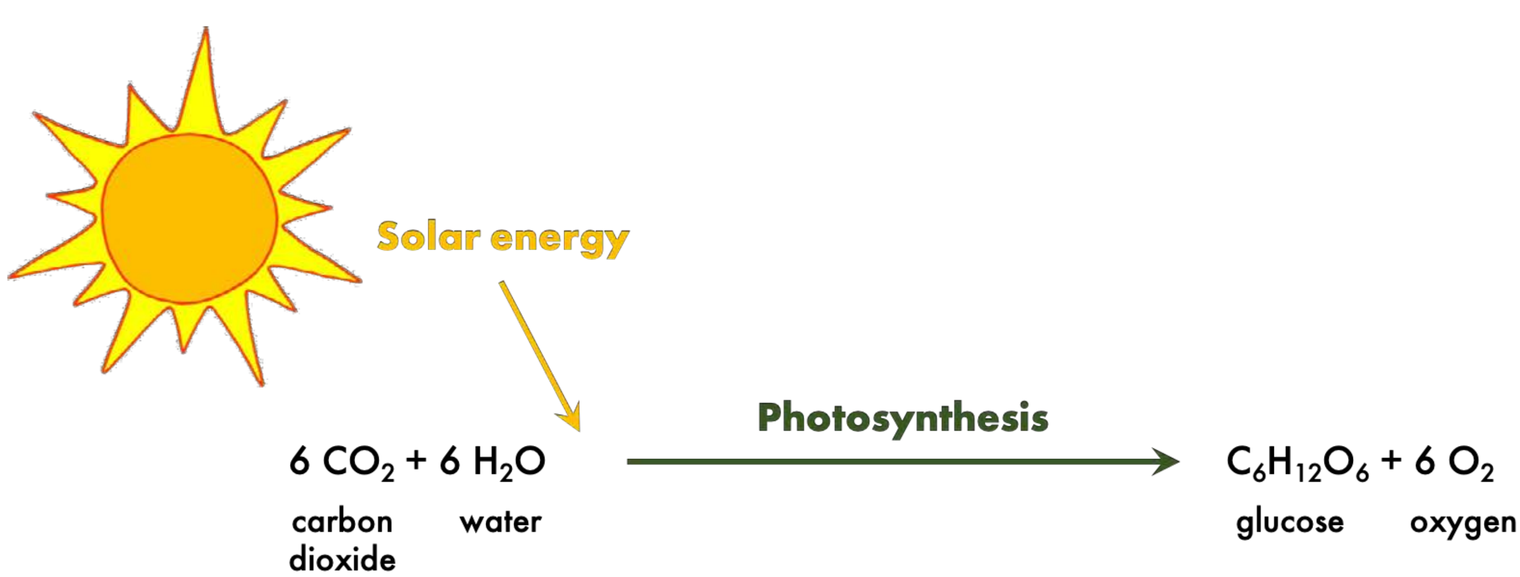
Biotic (living) characteristics of habitats also impact the organisms found within them. Interactions between species, competition for resources (food, habitat), predation, and parasitism, all impact species abundance and diversity.

TROPHIC ECOLOGY

The available energy in an aquatic ecosystem changes with daily and seasonal cycles, and the raw materials required by organisms continuously cycle through and within the ecosystem. Some time periods may be very productive (i.e., lots of organisms alive), and others may be less so (i.e., fewer organisms alive), and these fluctuations help to determine the short-term productivity, as well as the longevity of the system.

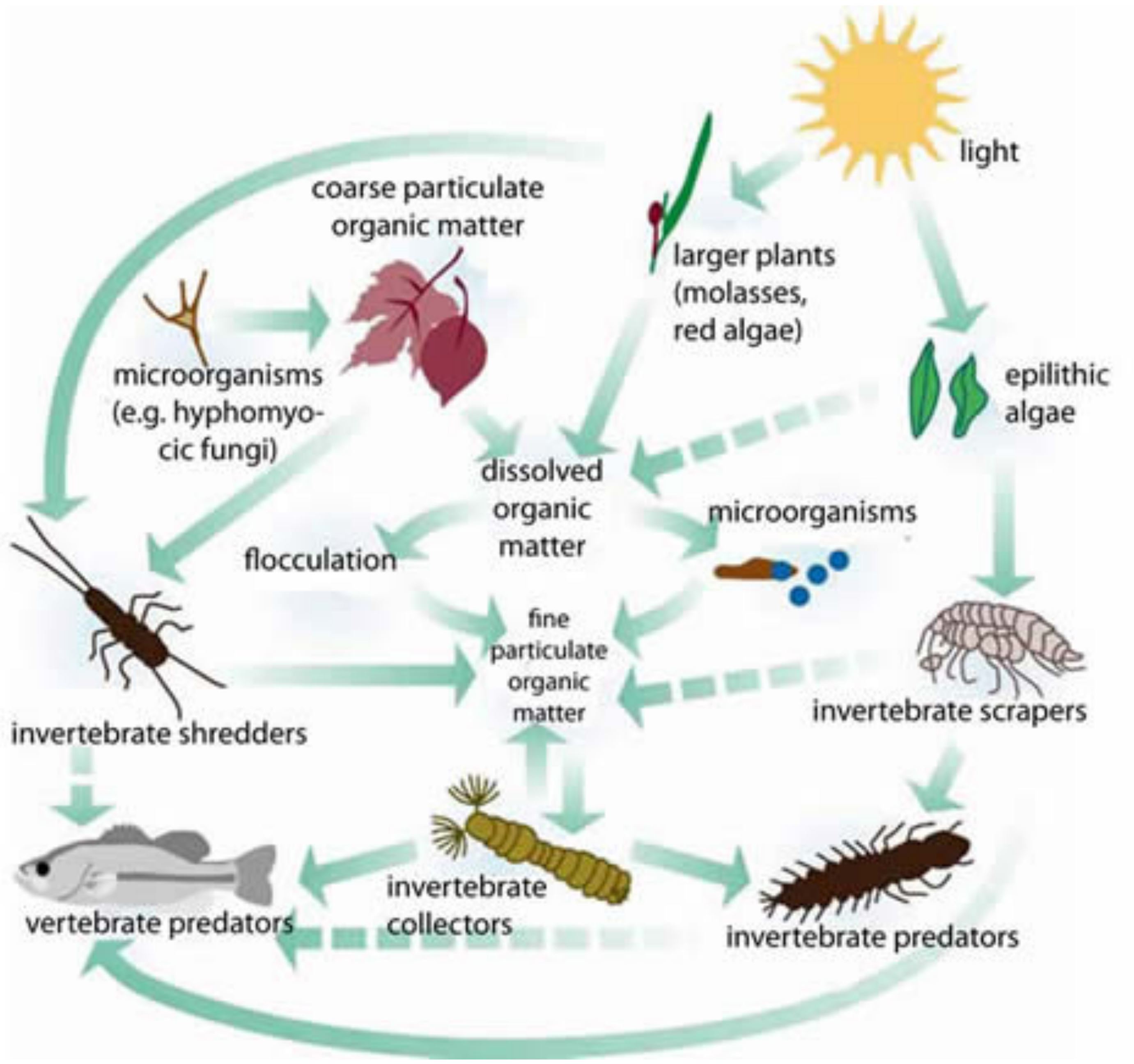
Photosynthesis and respiration

In aquatic ecosystems the basis of life and the resulting food web is **photosynthesis**, a chemical process performed by particular types of organisms (e.g., plants, algae). Photosynthesis uses *energy from sunlight* to transform *water* and *carbon dioxide* (CO_2) into *oxygen* and *carbohydrates*. The carbohydrates nourish the plant and the organisms that eat it, and the oxygen, released as a by-product into the environment, adds to the oxygen pool present in the aquatic ecosystem (the rest of the oxygen is from the atmosphere, also released through photosynthesis). In water layers where photosynthetic rates are very high (e.g., close to the shore of a lake), the water may become supersaturated, that is, the oxygen content may exceed 100% of saturation.



BIOLOGICAL COMMUNITIES

Biological communities within aquatic ecosystems are interconnected, and we can use **food webs** as maps to help us understand how the ecosystem functions.



Example of an aquatic (stream) food web

- **Primary producers** (**autotrophs**) are organisms that use inorganic sources of carbon and energy from solar radiation to make their own “food” (through photosynthesis) and do not consume other organisms. In aquatic systems, they are typically grouped as either **macrophytes** (large plants) or **algae** (microscopic plants). Both types occur in shallow, nearshore areas. In the deeper, open-water areas, algae are the dominant green plants. Collectively, these plants form the base of the aquatic food webs. Primary producers are an essential source of energy for consumers.

- **Heterotrophs** are organisms that use organic sources of carbon by consuming other organisms and/or their by-products. Heterotrophs often shift their position in the food web throughout their life cycle because as they grow they are able to access different types (sizes) of food. Examples include animals, bacteria, and fungi.

- **consumers** are species that consume other live organisms
- **decomposers** are species that consume dead organic matter or waste products

FOOD WEBS

The numbers and variety of organisms present in an aquatic food web are dependent on the **productivity** of the ecosystem. This productivity depends on the availability of energy and raw materials (nutrients, minerals) within the ecosystem, which are taken up by primary producers.

Primary Producers (Autotrophs)

Aside from light, primary producers require oxygen, carbon dioxide (CO_2), and mineral nutrients to survive and grow.

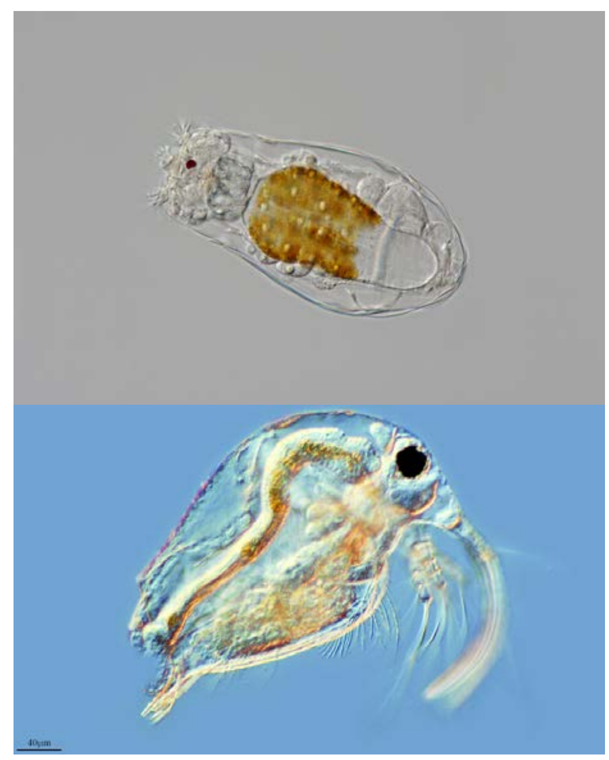
- Most algae are unable to survive in **anoxic** (no oxygen) conditions, meaning that plants and algae are not typically found in deep water where oxygen is low and the light can't reach.
- Carbon dioxide is almost always available as it has a variety of sources: diffusion from the atmosphere, weathering of carbonate rocks in the watershed, respiration of organisms, and decomposition of organic matter.
- Dissolved mineral nutrients are absorbed from the water by algae, and from the water and sediments by higher plants. Typically, the most important nutrients are **phosphorus** and **nitrogen**, because they are present in very low concentrations and are typically low enough to limit the growth of algae. Other minerals essential to life, such as the major ions (calcium, magnesium, sodium, and potassium) and certain trace metals (iron, cobalt, molybdenum, manganese, copper, boron, and zinc), are usually present at sufficient concentrations. Silicon is required by diatoms and a few other groups of algae and is usually, though not always, present at sufficient levels. Another mineral required by all living things, sulfur (in the form of sulfate), is typically not deficient in lakes.

Algae are one of the main groups of primary producers. They are found in countless forms and live in nearly all environment types. Most are microscopic and are found growing as single cells, small colonies, or filaments of cells. Suspended algae are called **phytoplankton**, while algae attached to surfaces (e.g., rock, macrophyte) are **periphyton**. Phytoplankton float in the open water and drift with currents. If key nutrients, such as phosphorus, are very abundant, they can grow and reproduce quickly (called an **algal bloom**).

Consumers (Heterotrophs)

While photosynthesis limits plant growth to the sunlit portions of lakes, consumers can live and grow in all lake zones, although the lack of oxygen (anoxia) may limit their abundance in bottom waters and sediments.

Primary consumers
Many primary consumers are **invertebrates** such as zooplankton, insect larvae, and molluscs. **Small fish**, including minnows and the young of larger species, also feed directly on algae and plants. Not all algae are equally edible; some algal species have spines and other structures that make their cells more difficult for small animals to consume, and some of the cyanobacteria and dinoflagellates can produce toxins that can be fatal. Examples include a rotifer (zooplankton) with its gut filled with diatoms and a *Bosmina* sp. (zooplankton) with its long gut filled with algae seen on the right.



Secondary consumers
Secondary consumers, such as predaceous invertebrates (e.g., dragonfly larvae) or **planktivorous fish** (fish that eat plankton), consume primary consumers.

Many **benthic organisms** are secondary consumers and are also important recyclers of nutrients otherwise trapped in the sediments. Benthic organisms include many invertebrates and bottom-feeding fish and their feeding strategies vary widely. Some, such as clams, filter small bits of organic material from water as it flows by. Others eat detritus that has sunk to the bottom.

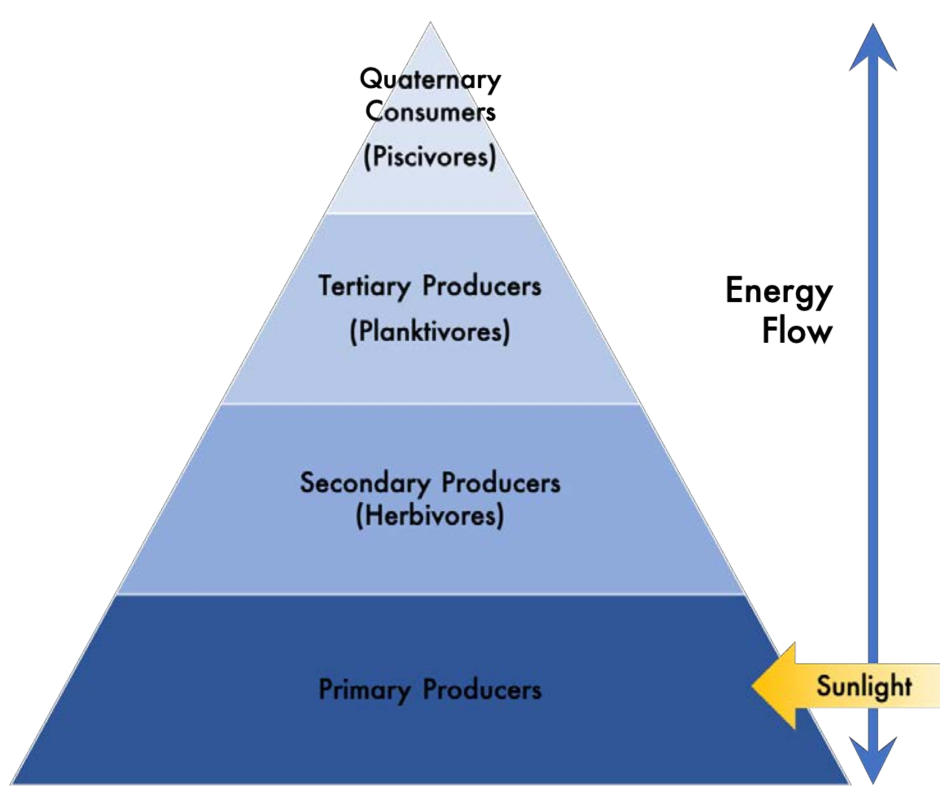
Higher-level consumers
The best-known group of aquatic consumers in freshwater systems is fish. Organisms that prey on the lower-level consumers include fish (**piscivorous fish** are fish that eat other fish)

Glassworm (*Chaoborus* sp.) *Mysis* sp. Fathead Minnow

and other carnivorous animals (loons, grebes, herons, albatross, and otters). Different species exploit different habitats (niches). Bass and northern pike are found in lakes that have beds of aquatic macrophytes suitable for spawning. Walleye spawn on a gravel bottom. Lake trout typically live in very clear lakes with cold, well-oxygenated deep water.

Decomposers

Decomposers, including bacteria, fungi, and other microorganisms, feed on the remains of aquatic organisms and in so doing break down (decay) organic matter, returning it to an inorganic state. Some of the decayed material is recycled as nutrients, such as phosphorus (in the form of phosphate, PO_4^{-3}) and nitrogen (in the form of ammonium, NH_4^+) which are readily available for new plant growth. Carbon is released largely as carbon dioxide that acts to lower the pH of bottom waters. In anoxic zones some carbon can be released as methane gas (CH_4). Methane gas causes the bubbles you may have observed in lake ice.



STREAM ECOLOGY

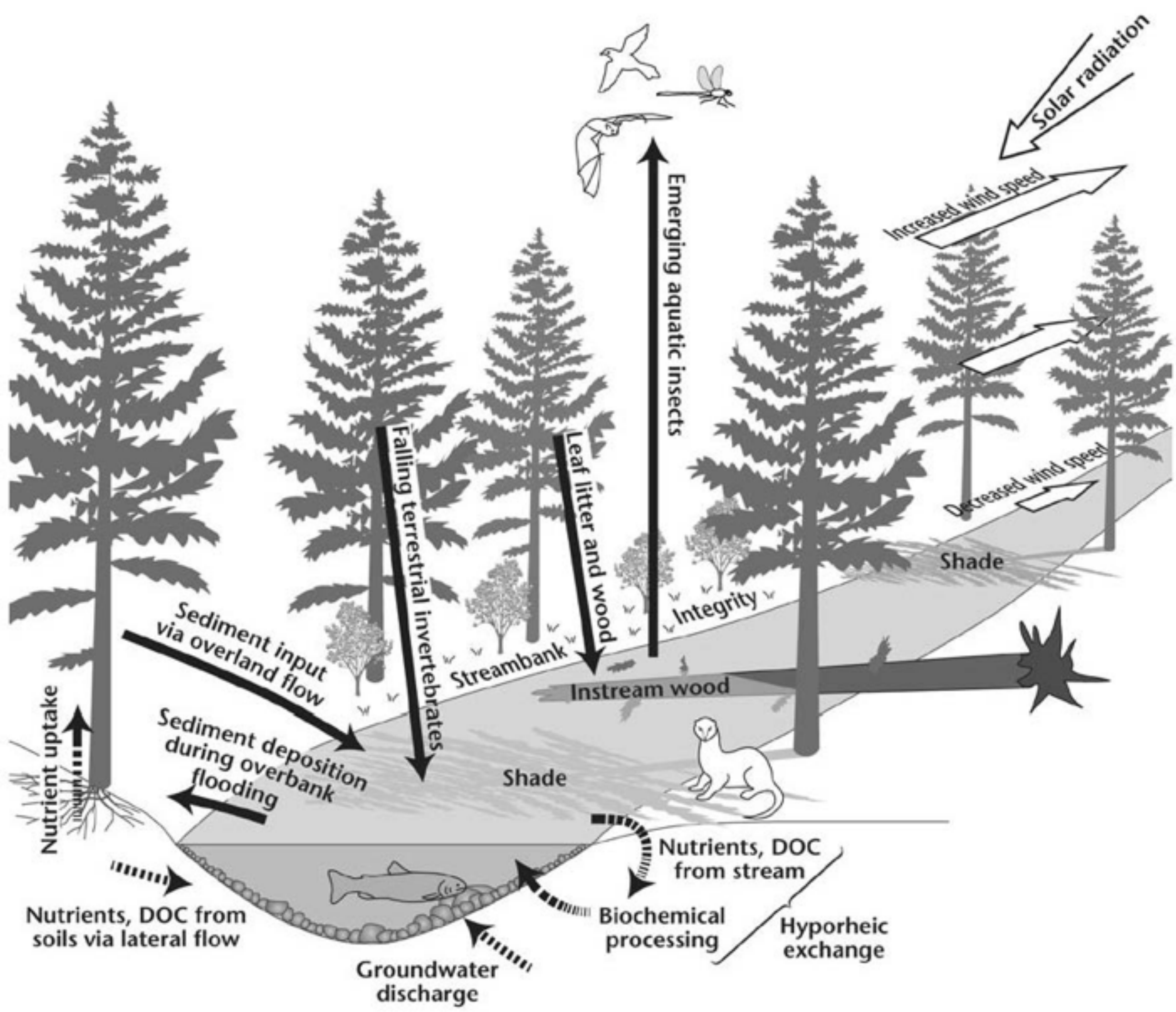
WHAT A STREAM CARRIERS

As water rolls down the slopes of a watershed, it carries things with it. It dissolves chemicals and carries them. It carries particles of dirt. If it is meltwater from a glacier, it will carry glacial flour, which is sediment that the glacier has made by grinding the rock beneath it very finely, making the water look almost milky. And it carries organic matter: tiny bits of leaves, bacteria, and a lot of other things too small to see. As it flows, it grows to rivulets, and carries larger bits of matter. By the time the water gets all the way down to the stream, it is full of whatever was on (and in) the land around it. The river can carry sticks, leaves, logs, brush, and even sand, pebbles, rocks, and boulders. There are other ways that things can end up in a river. Winds can blow in sediment (particles of dirt) and bits of organic matter. A lot of living things like insects depend on flowing water to carry out their life cycles. Birds leave urine, droppings, and feathers. Other animals visit the river and often leave their waste in it. Many animals die in the river, adding their organic materials to the water. Natural events can occur that alter the river's ecology. Mudslides, heavy rainfall, and fires can make drastic changes. These events (though they seem extreme from our human point of view), are a very large and slow, but nevertheless integral, part of the river's ecosystem.

Rivers are closely tied with the atmosphere. Gases from the air, like oxygen, carbon dioxide, and nitrogen dissolve into the water. The colder the water is, or the more it churns as it flows downhill, the more gases there will be in it.

RIPARIAN CORRIDORS

The narrow area alongside a stream that has its own special vegetation is called the riparian zone or corridor. What plants you will find in a riparian corridor depend on where the stream is: continent, climate, stream hydrology, geology, soil characteristics, and many other factors. Riparian zones contribute nutrients, shade, organic materials for small organisms to eat, stream bank/soil stability, and habitat.



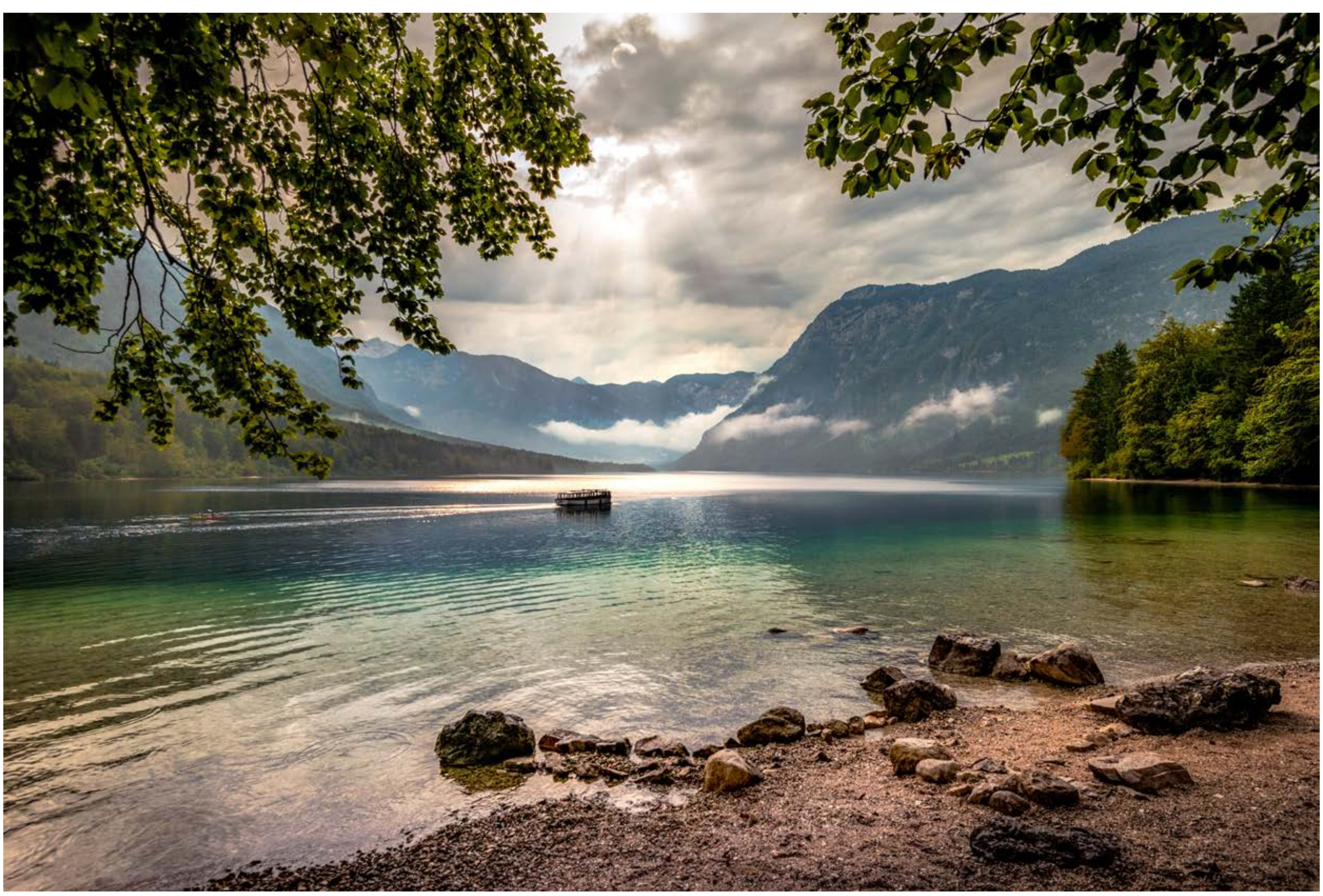
A stream reach showing many of the elements and process that link streams and riparian areas

© Richardson and Moore 2010

FLOODS

Floods are natural events that influence stream ecology. Animal and plant communities in rivers have spent millions of years adapting to the conditions around them, and floods have simply become a part of a larger cycle of stream ecology for them. Riparian corridors depend almost exclusively upon their streams' flooding cycles for their existence. Many fish wait until the first sign that the annual spring flood has begun to start **breeding**. Many insect larvae wait for flooding to begin to **lay eggs**, **hatch**, or **metamorphose**. Flooding provides a bonanza in new **food sources** for stream denizens. Floods flush insects, bugs, and worms from the land into the stream, which become food for fishes. Flooding results in increased **nutrients** for the stream. Nutrients (like nitrogen and phosphorus) are washed out of soil and animal feces. Nutrients added to the shallow, warmer waters of the floodplain lead to extra growth of **plankton**. The more nutrients present in a stream (up to a point), the more invertebrates will be able to live in it and invertebrates form the base of the **food web**. Floods also wash dead brush and trees into the stream, providing **habitat** for countless animals.

LAKE ECOLOGY

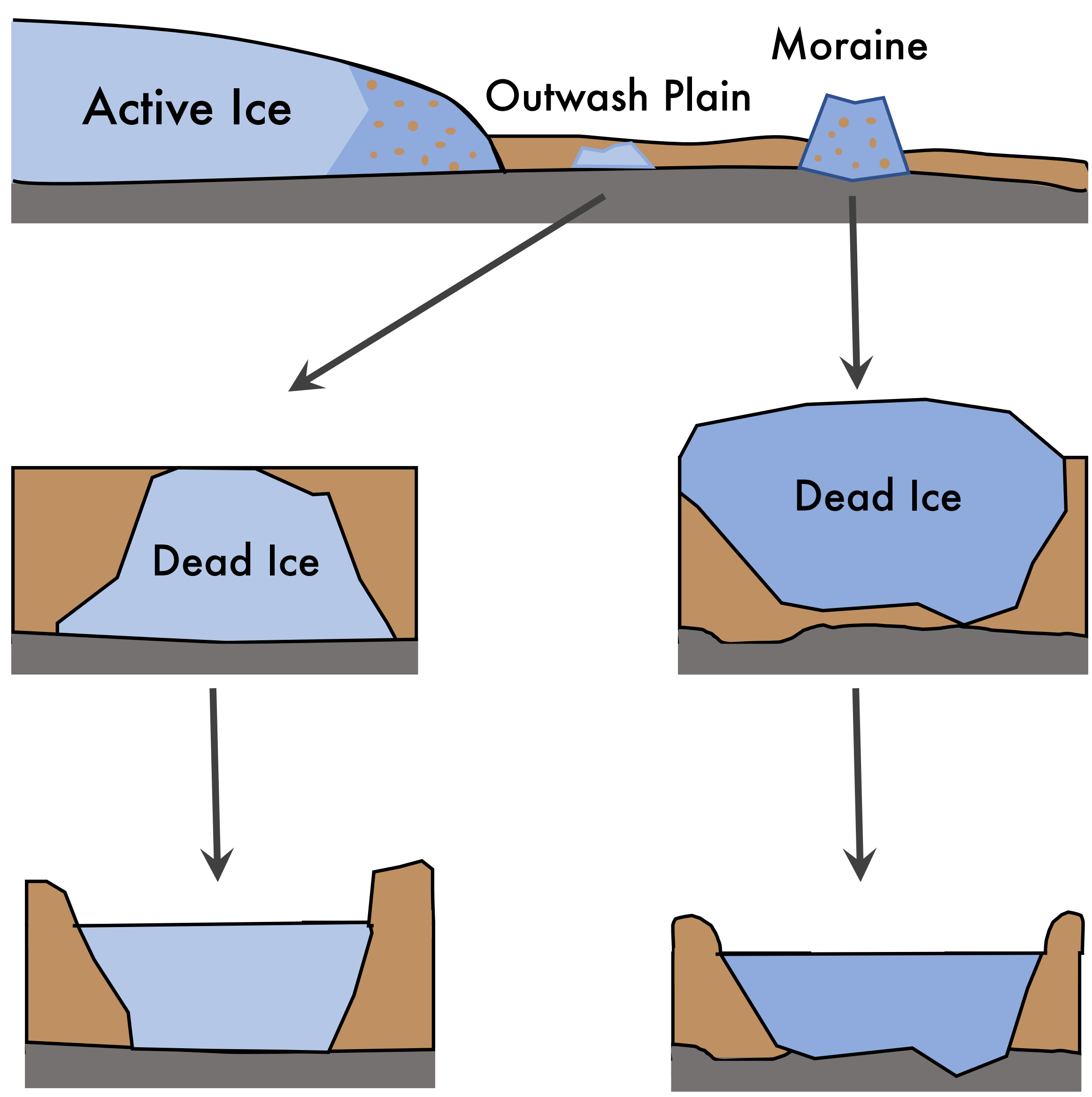


A lake is a sizeable water body surrounded by land and fed by streams and local runoff. Lakes provide us with a wide range of benefits. Much of our domestic, agricultural and industrial water requirements come from surface water and much of this surface water is contained in lakes. Lakes also provide us with avenues of transportation, recreational opportunities, and centres of biodiversity and natural ecosystems.

FORMATION AND HISTORY

The current chemical and biological condition of a lake depends on many factors, including:

- how it formed
- size and shape of the lake basin
- size, topography, and chemistry of its watershed
- regional climate
- local biological communities
- activities of humans



Glaciers formed lake basins by gouging holes in loose soil or soft bedrock, depositing material across stream beds, or leaving buried chunks of ice that later melted to leave lake basins (see right). When these natural depressions or impoundments filled with water, they became lakes.

After the glaciers retreated, sediments accumulated in the deep parts of the lake through transport by streams and within-lake cycling of organic material. Lake sediment deposits provide a record of a lake's history. **Paleolimnologists** collect lake sediments using specialized coring devices to study a lake's physical, chemical and biological history. Lake acidity, water clarity, and algal productivity have been inferred by analyzing diatom (a type of zooplankton that has a silica exoskeleton and therefore preserves well) abundance and community composition, as well as plant pigments. Soil erosion can be inferred by the proportion of inorganic and organic matter and by chemical analyses for metals.

LAKE VARIABILITY

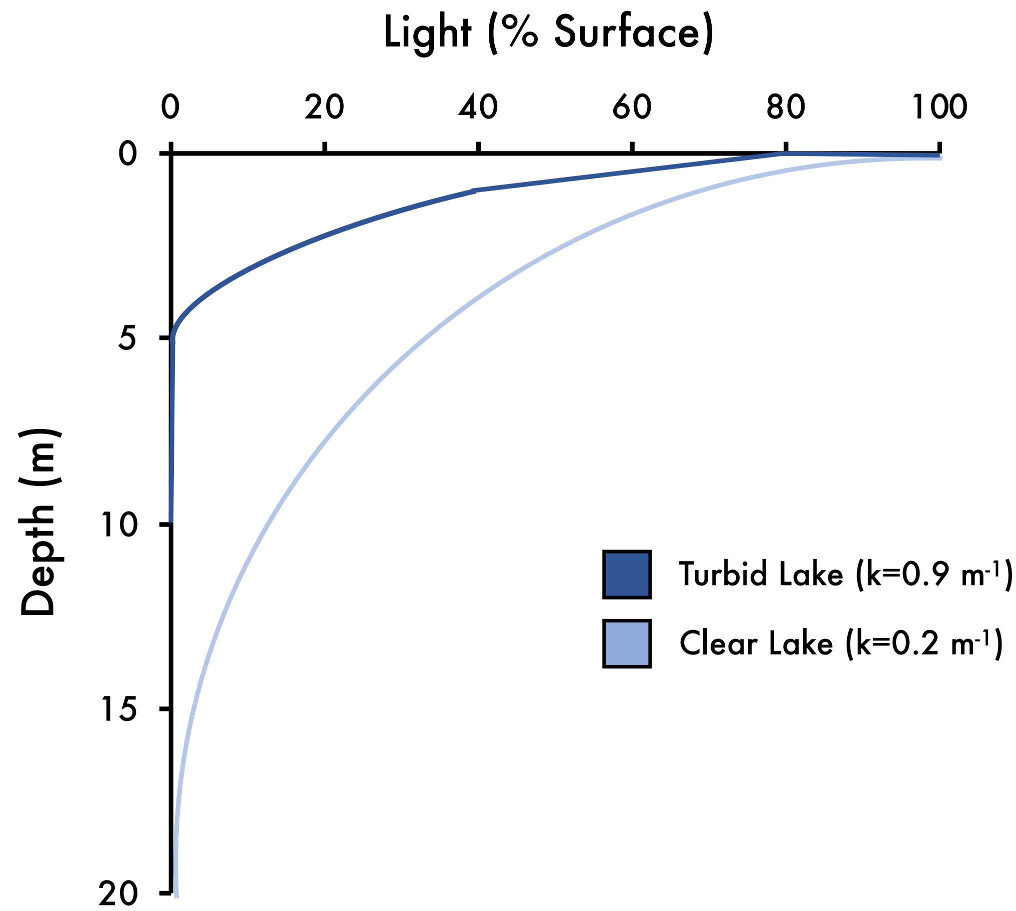
Lakes are often visualized uniform masses of water like a full bathtub that is evenly mixed. In fact, lakes are extremely **heterogeneous**. Lakes vary **physically** in terms of light levels, temperature, and water currents. They vary **chemically** in terms of nutrients, major ions, and contaminants. Lakes also have variable **biological communities** in terms of structure and function, biomass, population abundance, and growth rates. There is a great deal of spatial heterogeneity in each of these variables, as well as temporal variability on the scales of minutes, hours, days, seasons, decades, and geologic time.

Although lakes are spatially variable, they are also highly structured with characteristics that can be predicted based on a few key features such as water clarity (light), basin morphology, sediment type, and connectivity.

LIGHT

Light intensity at the lake surface varies daily (day-night cycle) and seasonally. When light travels from the surface down through the water column, some of it is **absorbed** by molecules in the water and some of it continues deeper into the lake. Absorption and attenuation of sunlight by the water column are major factors controlling water temperature and photosynthesis, and are also a major factor in determining wind patterns in the lake basin. The deeper into the water column that light can penetrate, the deeper photosynthesis can occur.

The amount of light-absorbing dissolved substances and the amount of absorption and scattering caused by suspended materials impact the rate at which light decreases with depth. Clear lakes will have light attenuation, whereas lakes with lots of particulates in them (high turbidity) or with a dark colour (high dissolved organic carbon) will have attenuation (the light will be absorbed before it can go deep into the lake). The percentage of the surface light absorbed or scattered in a 1 meter long vertical column of water, is called the **vertical extinction coefficient**. This parameter is symbolized by "k". In lakes with low k-values, light penetrates deeper than in those with high k-values.



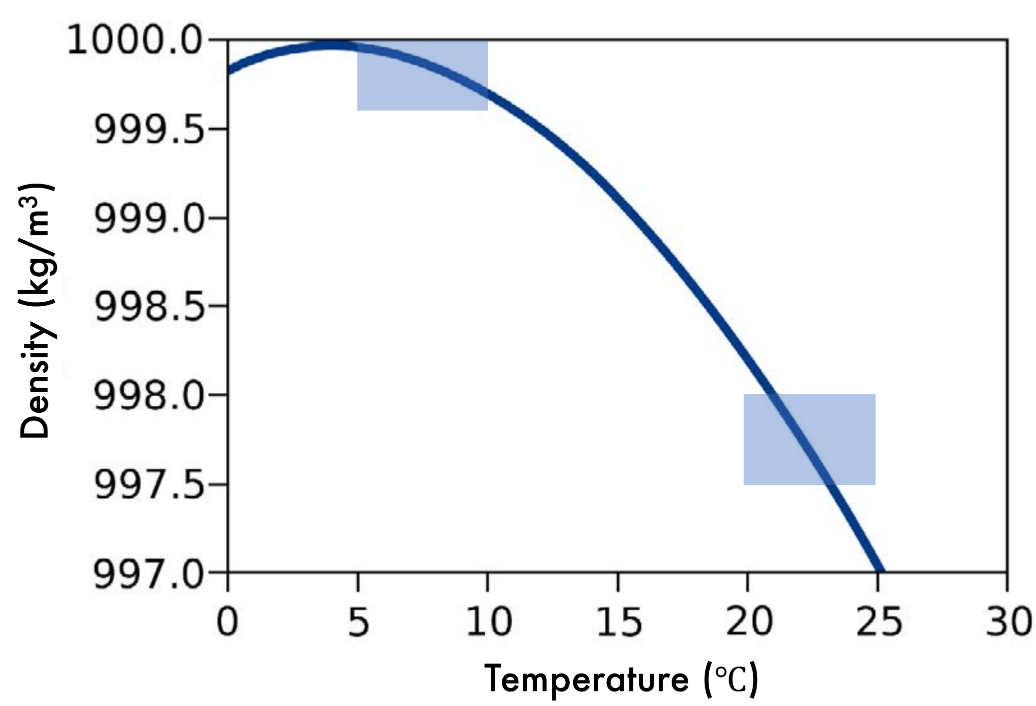
Light versus depth profiles for both a clear lake and turbid lake

Modified from © U.S. Environmental Protection Agency

DENSITY STRATIFICATION

Water changes density with change in temperature (see below). Water is most dense at 4°C and becomes less dense at lower and higher temperatures. Water at the bottom of lakes will often be around 4°C, even in mid-summer.

Density differences between water at different temperatures are so strong that when a lake is **stratified** (has layers), the layers are essentially physically separated from one another and barely mix. During stratification, the different layers will be very



Density/Temperature relationship for distilled water different temperatures, but during periods of mixing (no layers), the lake will be fairly **isothermal** (the same temperature throughout).

There are several types of lake stratification (discussed below), but in general lakes follow specific patterns throughout the season. A typical pattern for a **dimictic lake** (mixes twice per year) is as follows.

Spring (mixed)

Just before the ice melts in the spring, the water near a lake's bottom will usually be at 4°C. Water above that layer will be cooler, approaching 0°C just under the ice. As the weather warms, the ice melts. The surface water heats up and therefore decreases in density. When the temperature (density) of the surface water equals the bottom water, very little wind is needed to mix the lake completely. This mixing is called **spring turnover**. After turnover, the surface water continues to warm. As the temperature rises, the water becomes lighter than the water below. For a while winds may still mix the lake from bottom to top, but eventually the upper water becomes too warm and too buoyant to mix completely with the denser (colder) deeper water. The relatively large differences in density at higher temperatures are very effective at preventing mixing.

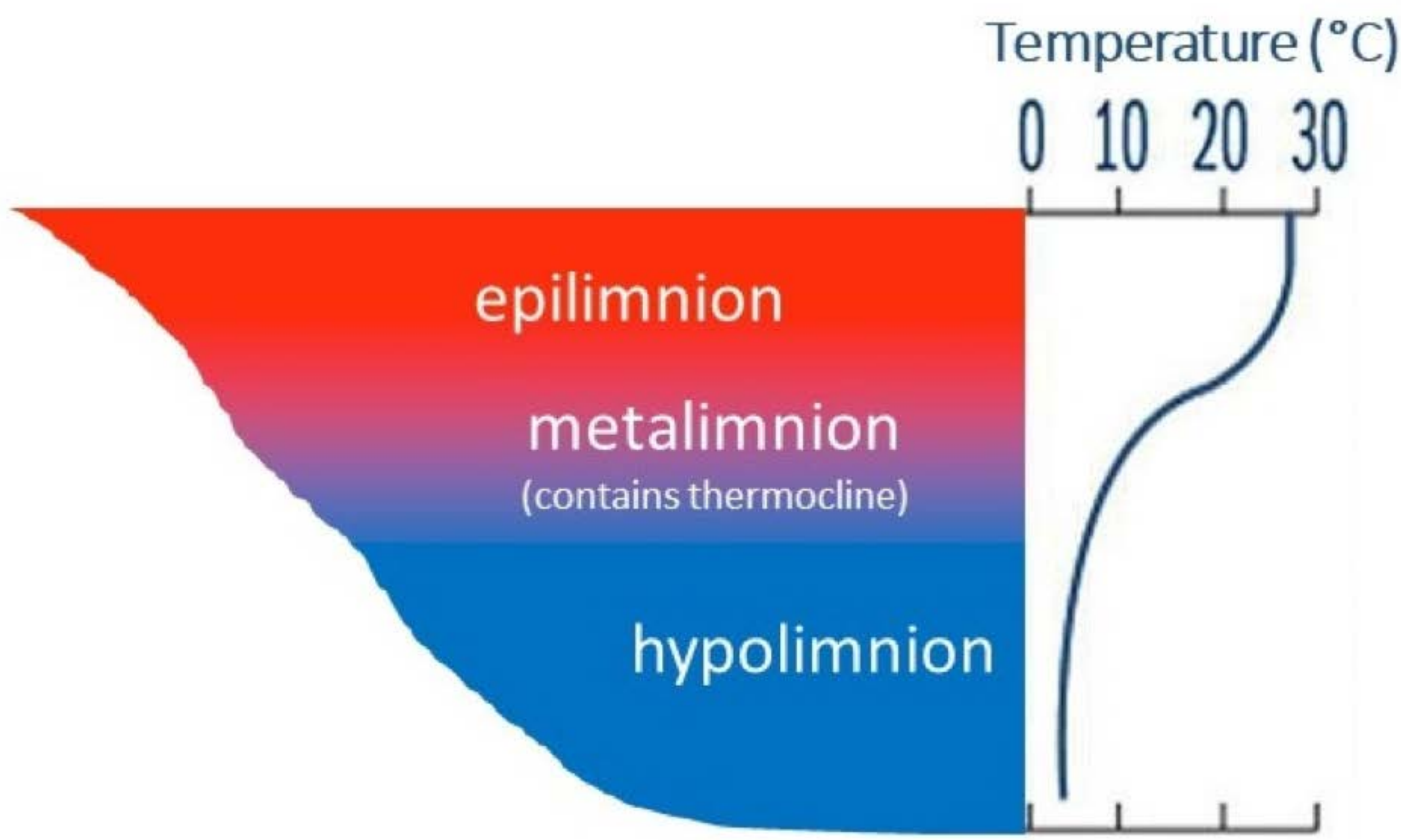
It is useful to visualize a more extreme example of density stratification. Imagine a bottle of salad dressing containing vegetable oil and vinegar. The oil is lighter (more buoyant) than the vinegar. When you shake it up you are supplying the energy to overcome the buoyant force, so the two fluids can be uniformly mixed together. However, if allowed to stand undisturbed, the more buoyant (less dense) oil will float to the top and a two-layer system will develop.

In some cases, the surface water may warm up rapidly immediately after ice-out, causing the lake to stratify thermally without completely mixing. This prevents atmospheric oxygen from reaching the bottom waters. Consequently, the entire water column never reaches 100% oxygen saturation.

Summer (stratified)

As summer progresses, the temperature (and therefore density) differences between upper and lower water layers become more distinct. Deep lakes generally become physically **stratified** into three identifiable layers. From top to bottom, these are the **epilimnion**, **metalimnion**, and **hypolimnion**.

- **epilimnion** - the upper, warm layer that is typically well mixed and **isothermal** (all the same temperature).
- **metalimnion** – the transition layer in which temperature declines rapidly with depth. The **thermocline** is located within the metalimnion and is defined as the shallowest layer of water where the temperature change is greater than 1°C per meter. The density change at the metalimnion acts as a physical barrier that prevents mixing of the upper and lower layers for several months during the summer.
- **hypolimnion** – the bottom layer of cold water, isolated from the epilimnion by the metalimnion.



Lake Thermal Stratification

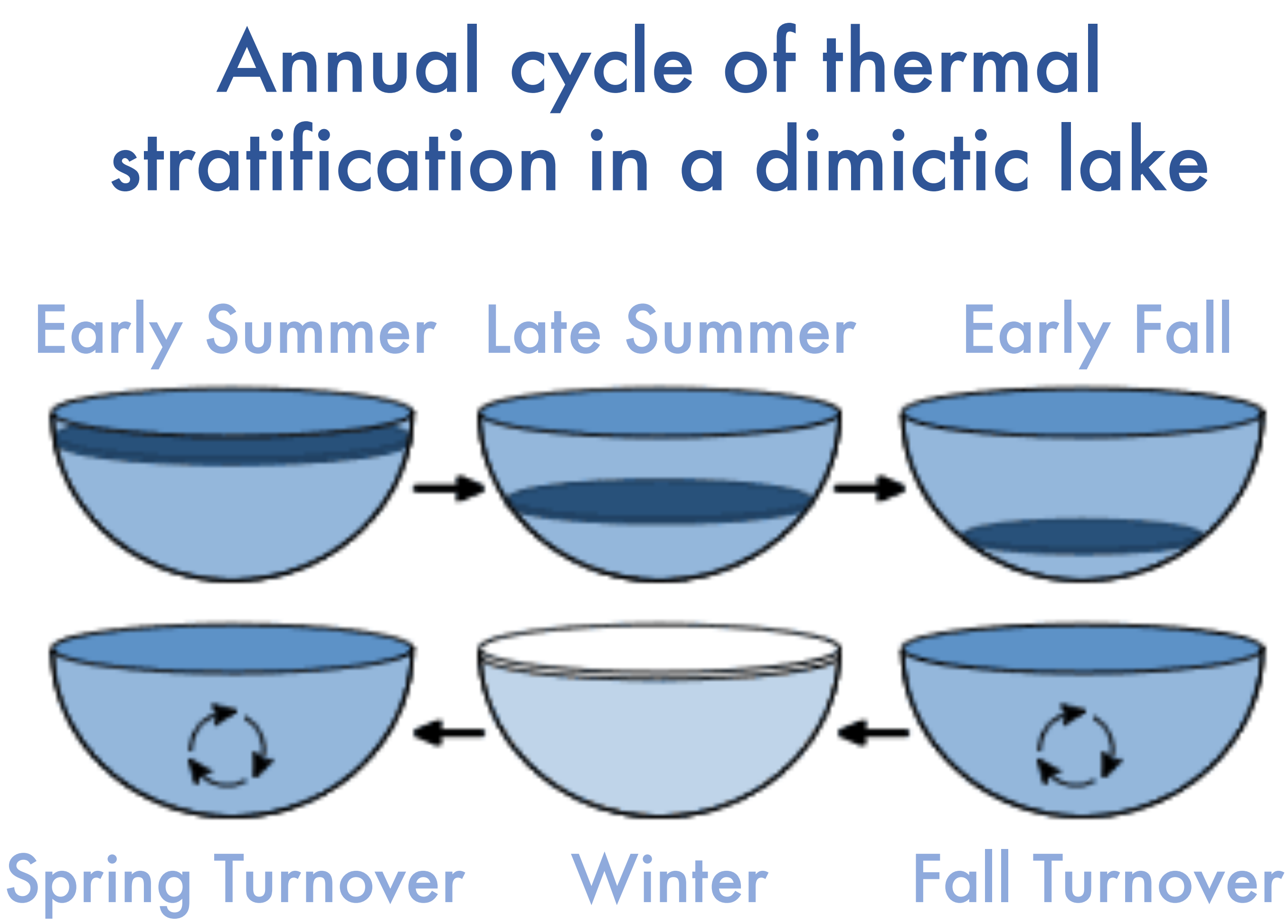
Autumn (mixed)

As the weather cools in autumn, the epilimnion cools too, reducing the density difference between it and the layers. As time passes, winds gradually mix epilimnion water with the metalimnion, which allows the thermocline to gradually deepen. When surface and bottom waters approach the same temperature (and therefore the same density), the entire lake can mix; this mixing is called "**fall turnover**".

Winter (weakly stratified)

As the atmosphere cools, the surface water continues to cool until it **freezes**. A less distinct density stratification than seen in summer develops under ice during winter. Most of the water column is isothermal at a temperature of around 4°C, but the water just below the ice is colder (and therefore less-dense). In winter the stratification is much less stable because the density difference between 0°C and 4°C water is relatively small. However, the water column is isolated from wind-induced turbulence by its cap of ice, therefore, the layering persists throughout the winter.

As discussed above, the deep areas of the lake can experience **oxygen depletion** during winter, sometimes leading to large anoxic (no oxygen) zones in the lake. Photosynthesis is much reduced in winter due to lack of light, and the ice prevents oxygen from entering the lake from the atmosphere, so oxygen availability can be a problem in highly productive lakes.



Annual cycle of thermal stratification in a dimictic lake. In early summer the epilimnion is fairly thin; it deepens throughout the summer and early fall, after which the lake cools and the layers mix together. In winter the lake is fairly uniform with slight stratification, and it will mix again in spring before warming up and stratifying

Mixing patterns

Lakes that mix fully from top to bottom at least once per year are termed **holomictic lakes** (as in the "whole lake mixes"). There are several types of holomictic lakes. The **dimictic** mixing pattern shown above is typical for temperate lakes, which experience two periods of mixing. **Polymictic lakes** are very shallow and do not stratify in the summer, or only stratify for short periods. The shallow depth allows wind to mix the entire water column easily, which destroys any stratification present. These lakes may stratify and de-stratify many times within a summer.

Lakes that only mix partially are much less common and are termed **meromictic lakes**. These lakes may have extensive mixing deep into the hypolimnion, but they do not mix completely, such that a layer of bottom water remains stagnant and anoxic. The non-mixing bottom layer is known as the **monimolimnion** and is separated from the **mixolimnion** (the zone that mixes completely at least once a year) by the **chemocline** (a strong chemical gradient). The stagnant, and typically anoxic, monimolimnion has a high concentration of dissolved solids compared to the mixolimnion.

LAKE CHEMISTRY

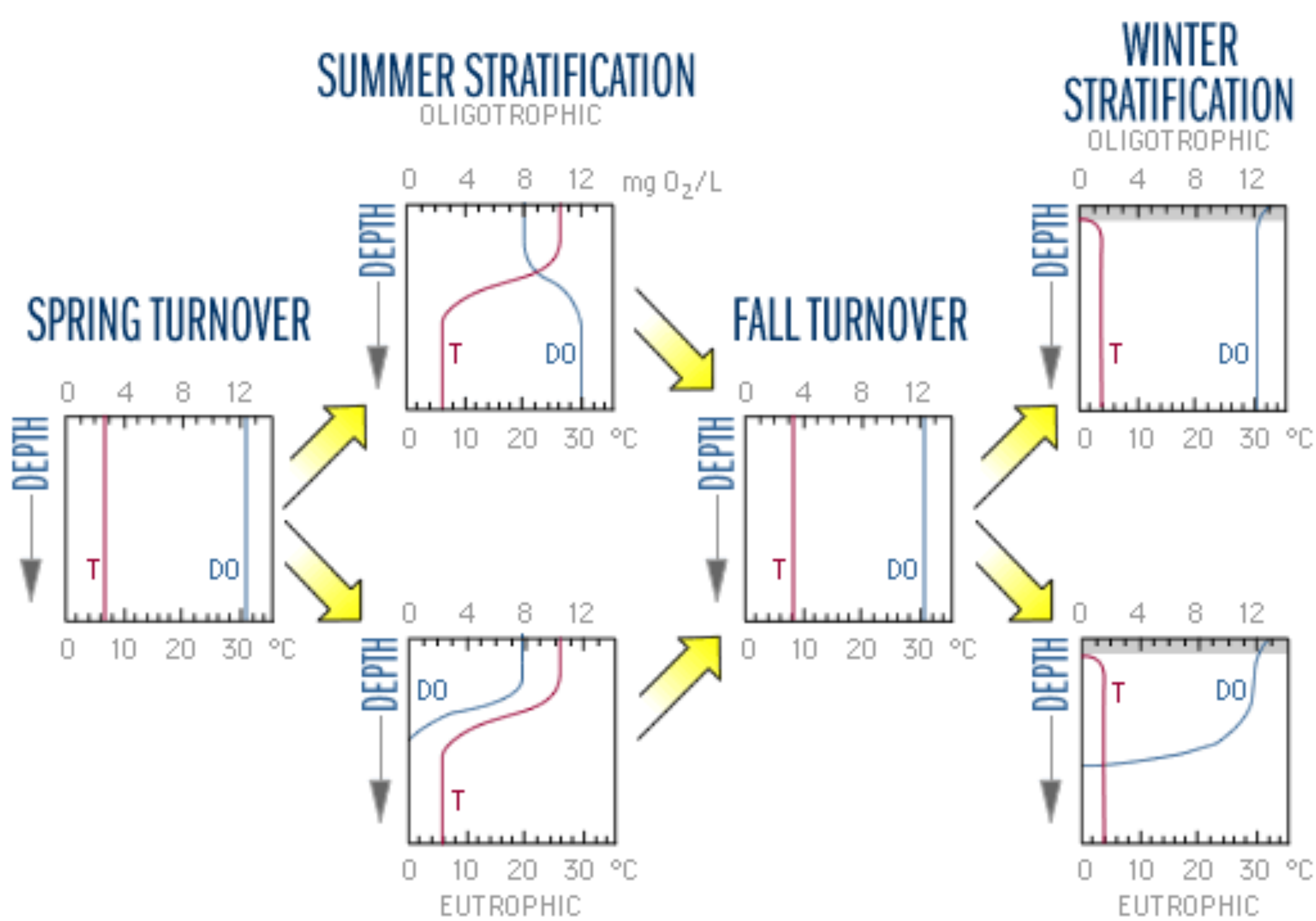
Lakes contain a wide array of molecules and ions from the weathering of soils in the watershed, the atmosphere, and the lake sediments. The chemical composition of a lake is a function of climate and basin geology.

Each lake has an **ion balance** of anions and cations. Ion balance means the sum of the ions (negative) equals the sum of the cations (positive). These ions include nutrients such as phosphate, nitrate, and ammonium, ions related to acidity (including hydrogen, sulfate, and nitrate). Lakes with high concentrations of ions calcium and magnesium are called **hardwater lakes**, while those with low concentrations of these ions are called **softwater lakes**. Concentrations of other ions, especially bicarbonate, are highly correlated with concentrations of the hardness ions, especially calcium. Ionic concentrations influence a lake's ability to assimilate pollutants and maintain nutrients in solution. For example, calcium carbonate in the form known as marl can precipitate phosphate from the water and thereby remove this important nutrient from the water. The total amount of ions in the water is called **total dissolved solids** (TDS). TDS concentration and ion ratios influence the types of organisms that can best survive in the lake and influence the chemical reactions that occur in the water.

Dissolved Oxygen (DO)

Cold water can hold more oxygen than warm water. During periods of stratification, the only potential source of oxygen to the deeper zones of the lake is photosynthesis, which only occurs only if light reaches those depths. Photosynthetic activity and algal growth peaks during summer when the most sunlight is available and temperatures are warmest. The combination of thermal stratification and biological activity causes characteristic patterns in dissolved oxygen.

The image below shows the typical seasonal changes in DO and temperature in **oligotrophic** and **eutrophic** lakes. (See lake trophic status section below for more information about oligotrophic and eutrophic lakes). The top scale in each graph is oxygen concentration (mg O_2/L), and the bottom scale is temperature (°C).



Stratification patterns
(adapted from Figure 8-1 in Wetzel 1975)

In spring and fall, the lakes tend to be well-mixed and uniform. DO concentrations in the epilimnion remain high throughout the summer because of photosynthesis and diffusion from the atmosphere. However, conditions in the hypolimnion vary with trophic status.

- In eutrophic (more productive) lakes, hypolimnetic DO declines during the summer because it is cut-off from all sources of oxygen, while organisms continue to respire and consume oxygen. The bottom layer of the lake and even the entire hypolimnion may eventually become **anoxic**.

- In oligotrophic (less productive) lakes, low algal biomass allows deeper light penetration, meaning that algae can grow deeper in the water column. Additionally, less oxygen is consumed by decomposition because there are fewer dead algae to decay. DO concentrations may therefore increase with depth below the thermocline where colder water is "carrying" higher DO leftover from spring mixing (recall that oxygen is more soluble in colder water).

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

WETLAND ECOSYSTEMS

Wetlands are areas permanently or temporarily submerged or permeated by water and they are characterized by plants adapted to saturated soil conditions. Any land area that can keep water long enough to let wetland plants and soils develop is considered a wetland.

Wetlands were once abundantly distributed throughout Canada. However, when Canada was settled, wetlands were considered wasteland, and many of southern Canada's wetlands were drained or filled in so that they could be farmed or built upon. Only about 25% of the original wetlands of the "prairie pothole" region of southwestern Manitoba remain in existence. Wetlands currently cover about 14% of the land area of Canada.

Recently the value of wetlands has been recognized and efforts have been made to protect them. Wetlands are the only ecosystem designated for conservation by international convention due to their many functions (discussed below). However, they are still disappearing under the pressure of human activity and are being threatened by other stressors including pollution and climate change.

FUNCTIONS AND VALUES

Wetlands represent one of the most important life support systems in the natural environment because they:

- Absorb the impacts of hydrologic events
  - Act as reservoirs, helping to control and reduce flooding through water storage
  - Reduce impacts of large waves and protect shorelines from erosion
- Act as water filtration systems, removing contaminants, suspended particles, and excessive nutrients, thus improving water quality and renewing water supplies
- Provide habitat for many organisms
  - e.g., nesting, feeding, and staging grounds for many species of waterfowl
  - e.g., high-quality spawning and nursery areas for fish
- The dense communities of plants present in wetlands emit oxygen and water vapour, thus playing a vital role in atmospheric and climatic cycles
- Are a source of a variety of products used by humans
  - Food products (e.g., wild rice, cranberries, fish, wildfowl)
  - Energy (e.g., peat, wood, charcoal)
  - Building material
- Are valuable recreational areas (e.g., hunting, fishing, birdwatching)

WETLAND HABITATS

The five major freshwater wetlands types: marsh, swamp, bog, fen, and shallow open water.

Marsh

- Nutrient-rich (the most productive of the wetland habitats)
- Periodically or permanently covered by standing or slowly moving water
- Emergent vegetation dominant, including reeds, rushes, cattails and sedges
- Water remains within the rooting zone of these plants for most of the growing season

An example of a marsh
© William Burt

Swamp

- Nutrient rich and productive
- May be flooded seasonally or for long periods of time
- Dominated by shrubs or trees (coniferous, deciduous)
- Most common in temperate areas of Canada.

An example of a swamp
©Allison Shelley/Smithsonian Magazine

Bogs

- Low in nutrients (the least productive of all wetland types) with a high water table
- Poor drainage, decay of plant material yields acidic surface water
- Dominated by sphagnum mosses (peat) and heath shrubs; bogs may also support trees.
- More common in northern areas of Canada

An example of a bog
© Bogology

Fens

- Not as low in nutrients as bogs (more productive)
- High-water table with slow internal drainage by seepage down low gradients
- Surface waters may be acidic or alkaline
- Dominated by sedges, but may also contain shrubs and trees
- Like bogs, they are more common in northern Canada

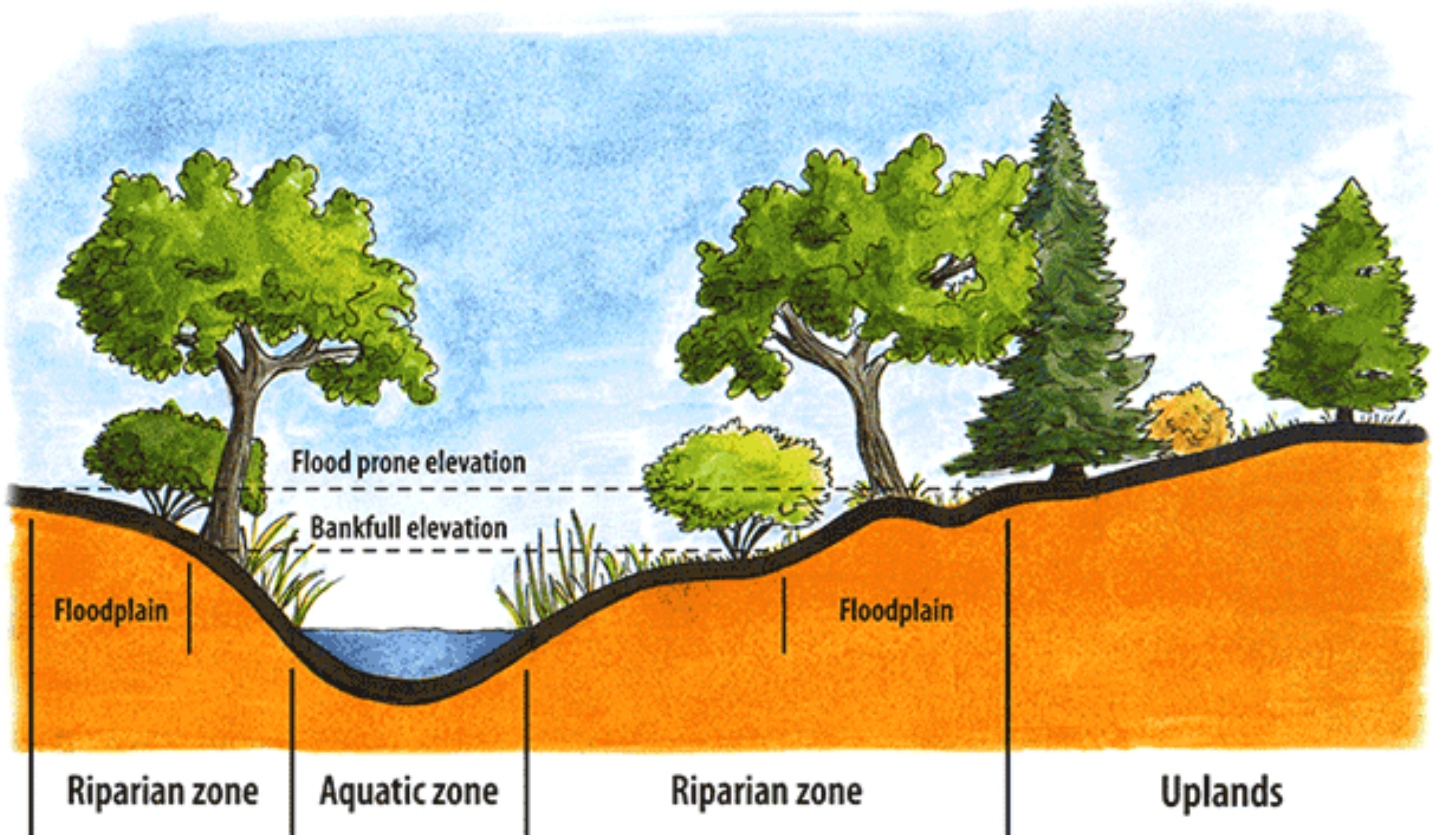
An example of a fen in Churchill, Manitoba

Shallow Open Water

- Small bodies of standing or flowing water commonly representing a transitional stage between lakes and marshes, or between spring high water levels and levels during the remainder of the year
- Include potholes and sloughs (ponds), and saturated stream and lake shorelines

An example of a shallow open water

RIPARIAN ZONES



The **riparian zone** is the ecosystem at the interface between land and a water body. Riparian zones serve as important transitional areas and support a wide diversity of plant and animal life. They also provide important services for the land-based (upland) and aquatic ecosystems that they border. Natural riparian zones typically contain vegetation such as trees, shrubs, wildflowers, grasses, and aquatic plants (e.g., cattails and rushes).

BENEFITS OF RIPARIAN ZONES

Protection of water quality

- Plant root systems purify water by filtering out toxic substances and pollutants (e.g., fertilizers, pesticides, heavy metals, etc.) out of runoff from the surrounding areas
- Vegetation traps soil particles from runoff, keeping water clear

Protection from erosion

- Roots of riparian and aquatic vegetation help stabilize shorelines, acting as 'rebar' does in concrete. By reinforcing soil and sand, they reduce the amount of erosion and slumping
- The leaves of plants reduce the energy of waves and currents, reduce the speed and force of falling rain, and slow water as it runs downhill.

Protection from flooding

- Vegetation and rocks in along shorelines slow flood waters
- Riparian vegetation will acts like a sponge, increasing the soil's ability to soak up water and reduce flooding

Protection of water supply

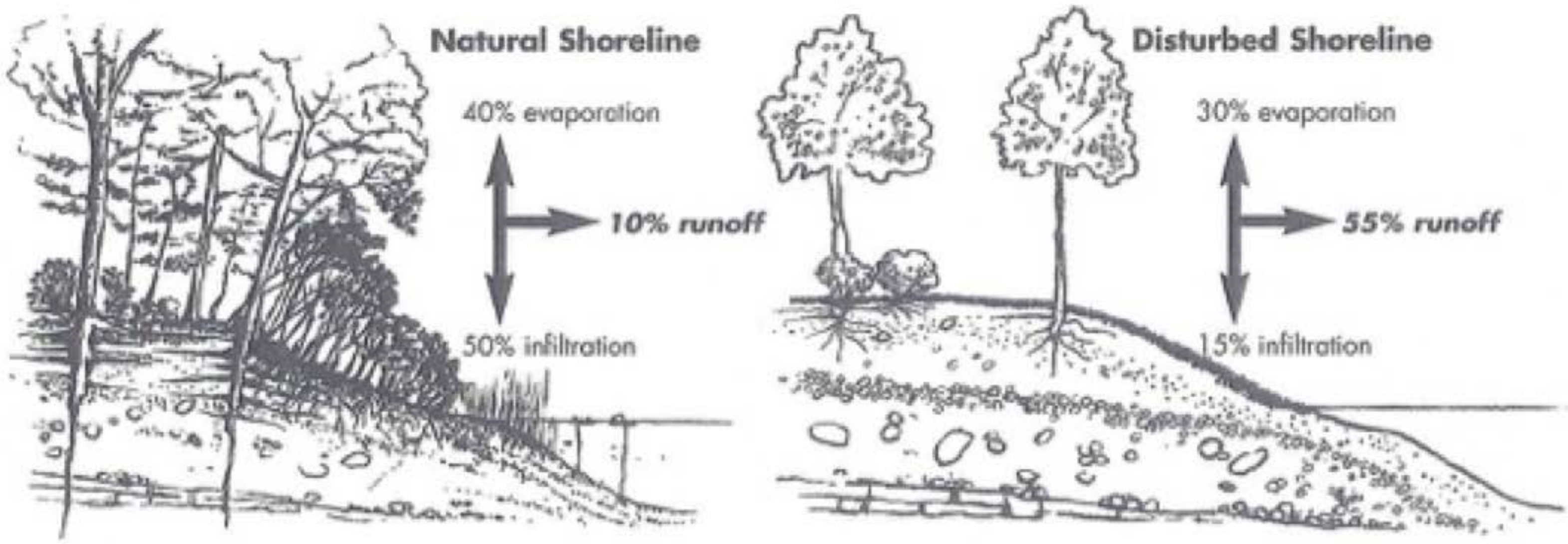
- Vegetation in the riparian zone takes in more water in the fall, winter, spring, and during storms. This water is then slowly released into the water body, during the summer, helping to maintain flows during dry periods.

Protection of animals

- Multi-story layers of vegetation (trees, shrubs, ground layer) provide habitat and shelter for a diverse array of species. In arid landscapes, this structurally complex arrangement is often unique to stream corridors
- Wildlife corridors are produced by vegetation along shorelines, helping animals to move between areas
- Shade produced by vegetation reduces water temperature.
- Roots create overhanging banks, which act as shelter for fish

RIPARIAN ZONE HEALTH

Over the years, many humans have cleared riparian zones to create access to shorelines. However, by adding lawns, gardens, artificial beaches, retaining walls, and other "hard" installations, the function of riparian zones has been gradually reduced. Removal of natural



Differences between natural and disturbed riparian zones
© 2003 Kipp and Callaway

vegetation can lead to erosion, which causes changes in shorelines and streambanks, siltation of fish and invertebrate spawning beds, pollution from runoff, and increased flooding. By returning these areas to their natural state, these problems can be reduced.

Healthy riparian zones have specific characteristics:

- A riparian zone must be at least 30 m wide to be effective, with riparian zones of 150m required for particularly vulnerable areas
- The presence of native vegetation and a high percentage of ground cover increases the health of a riparian zone
- Vegetation of different heights, types, and ages growing together will increase the health of the zone
    - In a natural system, new saplings grow beside their parent trees
    - Rotting wood from fallen trees provides nutrients for plants and cover for fish
    - Tall plants provide shade and protection for new plants, and as they die, make room for new plants
    - Land-based plants with deep, binding root masses help stabilize the shoreline
    - Aquatic plants (e.g., cattails, water lilies, coontail) bind the soil, break the force of the water, and filter out pollutants

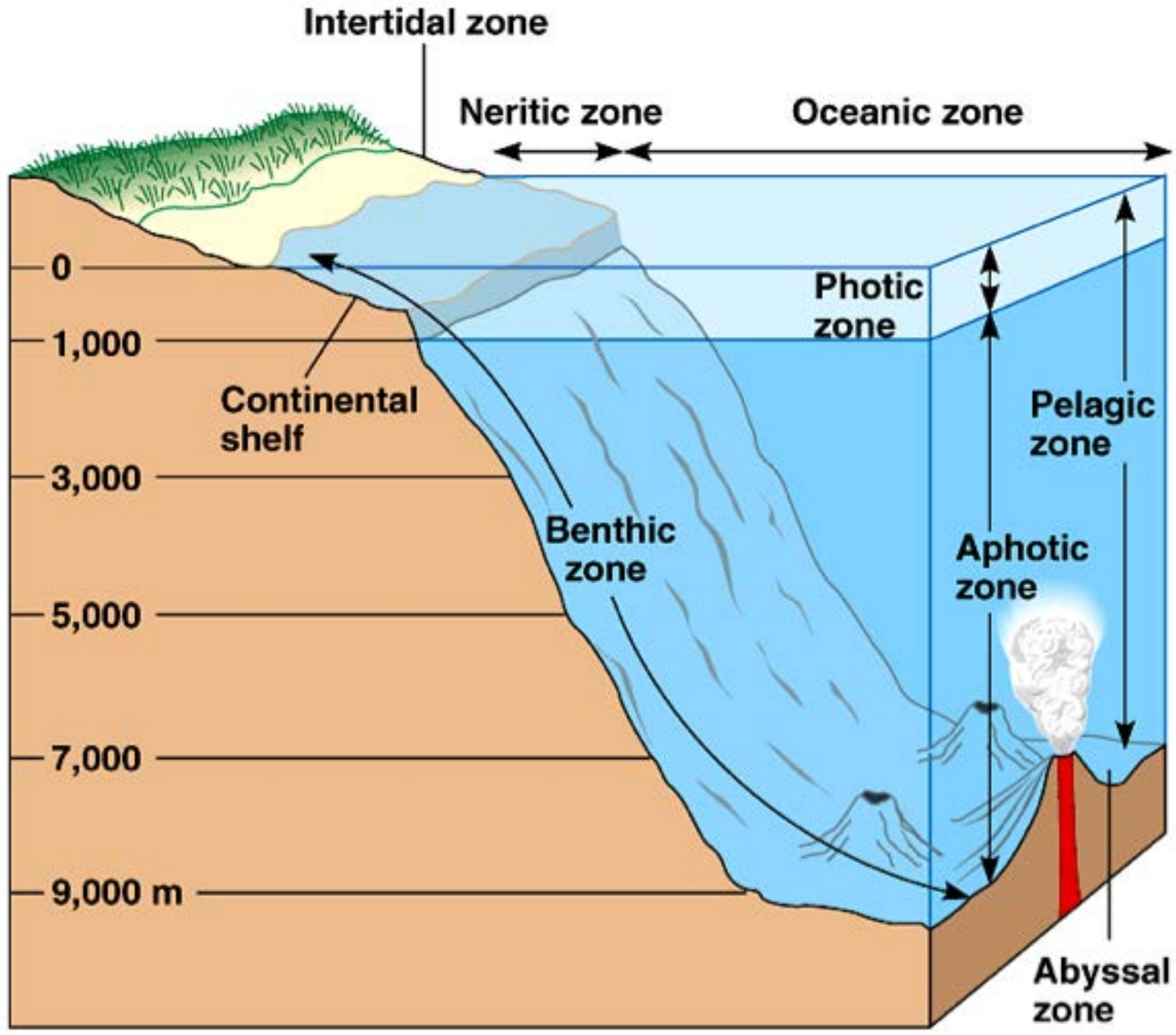
OCEAN ECOSYSTEMS

The ocean ecosystem covers about 70% of the earth's surface. It is the home to hundreds of thousands of plant and animal species. Oceans influence the weather and produce ~ 70% of the oxygen we breathe. Ocean ecosystems includes everything in the ocean, plus saltwater bays, seas and inlets, shorelines, and salt marshes. We have named five different oceans, although they are technically the same body of water: Arctic, Atlantic, Indian, Pacific, and Southern.

OCEAN ZONES

Oceanographers divide the ocean into three broad zones. Each zone has a different mix of species adapted to its light levels, pressures, and temperatures. About 75% of the ocean is deep, permanently dark, and cold.

Spatial zones



Oceanic Divisions/Zones based on depth and light

Intertidal zone - the area of few meters of extent located between the low and high tide of water. This zone is the most temporally (over time) and spatially (over area) variable of all marine habitats. The intertidal zone varies from sand and mud flats to rocky reefs, and these differences allow for the development of a wide variety of plant and animal communities.

Neritic zone - the shallow area extending from mean low water down to 200m depths, corresponding to the corresponding shelf. This zone has a variation of sunlight, which allows for photosynthesis by producers. As such, this zone is abundant in nutrients and biological activity.

Pelagic zone - the ecological realm that includes the entire column of open water, or all of the ocean other than that near the coast or the ocean floor.

Oceanic zone - the zone of open sea beyond the edge of the continental shelf , where the depth is greater than 200m. It includes both a photic (zone with sunlight) and aphotic zones.

Benthic zone - the bottom zone of the ocean, that includes the sediment surface and multiple sub-surface areas. The benthic zone is often a rich environment for plants and animals.

Abyssal zone - the portion of the ocean between 2000-6000 m. This zone has extremely uniform environmental conditions, as reflected in the distinct life forms inhabiting it. It is characterized by uniform darkness, low temperature (around 3°C), and unique animals.

Light zones

Surface (Euphotic) zone - The surface zone receives the most sunlight, allowing organisms like phytoplankton to photosynthesize. This is the smallest zone of the ocean (~5%) and reaches from the surface down to about 200m (or wherever there is about 1% of surface light). This zone is generally the warmest, although temperatures vary with season and latitude.

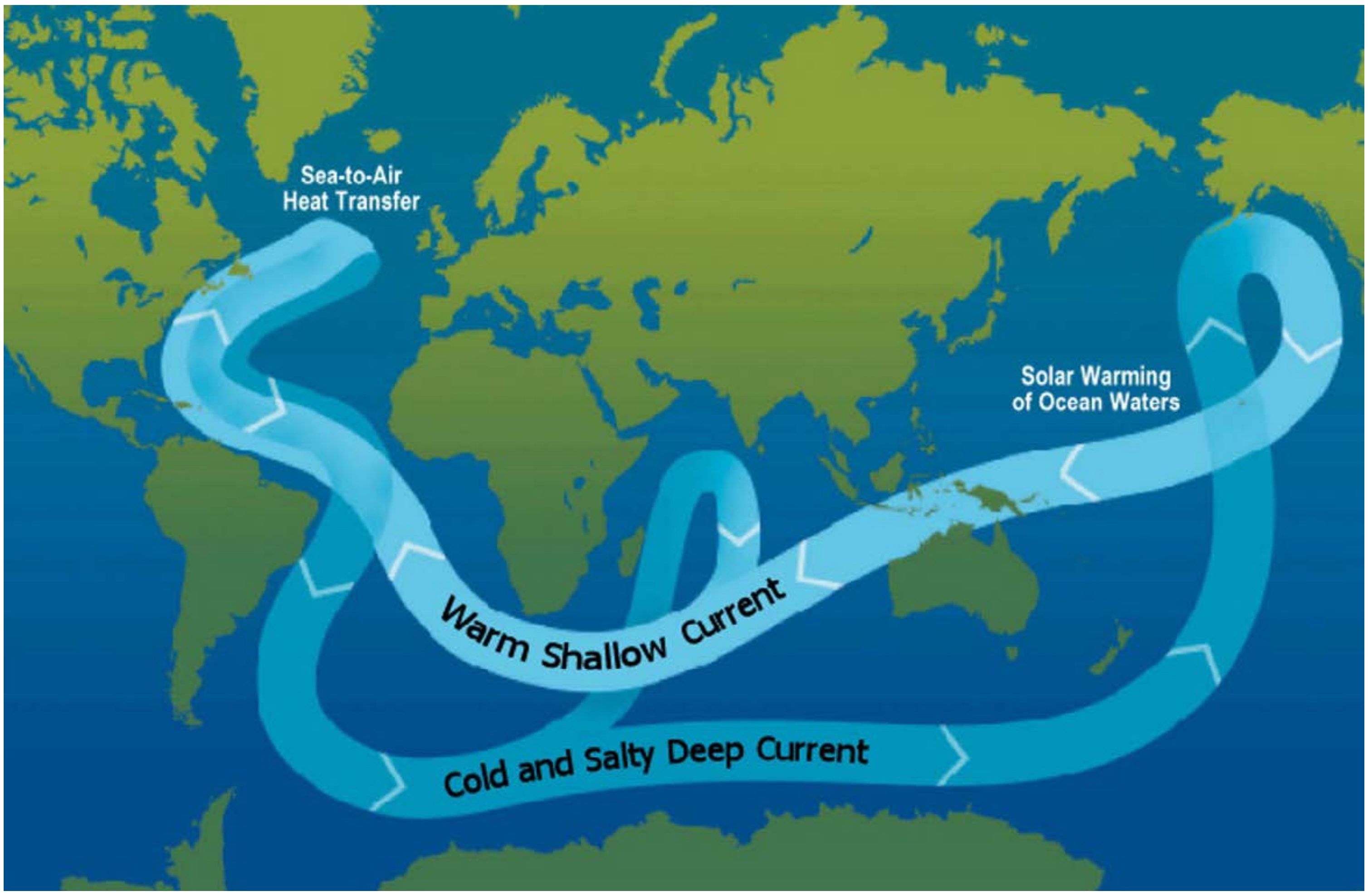
Twilight (Disphotic) zone - The twilight zone is at the boundary between the photic and aphotic zones, and receives only faint, filtered sunlight, such that no photosynthetic species can survive. Animals that live here have adapted to the near-darkness with large eyes and counterillumination. This zone includes ~20% of ocean depth, reaching from ~200m to 1000m. The cold temperatures do not vary seasonally.

Deep ocean (Aphotic) zone - The deep ocean gets no sunlight at all; animals create their own bioluminescent light and have light-sensitive eyes to detect other animals. The aphotic zone represents the largest zone in the ocean (~75%), from ~1000m and below. The water is at a constant cold temperature just above freezing.

WATER MOVEMENT

Currents

A large movement of water in one direction is a **current**. Currents can be near the surface or in the deep ocean, temporary or very long lasting. Large currents shape the earth's global climate patterns and local weather conditions, by moving heat worldwide. Currents, especially large currents, are driven by temperature and salinity differences. For example, in the Arctic, the cold salty water left after the sea ice freezes (trapping fresh water) is very dense and sinks toward the sea floor. This movement starts the planetary current pattern called the global conveyor belt, which slowly moves around the world. It takes approximately 1000 years for a molecule of water to make a complete circuit.



The global conveyor belt moves water all around the world.
US Global Change Research Program, © Wikimedia Commons

Waves

Waves move water and energy from one area of water to another or from water to shore. Large waves (called **swells**) can travel long distances. Waves found on the surface of the ocean are commonly caused by the transfer of energy from wind to water. The size of a wave depends on wind speed, duration, and the distance the wind has travelled across the water to build the wave (called the fetch; a small lake has a short fetch and therefore cannot build large waves, whereas the ocean is primarily made up of open expanses of water, meaning that the fetch can be enormous and so can the waves). A **tsunami** is a gigantic wave (like a wall of water) created by a disturbance that displaces a large amount of water such as an earthquake or landslide.

Waves can significantly impact landscapes when they crash on shore. Waves can shift entire islands of sand and carve out rocky coastlines. Storm waves can move massive boulders hundreds of meters inland and be very damaging. When tsunamis occur in the open ocean they are often only felt on land as high tides, but if they occur close to shore they can be devastating to shorelines.

Tides

Bay of Fundy, New Brunswick
© Jared Rover

Tides are the biggest waves on earth. They cause the sea to rise and fall along the shores of the world. The gravitational pull of the moon and the sun cause two bulges, or high tides, in the ocean on opposite sides of the earth. The moon has more power to pull on the tides than the sun, as it is much closer to the earth, and therefore is the primary pull force creating tides. As the earth rotates, the bulges (tides) move from place to place. The Bay of Fundy in the west coast of Canada has the highest tidal range on earth of between 3.5-16m.

WATER QUALITY

© USEPA Environmental Protection Agency

All species on earth depend on water for survival, therefore maintaining **water quality** is essential to maintaining life. However, water of good enough quality for one use may be unfit for another. For example, we may trust the quality of lake water enough to swim in it, but not enough to drink it. Drinking water can be used for irrigation, but water used for irrigation may not meet drinking water standards. It is the quality of the water which determines its uses.

We are interested in other aspects of water quality, including the types and amounts of substances dissolved and suspended in the water and what those substances do to inhabitants of the ecosystem. It is the concentrations of these substances that determine the water quality and its suitability for particular purposes.

The water of even the healthiest rivers and lakes is not absolutely pure. All water contains many naturally-occurring substances (mainly bicarbonates, sulphates, sodium, chlorides, calcium, magnesium, and potassium), as well as substances introduced by humans.

See **Aquatic Sampling Techniques** section for information about sampling for some of these parameters.

TEMPERATURE

Water has the unusual ability to absorb thermal energy (heat) with only minimal changes in temperature. Many fish, amphibians, and marine mammals have restricted ranges of temperatures that they can withstand. As seasons change, water temperatures change more slowly than air temperatures, which is easier on animals. If temperatures change too rapidly, aquatic animals can suffer thermal shock, leading to injuries or death, or increased vulnerability to pathogens and subsequent disease.

Natural factors that influence water temperature

- Size (volume) of water body (larger water bodies change temperature more slowly)
- Water (deeper waters warm up more slowly, the deeper the water, the less sunlight warms it and the cooler it stays)
- Colour and turbidity of water (dark water absorbs more sunlight and become warmer)
- Temperature of water entering a water body (rivers or lakes receiving water from snow-fed mountain streams will stay cooler than those fed by streams meandering through flatlands)

- Overhanging vegetation (shaded water will stay cooler than sunlight-exposed water)
- Stream direction
- Latitude
- Season
- Time of day

Human factors that influence water temperature

- Industrial facilities and power plants discharging warm water
- Storm runoff from urban areas that have been warmed
- Cutting trees along water bodies (decreases shade)
- Soil erosion increases water turbidity; increased turbidity increases heat absorbed

Effects of raising water temperature

- Warmer water holds less oxygen
- Increased metabolic rates of aquatic species
- Species require more oxygen due to increased metabolism
- Increased photosynthesis and decomposition
- Bacteria and some parasites can thrive

pH

Chemically, pH represents the number of hydrogen ions. At a pH level of 7.0, water contains an equal number of hydrogen ions (H^+) and hydroxyl ions (OH^-). If there are more hydrogen ions than hydroxyl ions, the substance is **acidic** and has a pH level lower than 7.0 If there are more hydroxyl ions, the substance is **alkaline** (**basic**), and it has a pH value higher than 7.0.

The pH scale is logarithmic, so each **one-digit change** in the scale indicates a **ten-fold change** in acidity or alkalinity. In other words, a substance with a pH of 4 is 10x more acidic than a substance with a pH of 5, 100x more acidic than a substance with a pH of 6, and 1000 times more acidic than a substance that is neutral (pH 7). Sometimes water contains dissolved minerals that act as buffering agents, reducing sudden large changes in pH. For example, freshwater is much more susceptible to changes in pH than sea water because the minerals in sea water act as buffering agents.

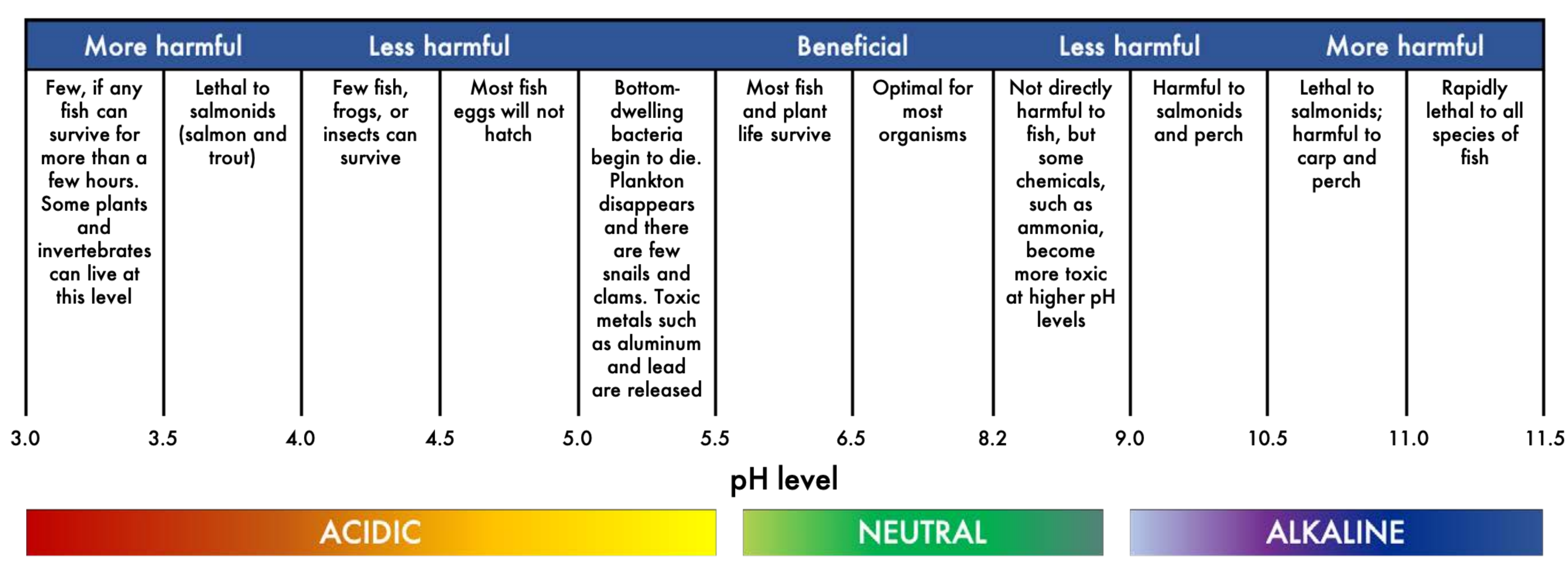
Natural factors that influence pH

- Decomposition of organic materials (releasing CO_2, which forms carbonic acid and decreases pH)
- Dissolving more alkaline minerals, such as limestone (increases pH)

Human factors that influence pH

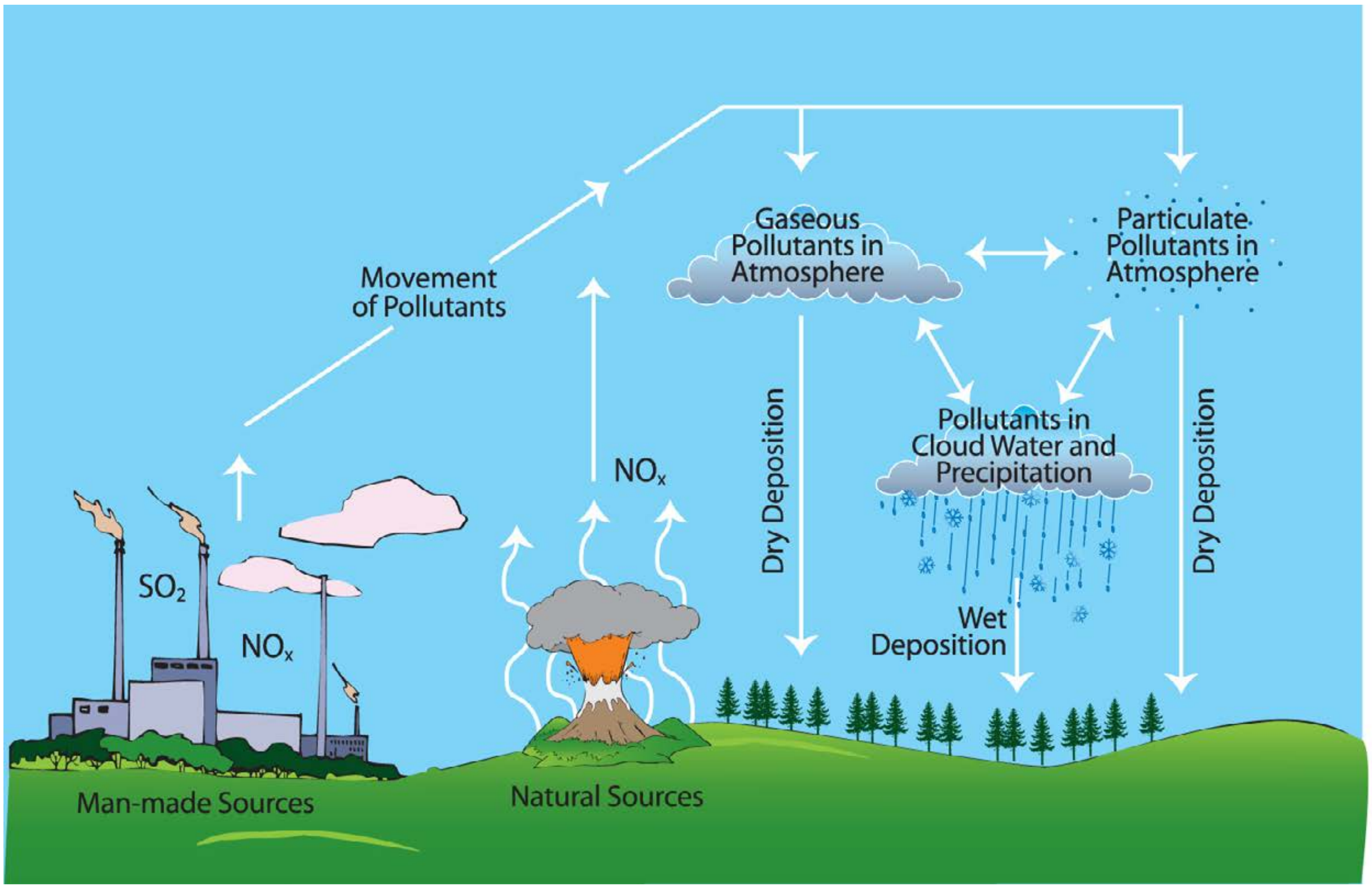
- Combustion technologies that release sulfur dioxide (SO_2), nitrogen oxides (NO_x), and carbon dioxide (CO_2) into the atmosphere, and return to earth as acid precipitation (see Acid Rain section below)

Effects of pH on freshwater aquatic life



The effects of pH on **freshwater** aquatic life

Acid Rain



Acid rain production

Acid rain refers to rainwater that, having been contaminated with chemicals introduced into the atmosphere through industrial and automobile emissions, and has had its acidity increased beyond that of clean rainwater (pH less than 5.3).

Emissions of sulphur and nitrogen enter the atmosphere. In the atmosphere, these compounds combine with atmospheric water to form acids (e.g., sulphuric acid, nitric acid), which then fall to earth in precipitation as acid rain. In the absence of rain, the particulate matter slowly settles to the ground as **dry deposition**. Together, wet and dry deposition of acidic substances is known as **acid precipitation**.

Acid rain deposition can cause damage in environments that cannot tolerate acidification. Interactions of acid deposition with the terrestrial ecosystem, including vegetation, soil, and bedrock, result in chemical alterations of the waters draining these watersheds, eventually altering conditions in the lakes downstream. Many species of fish, insects, aquatic plants and bacteria develop reproductive difficulties. Damage caused by acid rain can be lethal. Dwindling populations of insects and small aquatic plants are can **cascade through food webs**.

DISSOLVED OXYGEN (DO)

Oxygen is essential for life and water can hold a large amount of dissolved oxygen (DO) to be used by aquatic species. Oxygen enters water through two pathways:

- Plants and algae release oxygen into the water through photosynthesis
- Water movement (e.g., waves) mixes atmospheric oxygen with water.

Several factors affect the amount of oxygen in water, all of which are interconnected.

- **Salinity**: high salinity = lower DO
- **Agitation and turbulence**: more contact with atmospheric oxygen = higher DO
- **Temperature**: low temperature = higher DO
- **Minerals**: high mineral content = lower DO
- **Plant life**: more photosynthesis = higher DO
- **Organic wastes**: more waste decreases DO through decomposition by aerobic bacteria (which consume oxygen)

During extended warm sunny periods, algae can grow quickly. If the sunny period is followed by a few days of clouds, the algae may die due to inadequate sunlight. Bacteria decompose the algae, using oxygen in the process. If DO becomes too low, fish and other species will die.

Acceptable levels of dissolved oxygen

All organisms need a minimum level of dissolved oxygen to survive (different for each organism). Most aquatic animals can live with DO levels lower than 2.0 ppm (parts per million) for only short period of times. Few fish can survive for extended periods with DO levels below 3.0 ppm, and at DO levels below 5.0 ppm fish grow and develop slowly. Simply measuring the concentration of DO in a body of water indicates whether or not it can support a healthy fish population at a given moment.

NUTRIENTS

Nutrients are an essential part of the cycle of life. Nutrients are taken up by primary producers and then cycle through the food web. When organisms die, their tissues decompose and the nutrients are freed up to be taken in by other organisms. Oligotrophic water bodies are low in nutrients, while eutrophic ones have high nutrient levels.

Nitrogen

Nitrogen is abundant throughout nature. It is often considered a 'nutrient' as it is essential for plant growth. Cyanobacteria is the only organism that can use (or 'fix') nitrogen (N_2) directly from the air. Some terrestrial plants, such as legumes, can also do this. Plants cannot use nitrogen in its pure state, rather plants take up nitrates (NO_3) or ammonia (NH_3). Animals obtain nitrogen by consuming other organisms, and animal excrement is rich in ammonia. Ammonia can be oxidized by other bacteria into nitrites (NO_2) and nitrates. Fertilizers, sewage, and septic tanks can also be human-linked sources of nitrates. High blood nitrate levels reduce the ability of an animal to carry oxygen. For example, fish can develop 'brown blood disease', caused by a lack of blood oxygen.

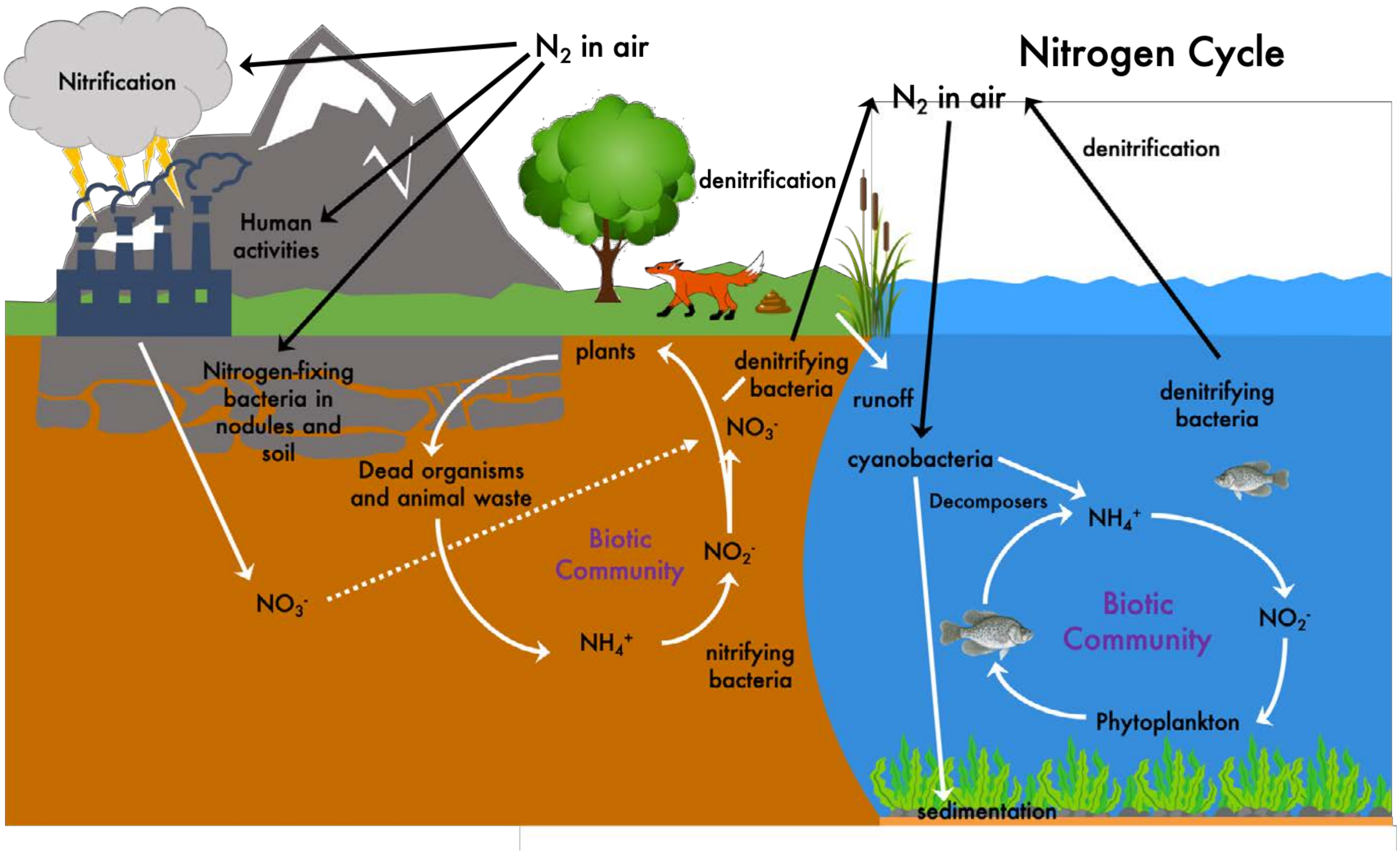
Phosphorus

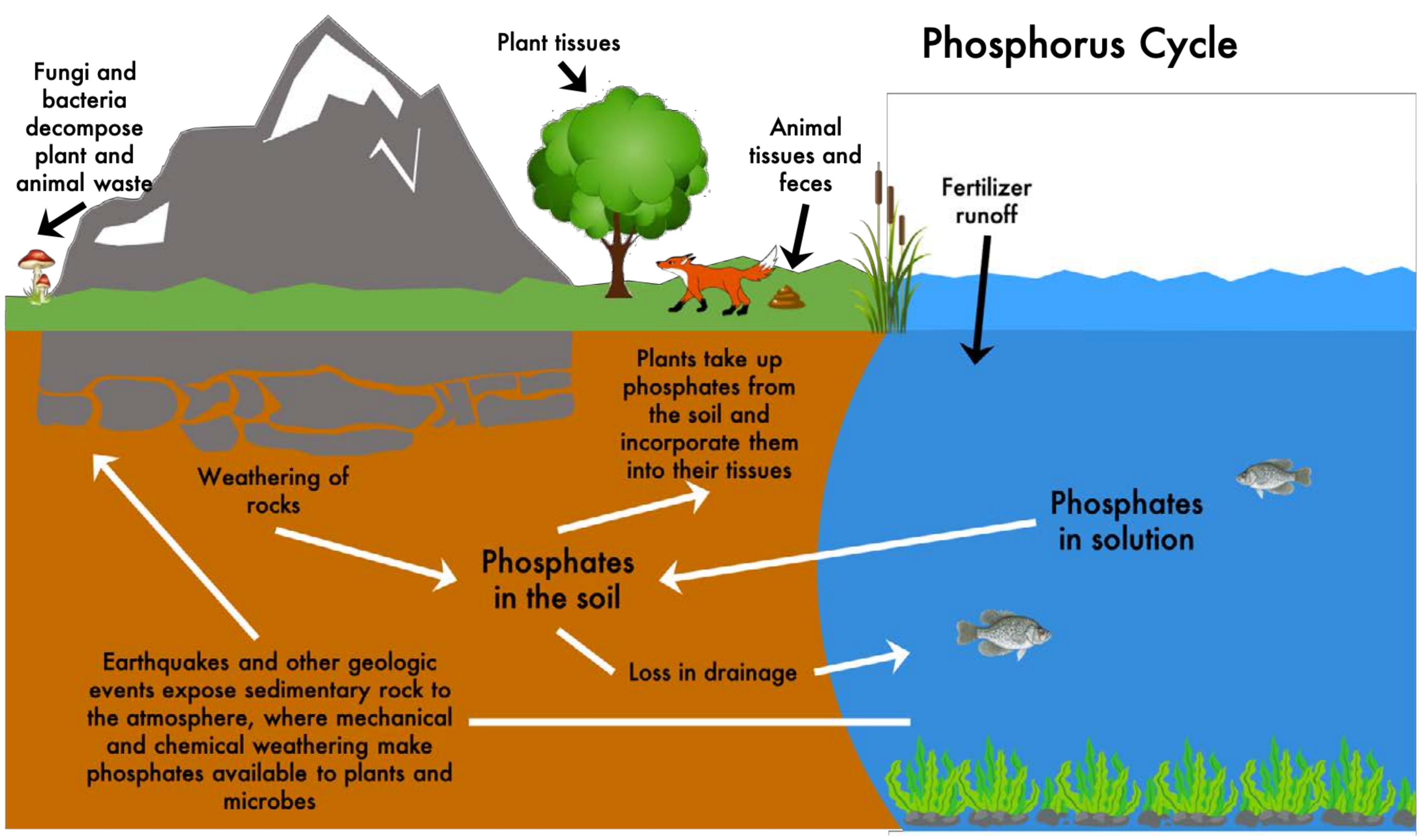
Phosphorus is another substance that is essential for life. Phosphorus often combines with four oxygen atoms, forming a phosphate ion (PO_4). Algae and larger aquatic plants rapidly take up this ion for metabolic reactions and growth. Animals need phosophorus for similar reasons, but they uptake phosphorus through the food chain.

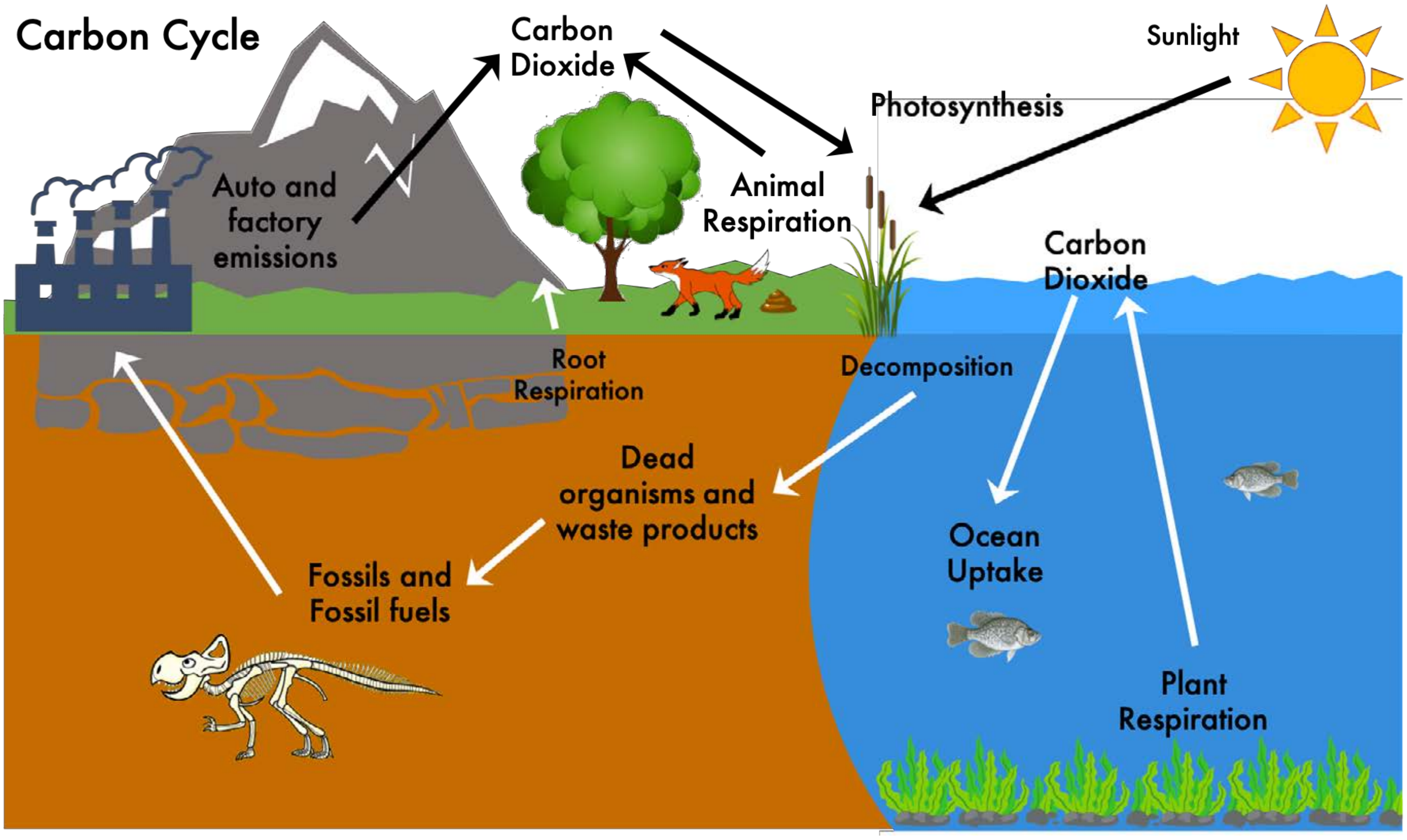
Phosphate that is not combined with any molecules in organisms is called "**orthophosphate**", meaning "straight phosphate". Orthophosphate, the reactive form of phosphate, is the easiest to test for in the environment. In most water bodies, orthophosphate is found in very low concentrations. Therefore, phosphorus often acts as the **growth-limiting** factor for producers (autotrophs), as plant growth and reproduction is limited by the amount available.

Algal blooms occur if orthophosphates are available in excess amounts as algae can reproduce rapidly . Humans actions can lead to excess orthophosphates in water bodies (**eutrophication**), such as the use of manufactured substances that contain phosphates (fertilizers, industrial wastes), and the disposal of human and animal wastes. Eutrophication resulting from nutrient pollution is the biggest problem facing lakes worldwide.

NUTRIENT CYCLES







Nutrients in the Community

Aquatic organisms influence (and are influenced by) the chemistry of the surrounding environment. For example, phytoplankton extract nutrients from water and zooplankton feed on phytoplankton. Nutrients are redistributed from the upper water to the lake bottom as dead plankton gradually sink to lower depths and decompose. The redistribution is partially offset by active vertical migration of the plankton.

In contrast to dissolved oxygen, essential nutrients such as the bioavailable forms of phosphorus and nitrogen (dissolved phosphate, nitrate, and ammonium) typically increase in spring from snowmelt runoff and from mixing of accumulated nutrients from the bottom during spring turnover. Concentrations typically decrease in the epilimnion during summer stratification as nutrients are taken up by algae and eventually transported to the hypolimnion when algae die and settle out. During this period, any "new" input of nutrients into the upper water may trigger a "bloom" of algae. Such inputs may be from upstream tributaries after rainstorms, from die-offs of aquatic plants, from pulses of urban storm water, direct runoff of lawn fertilizer, or from leaky lakeshore septic systems. In the absence of rain or snowmelt, an injection of nutrients may occur simply from high winds that mix a portion of the nutrient-enriched upper waters of the hypolimnion into the epilimnion. In less productive systems significant amounts of available nitrogen may be deposited during rainfall or snowfall events (wet deposition) and during the less obvious deposition of aerosols and dust particles (dry deposition). Nitrogen and phosphorus in dry fallout and wet precipitation may also come from dust, fine soil particles, and fertilizer from agricultural fields.

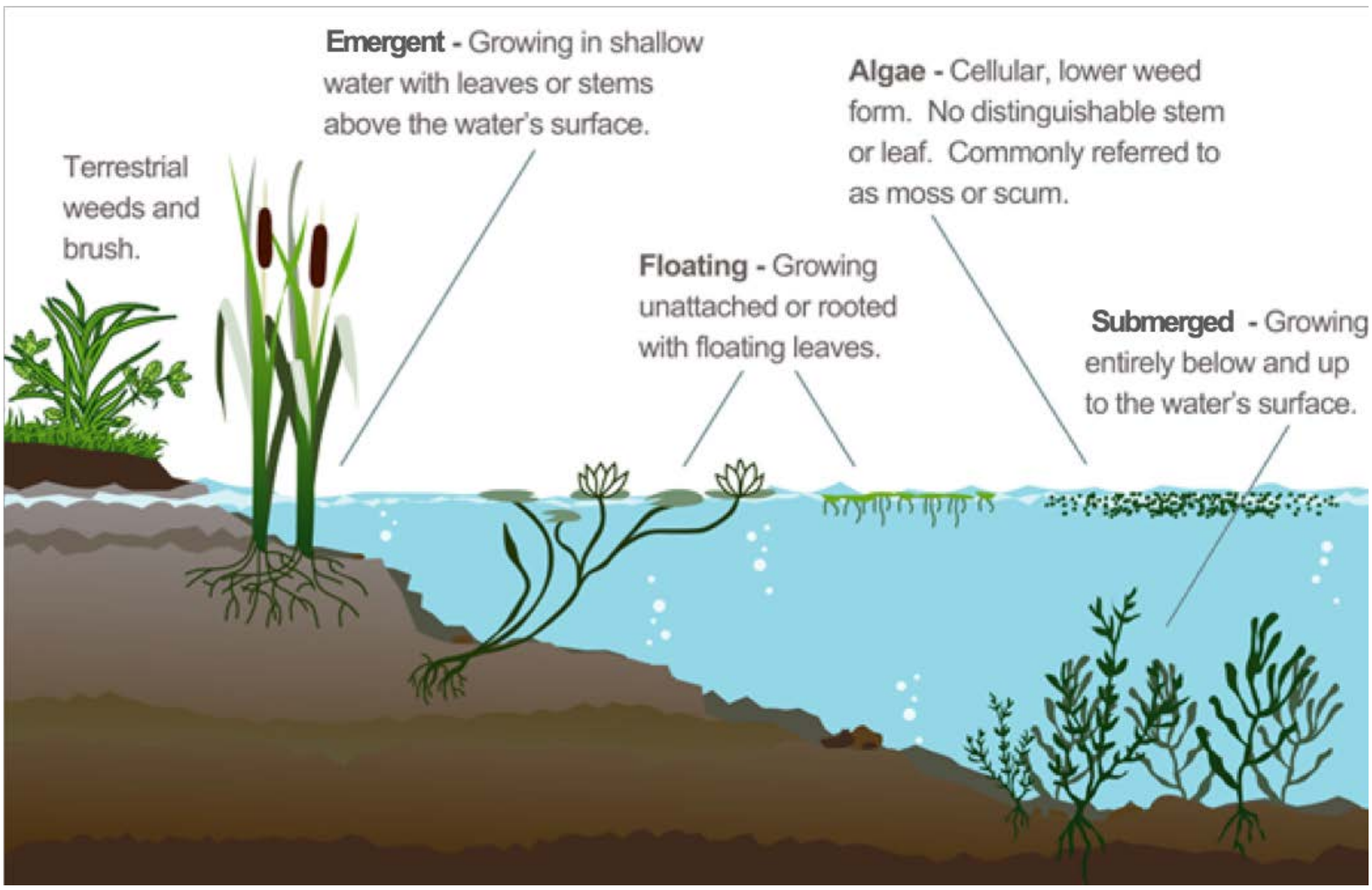
AQUATIC PLANTS

Aquatic macrophytes are plants that require a water environment to complete all or most of their life cycle. There are three main types:

Emergent macrophytes extend above the water surface in shallow areas of lakes, ponds and ditches. They have rigid stems and do not rely on water for physical support. Cattails and bulrushes are among the most common types.

Floating macrophytes may be rooted or free-floating. **Free-floating** plants obtain their nutrients directly from the water. Duckweed, a small plant often mistaken for algae, is the most common free-floating aquatic macrophyte in Manitoba. **Rooted** floating plants lack stem rigidity and depend on water for support. Pondweed and yellow pond-lily are common rooted types. Some plants, such as bur-reeds, water plantains and arrow-heads share characteristics of both emergent and floating aquatic plants. Parts of these plants extend out of the water like emergent plants, but they also floating leaves like floating aquatic plants.

Submerged aquatic plants have flexible stems and leaves, are rooted in the sediments and are completely covered by water (although some species have flowers that extend above the surface). Common plants include water buttercups, water milfoils and bladderworts.



THE IMPORTANCE OF AQUATIC PLANTS

Aquatic plants are an important part of the aquatic ecosystem. They provide excellent habitat for fish, aquatic insects and terrestrial wildlife, are an important constituent in the diet of muskrats and moose and are a source of food and nesting material for waterfowl. Aquatic plants help prevent turbidity (cloudy, silty water) by stabilizing lake sediments. They also protect shorelines from excessive erosion by absorbing the force of wave action. These plants use up large amounts of nutrients, reducing the amount available for algal growth and they absorb potentially toxic substances, like mercury and lead, thus improving water quality.

PROBLEMS CAUSED BY TOO MANY AQUATIC PLANTS

Excessive growth of aquatic plants in recreational waterbodies and drinking water reservoirs can create several problems, including:

- **Swimming nuisances** - excessive aquatic plant growth in shallow water discourages swimming and interferes with activities along shorelines and beaches.
- **Boating difficulties** - plants clog motorboat propellers and interfere with sailboat centreboards.
- **Less appealing drinking water** - aquatic plant decomposition can lead to foul odour, taste and discolouration of drinking water, making more advanced water treatment necessary.
- **Less dissolved oxygen in the water for fish** - a result of the decomposition of excessive amounts of aquatic plants. Artificial water aeration has been used in Silver Beach Lake, Oak Lake, Gull Lake and others, to alleviate this problem.
- Dense aquatic plant growth in small streams and drains can impede water flow and contribute to flooding.

High densities of aquatic plants may be an indicator of water quality problems. If your lake or river has too many plants, it may mean that there is too much nitrogen and phosphorus entering the water. Check to see which of the following nutrient sources you can control: fertilizers, sewage, greywater, pet feces, cleaning products or shoreline erosion.

What you can do:

- Disrupt as few aquatic plants as possible - remember that they provide essential habitat for fish and waterfowl.
- Don’t use herbicides in lakes and rivers - it is illegal.
- Consider the role that aquatic plants play as home to waterfowl, fish, amphibians and aquatic insects.

Free floating aquatic plants

Lesser duckweed (*Lemna minor L.)*
Has no leaves, rarely has flowers, and is in the form of a flat thallus. Eaten by waterfowl, this plant also provides shade and cover for fish and other aquatic invertebrates. Reproduces predominantly by budding. Is found on the surface of shallow ponds, marshes, and pools.

Common bladderwort (*Utricularia vulgaris L.*)
Has numerous leaves and yellow flowers. Is food for waterfowl, provides cover for fish, and consumes small aquatic animals using its bladders. Is found in lakes, sloughs, and ditches, floating near the surface in quiet water.

Floating Leaved Aquatic Plants

Yellow Water Lily (*Nuphar lutea*)
Has broad oval leaves with yellow flowers. Reproduces through seeds, tubers, and proliferation of the rhizome. Found in sheltered ponds, lakes, and slow-moving streams. Eaten by deer, moose, and insects. Rhizome is a chief source of food for muskrats. Floating leaves provide shade and cover for fish and aquatic invertebrates.

Floating-leaf pondweed (*Potamogeton natans*)
Has numerous, broad, leathery floating leaves on petioles and small, green, numerous flowers. Reproduces through seeds and proliferation of the rhizome. Seeds provide food for ducks, and the plants provide cover for aquatic invertebrates. Found in shallow or deep water of lakes and marshes.

Lesser duckweed

Common bladderwort

Yellow water lily

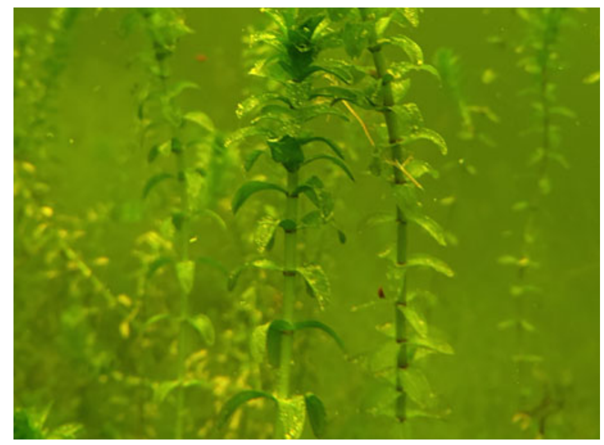
Floating-leaf pondweed

Submerged aquatic plants

Coontail (*Ceratophyllum demersum* L.)
Has leaves in whorls of 5-12 variably spaced on the stem. Is eaten by muskrats and waterfowl, shelters young fish and supports insect life. Moderately efficient as an aerator.

Coontail

Canada Waterweed (*Eloda canadensis michx*.)
Plant has dark green, translucent, small and narrow leaves, with unisex flowers (male and female). Provides shelter for a wide variety of aquatic organisms. Is an efficient oxygenator of water. Is found in dense stands in the shallow areas of lakes, sloughs, and slow-moving streams. Reproduces primarily by winter buds.



Canada waterweed
© Michael Millane

Flat-stemmed pondweed (*Potamogeton compressus*)
Has linear, long leaves. Tubers and seeds are important duck food. Found in lakes, sloughs, and slow-moving streams. Reproduces primarily through tubers and winter buds.

Emergent aquatic plants

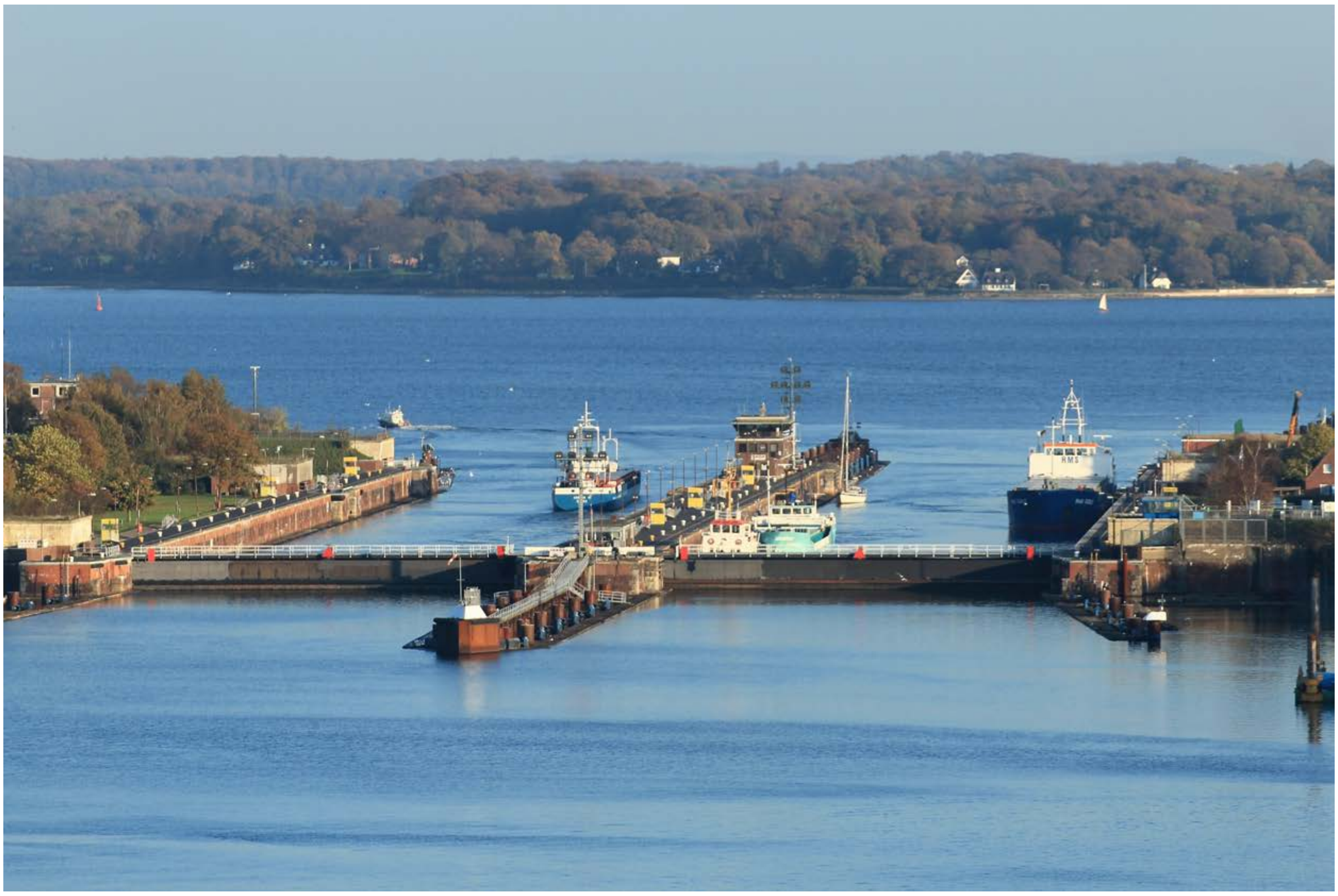
Common cattail (*Typha latifolia*)
Leaves are linear, upright, sheathing a stem and have flowers that form a dense terminal spike, with male portion of the spike produced above the thick, cigar-shaped female portion. Reproduce through seeds and proliferation of the rhizome. Found in any wet place within a marshy area. Provide excellent habitat for birds and small mammals. Rhizomes are eaten by muskrat and beaver.

Common cattail

Bulrush (*Schoenoplectus* spp.)
Plants with flowers forming spikelets, arranged laterally or terminally on the stem. Leaf blades are often lacking, but when present they are linear and sheathing the stem. Found in shallow shoreline waters and wet meadows. Important food for muskrats, used as nesting sites for birds, and are an important soil binding species.

Giant Bulrush
© Illinois Wildflowers

AQUATIC ECOSYSTEM HEALTH



Healthy aquatic ecosystems are those where human disturbances have not impaired the natural functioning (e.g., nutrient cycling) nor appreciably altered the structure (e.g., species composition) of the system. An unhealthy aquatic ecosystem is one where the natural state is out of balance.

Ecosystem disturbances can be physical (e.g., injection of abnormally hot water into a stream), chemical (e.g., introduction of toxic wastes), or biological (e.g., introduction and propagation of non-native species). Symptoms of poor ecosystem health include the following:

- Loss of species
- Accelerated proliferation of organisms (e.g., algal blooms)
- Changes in chemical properties (e.g., acid rain)
- Presence of organisms that indicate unsanitary conditions (e.g., coliform bacteria)

Many symptoms of poor ecosystem health occur simultaneously. For instance, increased lake acidity may kill certain species, thereby allowing the temporary proliferation of species more tolerant of acidity, while reducing populations of organisms who relied on the sensitive species for food.

THE IMPORTANCE OF HEALTHY AQUATIC ECOSYSTEMS

Why is aquatic ecosystem health important to humans? Everything is connected, and when an ecosystem is out of balance humans will eventually suffer as well. Our health and many of our activities are dependent on the health of aquatic ecosystems. Most of the water that we drink is taken from lakes or rivers. If the lake or river system is unhealthy, the water may be unsafe to drink or unsuitable for industry, agriculture, or recreation, even after treatment. Uses of aquatic ecosystems are impaired when these systems are unhealthy. For example:

- Inland and coastal commercial fisheries have been shut down due to fish or shellfish contamination or the loss of an important species from the system.
- Frequency of urban beach closures has escalated as a result of contamination by animal feces and medical waste.
- Navigation problems for pleasure craft, caused by the rapid expansion of bottom-rooted aquatic plants, have increased.
- Proliferation of non-native species has created problems. One recent example is the rapidly expanding zebra mussel population, which were detected in Manitoba in 2013. This mussel species is already clogging industrial and municipal water treatment intake pipes, coating boats and piers, and causing beach closures.

STRESSORS ON AQUATIC ECOSYSTEMS

Direct stresses

Direct stresses are those that occur within a water body, such as dredging, filling, draining, and invasive species. They are usually human-induced, highly visible and can result in rapid changes to water bodies. Two examples are presented below:

Great Lakes coastal wetlands are often located at river mouths and in protected areas which are also favourable places for harbours. As a result, **dredging** has historically occurred in wetland areas to allow the safe entry of boats. Deepening the water and removal of sediments can result in the destruction of wetland habitat. In the same way, draining and filling of small wetlands for urban development and to increase agricultural areas results in significant losses of wetland area and function each year. Carp, an **invasive fish species** introduced from Europe, damages wetland ecosystems while feeding and spawning by uprooting submerged vegetation and increasing the cloudiness of the water which decreases light penetration required for plant growth.

Indirect Stresses

Indirect stresses are often less pronounced, with changes occurring over a longer period, meaning that it can be difficult to pinpoint their exact source. Indirect stresses include runoff from upstream agricultural areas, sewage treatment plants and industrial sources which can cause loading of nutrients, sediments and toxic chemicals in downstream wetlands. Due to the collective contribution of sources, it is often difficult to remediate these problems. Fortunately, water bodies can assimilate some nutrients and toxic chemicals through plant uptake and the interaction of flowing water with microbial communities in sediments.

Lake-wide wide water level regulation is a common indirect stress. Water levels are regulated to accommodate navigation, shipping, hydroelectric power and shoreline landowners, meaning less natural variability in water levels. Alternating high and low water levels often lead to more diverse plant communities, thus, consistent high or low water levels can cause less diverse systems by excluding those species that rely on periodic changes in water level.

AQUATIC SAMPLING TECHNIQUES

Water sampling in the Antarctica

© Gordon Picken/Cool Antarctica

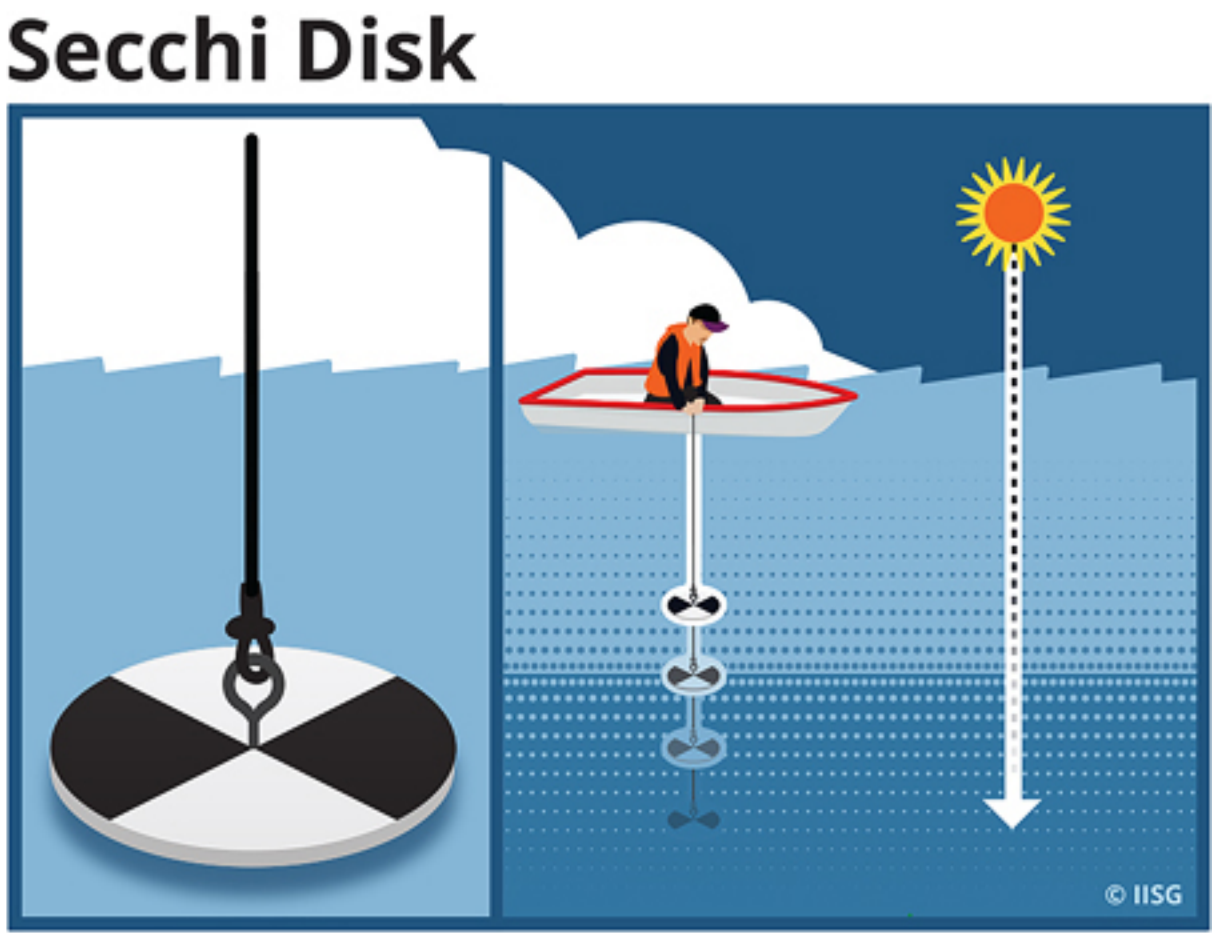
In order to better understand aquatic ecosystems, scientists have developed specialized techniques and equipment to assist in sampling the different ecosystem components. You may be asked to use some of these pieces of equipment on an Envirothon test! Demonstrations of many of these sampling techniques can be viewed in the training videos linked on the Aquatic resources page.

PHYSICAL FACTORS

Water **clarity** (especially the depth to which light penetrates through water) and **temperature** are among the most important physical factors for aquatic ecosystems, and both affect the chemistry and biology.

Water clarity

Solar radiation covers a broad spectrum of wavelengths, but **Photosynthetically Active Radiation** (PAR) represents the portion of the solar spectrum (400 to 700 nm) that can energize photosynthesis in algae and other aquatic plants. By measuring depth of PAR, a



Secchi Disk
© Limno Loan, IISG

researcher can estimate the potential for photosynthesis in the water column. The depth of PAR into the water is typically measured using a light sensor attached to an electronic instrument, however, a very simple device called a **Secchi disk** (named after its inventor) can provide some of the same information at a fraction of the cost of the electronic device.

Method

- The secchi disk must be deployed on the shaded side of the platform (boat, dock, etc.), and the user must not wear sunglasses.
- While suspended in a horizontal position from a metered line, the disk is slowly lowered into the water until it just disappears from view.
- The disk is then brought up until it is just visible, but it is not possible to differentiate between the black and white portions.
- Using the metered marks on the line, the depths of disappearance and reappearance are noted and, the average of the two is recorded as the **Secchi depth**.

Over time, this measurement can be repeated frequently to determine whether the penetration of solar radiation is changing. It can also be used to compare the penetration of solar radiation in different water bodies. With this device, our eye serves as the sensor. For the disk to be visible at depth, the light being detected by our eye must travel down through the water column, reflect off the disk, and travel back up to our eye. There is sufficient water transparency for photosynthesis to occur down to a depth of approximately **twice the observed Secchi depth**. For example, if we can see the disk at a depth of 2.4 metres, light is penetrating the water column to a depth of at least 4.8 metres, therefore, algae living in that water column have enough light for growth, provided they are not deeper than 4.8 m.

Water temperature

Water temperature is important because it affects the **metabolism** or internal life processes of many species living in the water. At warmer temperatures, animals tend to be more active than at cooler temperatures. Many species will feed more and grow faster in warmer water. Temperature variations will also affect mixing of water between the surface and lower depths, which, in turn, will affect the concentrations of dissolved oxygen at depth.

In order to measure how water temperature changes with increasing depth, **limnologists** (people who study lakes) often use an electronic thermometer with the temperature sensor connected to a meter by a cable marked at measured intervals. To use this device, the researcher sits in a boat or on a dock floating on the surface and lowers the sensor down through the water column, recording the temperature at various depths to produce a profile or graph of temperature versus depth. By repeating such profiles over time, a heat budget can be calculated for the water body, providing an indication of how much heat energy is present in the water to drive internal mixing and metabolic processes.

Electronic thermometer

CHEMICAL SAMPLING

As the "**universal solvent**", pure water is almost non-existent in nature. As soon as pure water droplets are created, they begin to absorb or dissolve other chemical elements from the surrounding air or substrate. Water is the life-blood of an ecosystem, as it carries to all parts of the system a variety of chemicals needed for photosynthesis, respiration, and other essential life processes. It also carries waste materials, including those that cause what we call "pollution".

Not all substances carried by water are dissolved. Some larger particles are less dense than water and will float. If the water is moving quickly enough, it may have enough energy to carry along more dense materials in suspension. This is particularly true of smaller soil granules, such as clay particles and even sand grains.

Sample collection

In order to identify and quantify the chemical constituents carried in water, a water sample must be collected and subjected to a number of chemical analyses, usually in a laboratory. A surface water sample can be obtained by dipping a bottle, but either a battery-powered pump used with metered tubing attached, or a specialized water collecting device (e.g., Van Dorn sampler), is typically used to obtain water from various known depths.

Peristalic pump

Van Dorn Method

- The Van Dorn device is suspended from a boat or dock by a metered line and lowered to the depth from which a water sample is desired. The sampler is essentially a large, open pipe, so it fills with water wherever it is stopped in the water column.

- To close the sampler, a weight called a messenger is dropped down the line to trigger a release of the end stoppers, which causes the stoppers to snap onto the ends of the device, trapping the water inside.

- The device is then pulled to the surface and the water is released through a spigot into a collection bottle.

- The sampler can be rinsed and used again at other depths to obtain “profile” sample throughout the water column.

Van Dorn Sampler

Filtration

Once a water sample is obtained, there are many different analyses that can be made, including pH, dissolved oxygen, conductivity, nutrient concentrations, metal concentrations, etc. Some of these substances, such as oxygen, will be dissolved in the water. Others, such as carbon, will be partially dissolved and partially suspended in the water. In order to separate the **dissolved fraction** from the **particulate or suspended fraction**, it is usual to use a very fine pore filter. Typically, this filter will have pores no larger than 1 micron (1 millionth of a metre, or 1 thousandth of a millimetre) in diameter. Thus, anything in the water that is more than 1 micron across will be trapped on the filter is part of the particulate or suspended fraction. Everything smaller will go through the filter is part of the dissolved fraction.

A typical filtration apparatus consists of a vacuum flask connected to a vacuum pump. In the laboratory, the pump is usually electrically powered, however, in a field situation, a hand-operated pump may be used.

Filtration Method

- A three- piece filter funnel is mounted in the neck of the flask using a rubber stopper. The funnel consists of an upper section that receives and contains the sample during the filtering process, a base that drains to the flask and supports the filter, and a spring-loaded clamp to hold the filter tightly between the two sections and prevent the sample from leaking out during the filtration process.

- To operate the system, one must remove the clamp and the upper section, carefully place a new, clean, filter paper (making sure that it is properly centered) on the base, then place the upper section over the filter paper and securely clamp the two sections together.

- A measured amount of water sample is poured into the funnel, and the vacuum pump is used to lower the air pressure within the flask, thereby drawing the water and dissolved fraction through the filter into the flask.

- The suspended or particulate fraction will remain on the filter paper as (usually) visible residue.

Sample analysis

Following filtration, the two fractions may be analyzed separately using various techniques. While not quantitative, a careful visual examination of the colour and texture of the residue on the filter, and the colour of the filtrate in the flask, sometimes can provide a useful comparison of two different water samples.

The **residue on the filter** may include a variety of particulate materials. If it is green in colour, it probably contains algal cells, indicating that the system from which the water was collected is productive and nutrient-rich. The particles on the filter may consist primarily of dead and decomposing materials, either from the aquatic system being sampled or from the land draining into this lake or stream. In systems located in clay soils, the residue may largely consist of minute clay particles that were held in suspension by wind and currents.

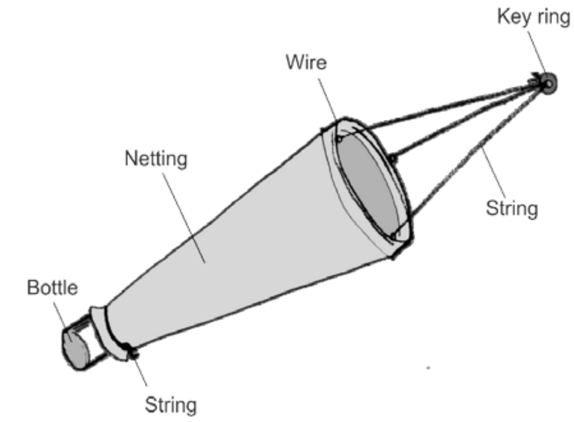
The **filtrate in the flask** will contain dissolved substances, including forms of carbon, nitrogen, and phosphorus that can promote algal growth. It may be coloured but should not contain visible particles. The filtrate may also contain pharmaceuticals and other manufactured chemicals as contaminants, particularly if the sample was collected downstream from a major urban centre.

BIOLOGICAL SAMPLING

Methods of biological sampling differ according to the biological community and particular populations of organisms being studied.

For most **bacteria and algae**, because of their minute sizes, it is necessary to take a water sample back to the laboratory where the organisms can be carefully concentrated through filtration and observed under microscopes or using other specialized techniques for identification. This sample can be collected using a pump or water bottle, as described above for chemical sampling.

For slightly larger organisms, such as most **zooplankton**, a very fine mesh net can be used to separate them from the water during the sampling process. These zooplankton sampling devices can take various forms, but all use a fine mesh net (usually between 40 and 75 micron pores) for the separation process. Two such samplers are shown in the pictures, below. On the left is a simple **zooplankton tow net**. On the right, is a **Schindler-Patalas trap**, named for the two scientists at Winnipeg's Freshwater Institute who devised it 40 years ago. The tow net is lowered through the water to a desired depth, and then pulled vertically through the water column, capturing any zooplankton present in the water column while letting water flow through the net as it goes. At the surface the net is emptied into a bottle and preserved. The tow net can also be pulled horizontally through the water. The Schindler-Patalas trap is designed to capture organisms at specific depths, rather than through the entire water column. It is lowered to the desired depth, the plastic box is allowed to fill with water, and then the door to the box is triggered from the surface of the water,



Zooplankton Tow Net

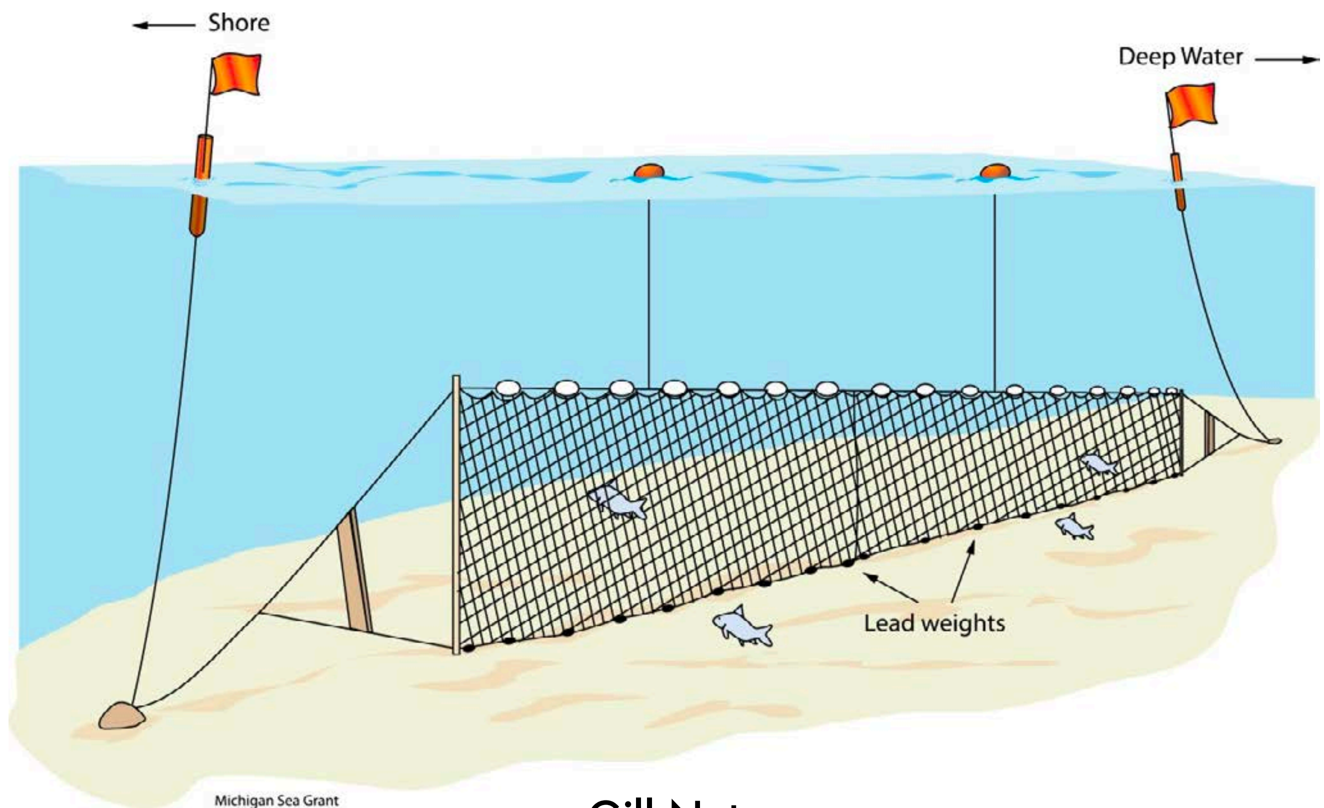
capturing a cube of water from that depth. After being pulled to the surface, the contents of the sampler is filtered through a mesh funnel before being placed in a bottle and preserved.

Schindler-Patalas trap

For capturing small, **benthic invertebrates** (bottom-dwelling), various kinds of sediment samplers are used. Some of these are coring devices (e.g., KB corer), while others are dredges or grabs (e.g., Ekman dredge). Both can be operated from a boat to collect samples of the bottom material and bring them to the surface for further analysis. In all cases, samples of sediment must be sieved through fine mesh sieves and invertebrates picked out by hand.

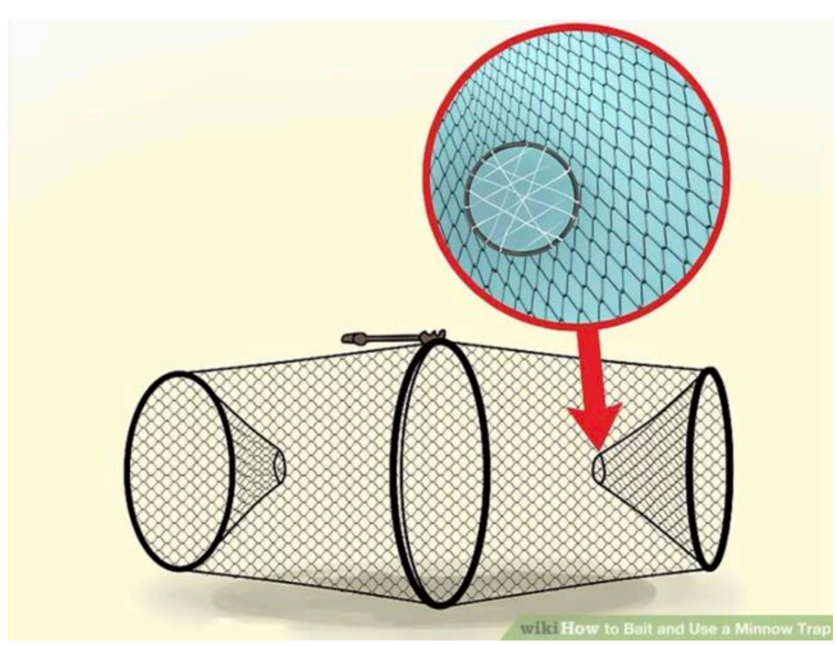
Ekman dredge

Fish can be captured for research purposes in a variety of ways, including nets (gill nets, seine nets, trap nets, fyke nets), minnow traps, and by angling (rod and reel). Used properly, these techniques generally prevent the fish from being killed. Some methods, like trap netting and seine netting may catch other animals as well, such as turtles, newts, crayfish, insect larvae, and small crustaceans. The figure below outlines a few of the capture techniques.



Gill Net
© Michigan Sea Grant

Seine Net
© IISD Experimental Lakes Area

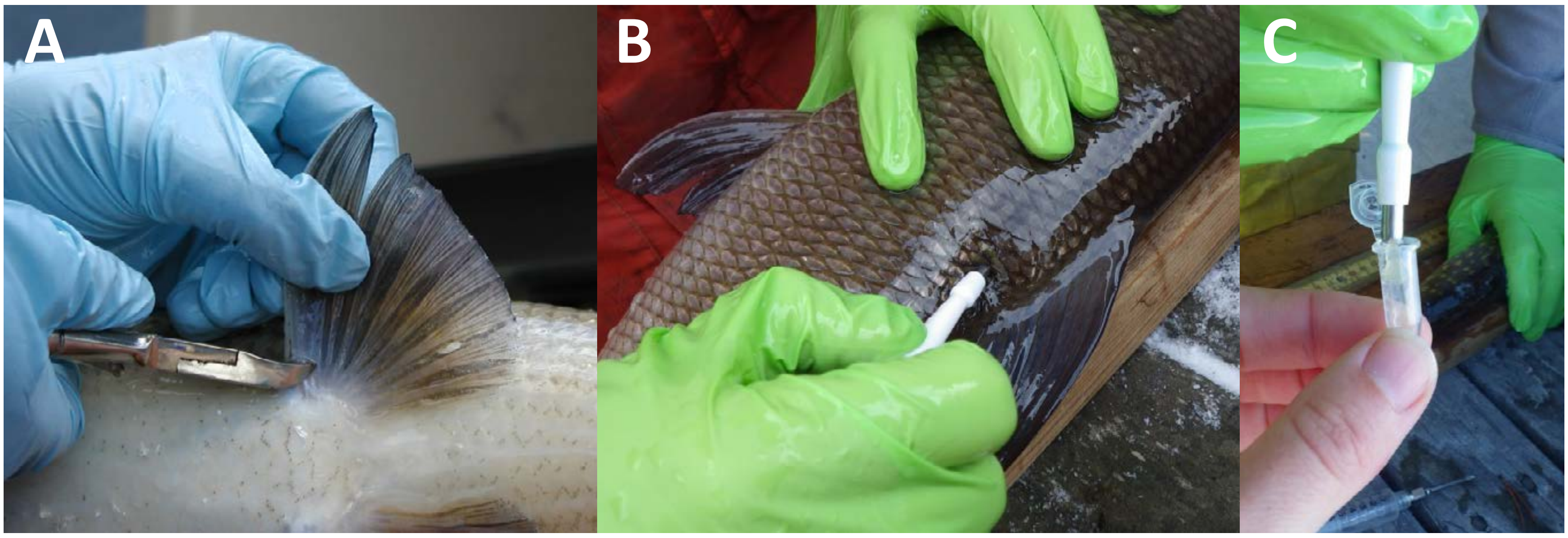


Minnow Trap
© WikiHow

Gill nets hang vertically in the water because they have floats along the top and weights along the bottom. Fish swim into the nets and become entangled. Researchers pull in a seine net to capture fish near the shore. Minnows swim into the trap through a small hole in one end and then can't find their way out.

Once captured, various types of biological information can be collected from a fish, including length (fork length, total length) and weight. These data help researchers to determine whether a fish is healthy or unhealthy. The following figures illustrate how this information is gathered by researchers.

A: Weighing a lake whitefish using an electronic scale.
B: Fork length is the distance from the tip of the snout to the fork of the tail (if present); total length is the distance from the tip of the snout to the end of the tail.
C: A researcher measures the fork length of a northern pike
Researchers may also collect tissue samples, such as fins and otoliths (ear bones) for determining the age of a fish, or muscle samples for determining concentrations of contaminants such as mercury.



A: A researcher clips the first fin ray of a pelvic fin. Growth rings (like tree rings) in the cross section of a fin ray may be counted to determine the age of the fish.
B: A researcher uses a biopsy punch to collect a small muscle sample from a live lake whitefish. The hole left by the punch will be sealed up with tissue glue, and the fish will be released back into the wild. This non-lethal sampling method makes it possible to sample the same fish multiple times during its life.

SUMMARY

This section has provided a brief overview of various methods commonly used for sampling freshwater systems. Most of the methods described are primarily used in lakes and reservoirs, where the water is relatively still. Usually, different methods would be used for faster flowing systems, such as rivers and streams.

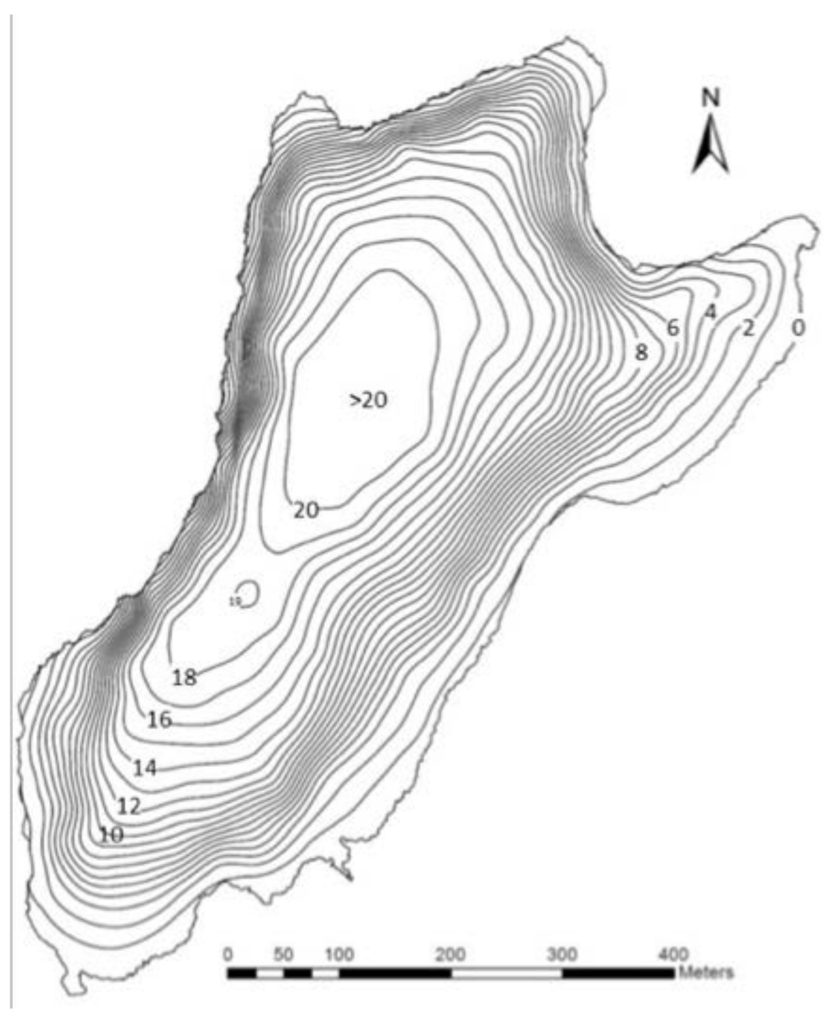
Of course, collecting the samples is only the beginning of the process. Careful analyses of these samples must be carried out to provide empirical (derived from experiment or observation) data that can be correctly interpreted to provide new understanding of ecosystem processes and the impacts of human activities on these systems. However, this new understanding would be flawed without the use of effective and appropriate sampling techniques.

MAPPING TECHNIQUES

TOPOGRAPHIC AND BATHYMETRIC MAPS

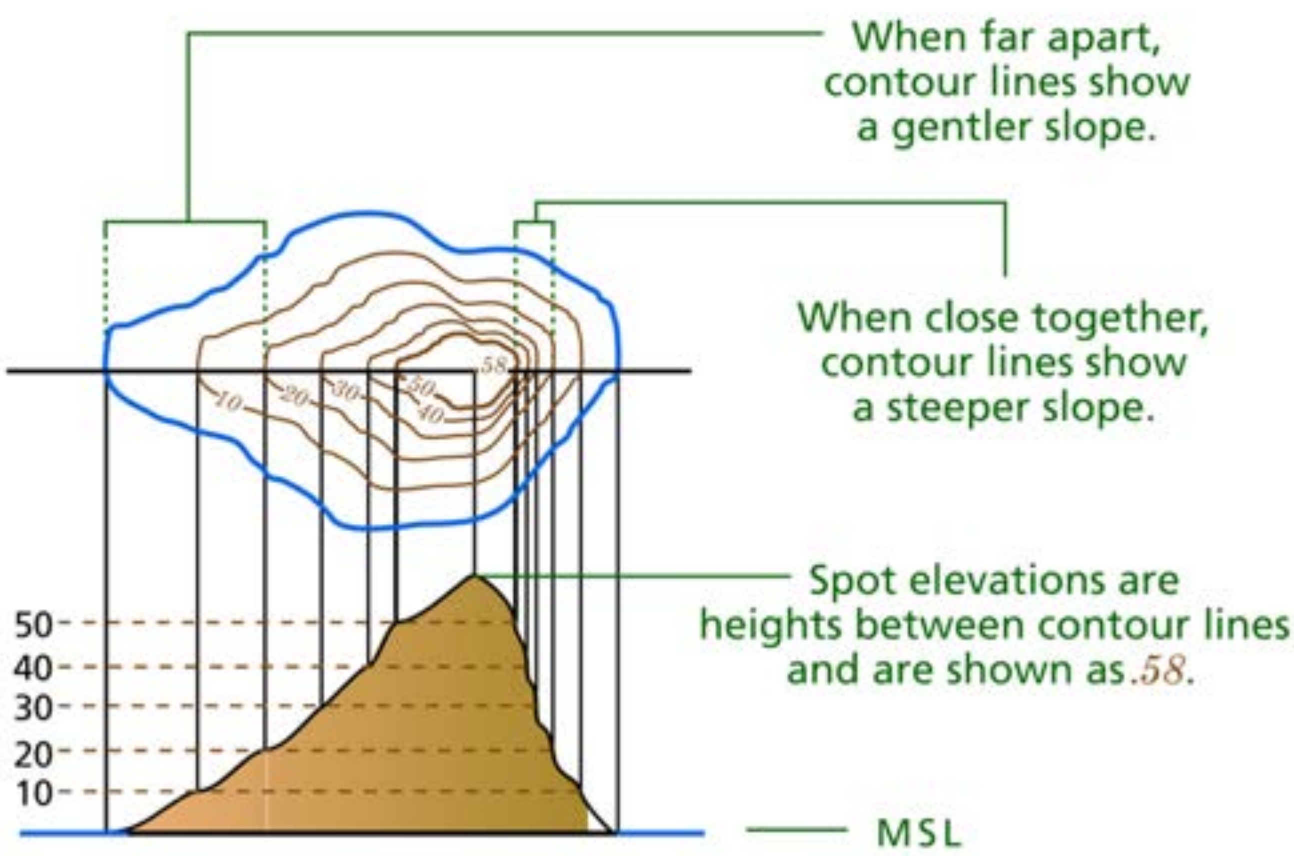
Topographic and bathymetric maps are detailed, accurate, 2-dimensional, illustrations of 3-dimensional features on the ground (**topographic maps**) and under water (**bathymetric maps**). Both types of maps provide information about landscape elevation using **contour lines**. Since water bodies are just depressions in the landscape that happen to be filled with water, contour maps may illustrate both the **height of topography** and the **depth of water bodies** in detail.

Bathymetric (left) and topographic (right) maps are used to illustrate 3-dimensional elevations on 2-dimensional maps. The bathymetric map on the left illustrates the depth of a lake (max depth >20 m), while the topographic map on the right illustrates the height of land (max >650 m).



WHAT ARE CONTOUR LINES?

Contour lines connect a series of points of equal elevation and are used to illustrate relief on a map (see above). They show the height of ground above mean sea level (topographic maps) or below the surface of the water (bathymetric maps). Contour lines can be drawn at any desired interval (e.g., 1 meter, 10 meters). Some maps will identify the elevation of each contour line, while others will label only some contour lines (e.g., every 5th line). Since the contour interval is fixed, however, it is easy to count the unmarked contour lines to determine elevation.



An illustration of contour lines. Contour lines are shown at the top, and a cross section of the feature in question shown at the bottom. On a bathymetric map, the lines will illustrate a depression instead of elevation.
Image from © Natural Resources Canada 2014

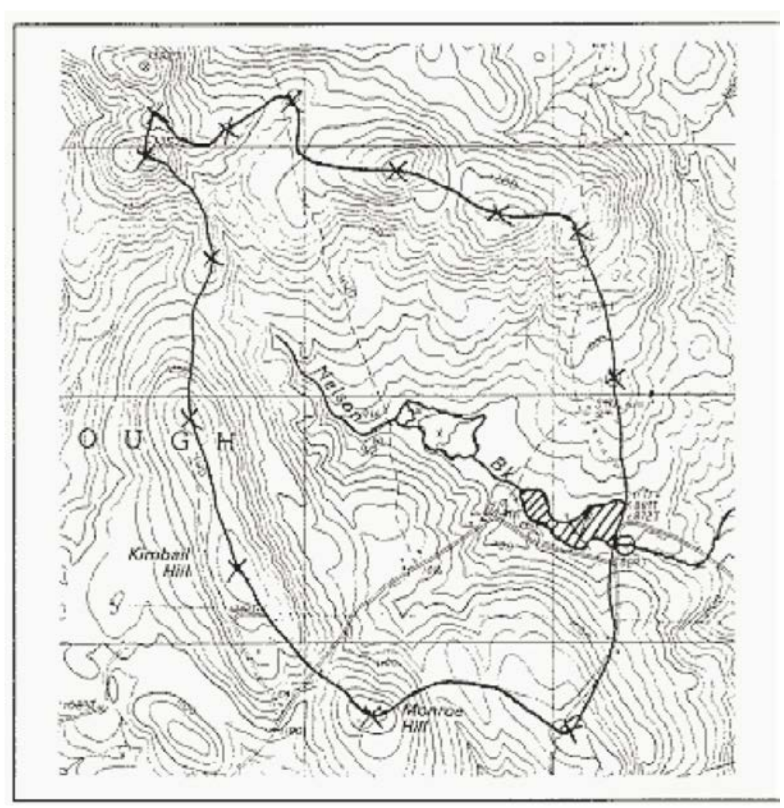
HOW ARE TOPOGRAPHIC AND BATHYMETRIC MAPS GENERATED?

Although topographic maps show heights of land and bathymetric maps show depth of water, both types of mapping are based on determining the elevation of specific features. Most maps of this kind are generated using equipment attached to vehicles that travel in transects (pre-determined grids) across the landscape (such as an airplane) or water body (such as a boat). This equipment senses the elevation of the land (topographic maps) or the bottom of the water body (bathymetric maps) and records it on a computer. After completing the survey, technicians import the data into map-generating software to generate the contours and finalize the maps.

WHAT ARE TOPOGRAPHIC AND BATHYMETRIC MAPS USED FOR?

Maps with contour lines offer detailed information about the landscape, including ground features and waterbody depths, meaning that they can have many applications. Some examples of uses include: scientific research, emergency preparedness, urban planning, resource development, and outdoor recreation.

For example, **hydrologists** (scientists who study the movement of water on the landscape), use topographic maps to determine the extent of watersheds by drawing lines between the highest points of land on a topographic map. Since water will always travel downhill, the highest points of land represent barriers between watersheds, while the lowest points of land represent depressions where water will collect (such as streams, rivers, and lakes). **Water will always flow perpendicular to contour lines, and always downhill.**



Example of delineating a watershed on a contour map. "X" marks are made at the highest points of elevation around the waterbody (Nelson Brook). These marks are joined by lines that pass through the highest elevation areas located between the marks. The resulting shape represents the extent of the watershed, meaning that all precipitation that falls within that area will travel downhill toward the brook

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