MANITOBA ENVIROTHON
AQUATIC ECOLOGY
PROVINCIAL RESOURCES

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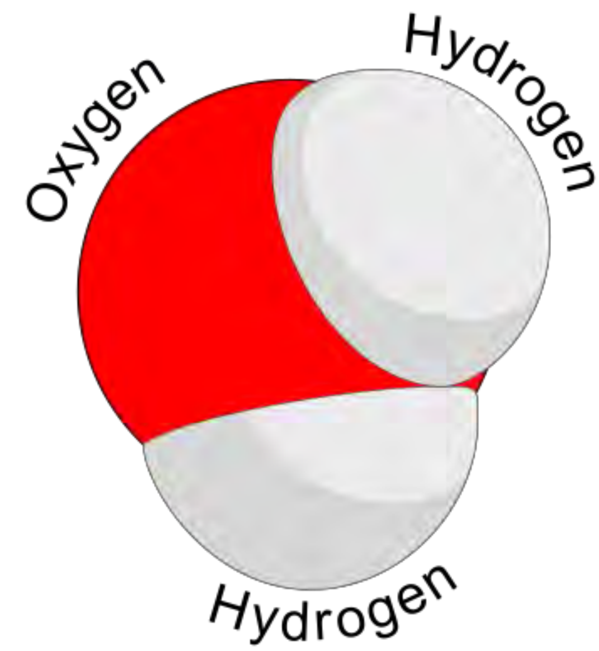
MANITOBA ENVIROTHON

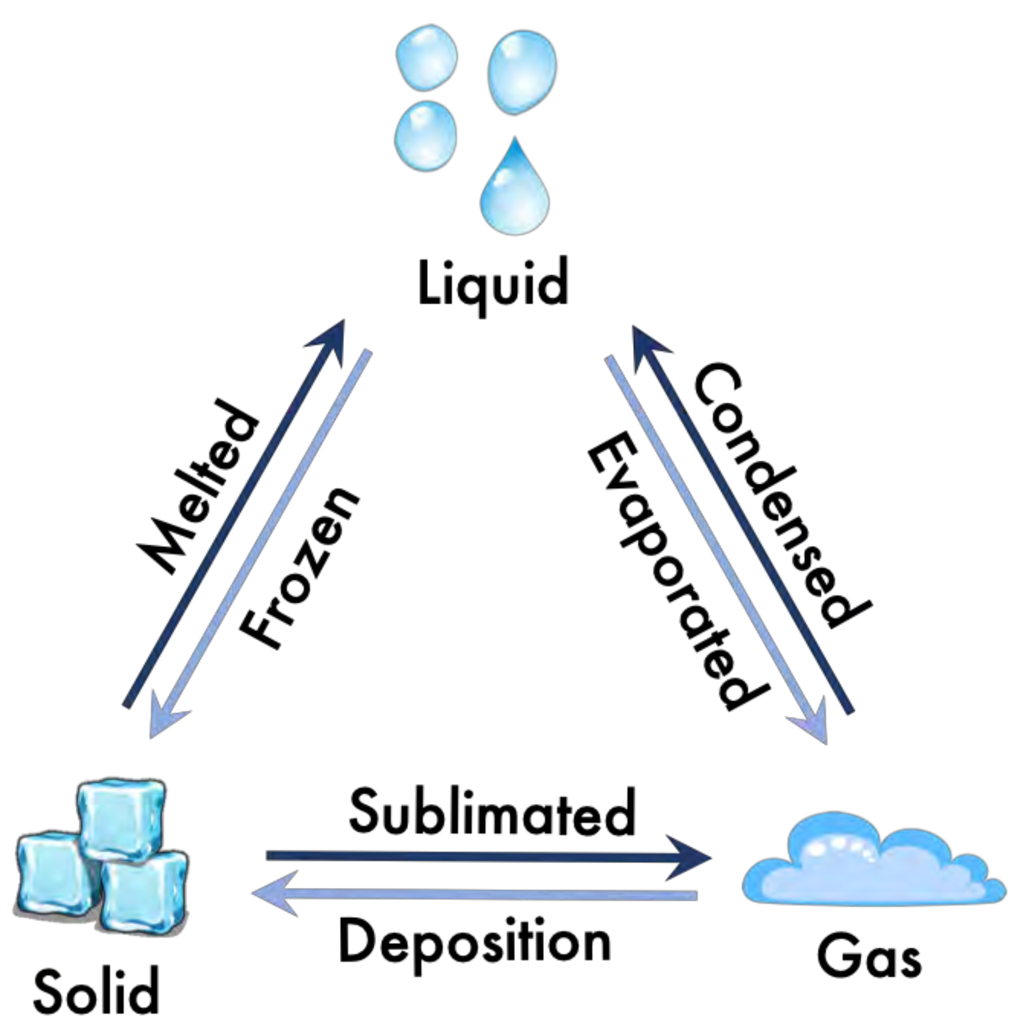
Manitoba Association of Watersheds

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

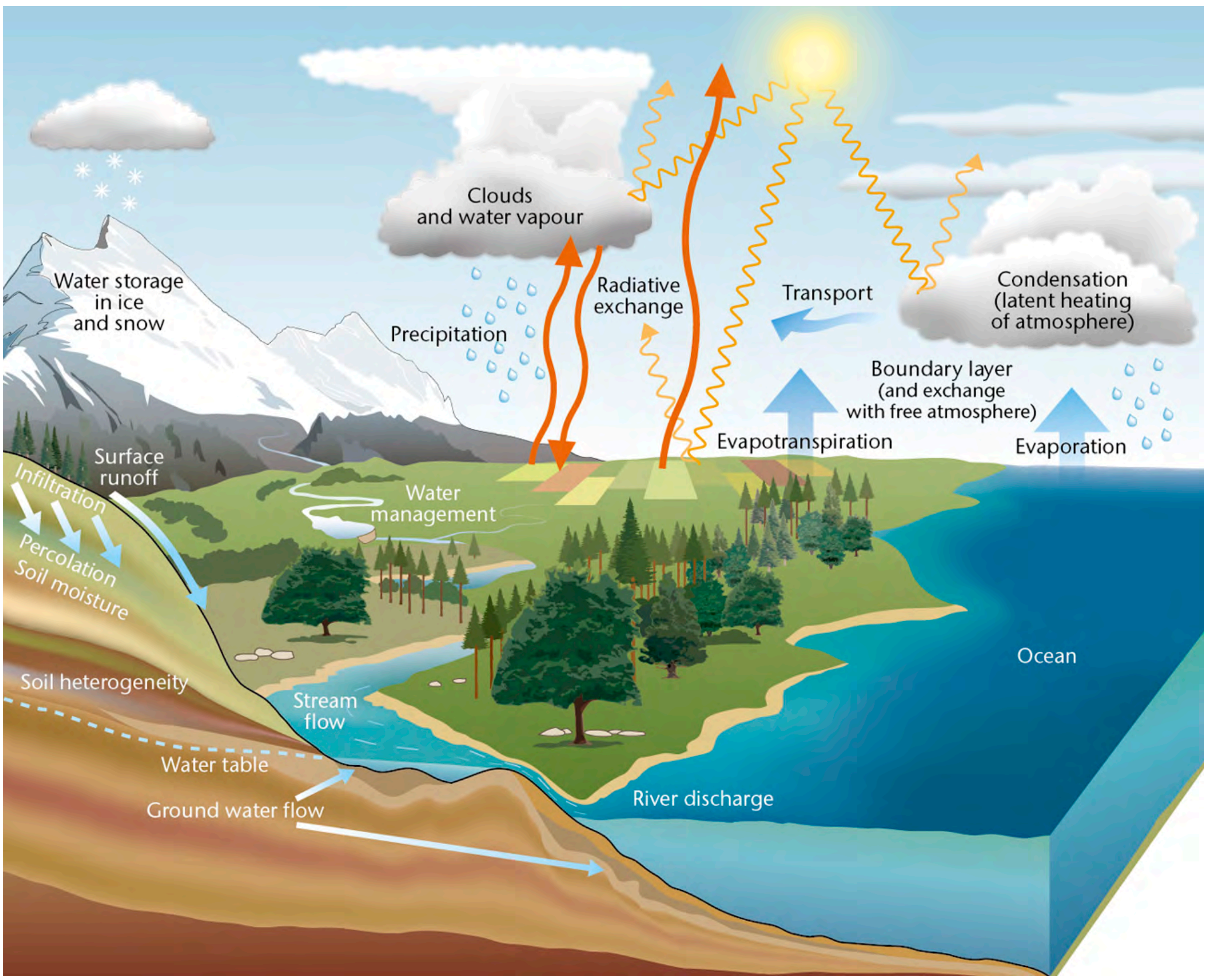
Water molecules bind to themselves through an interaction called **cohesion**, and to other substances through a process called **adhesion**. In the case of adhesion, the water molecules "stick to" the other substance, but do not change the molecular structure of the substance. For example, a droplet 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 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 run 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 appears 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.

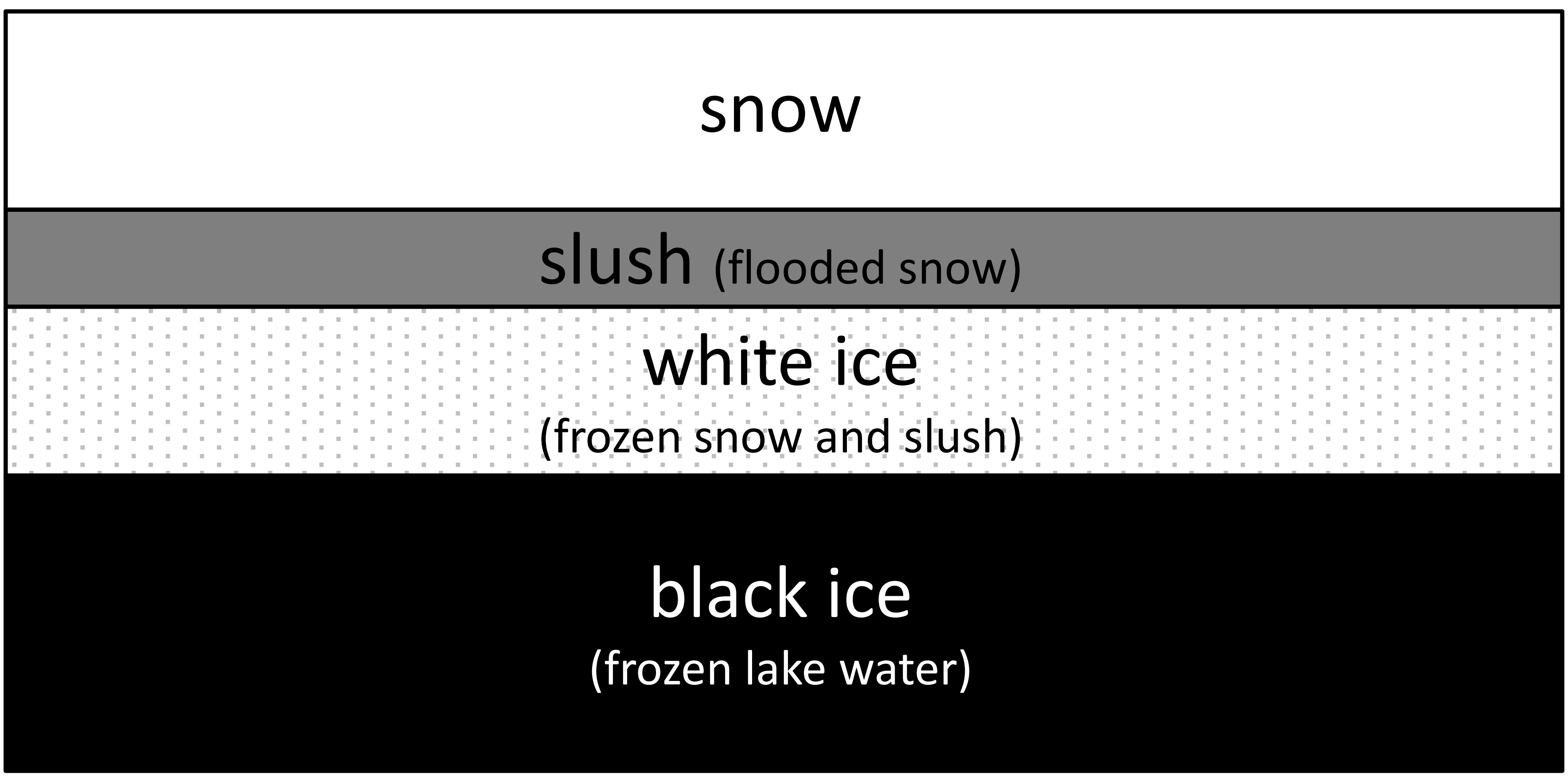
Antarctic glacier stream iron
© Lee Hrenchuk

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.

POLAR HYDROLOGIC CYCLE

The cold polar climate slows many processes in the hydrologic cycle. For example, in arctic regions where water bodies remain ice-covered for six to ten months of the year, little evaporation or precipitation occur in winter. Runoff from winter snowfall is concentrated for the brief spring snowmelt, breakup, and flooding. Melting snow can also contribute to runoff for substantial parts of the summer. For example, it takes about two months for snowmelt to make its way through the Mackenzie River system to the Beaufort Sea.

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.

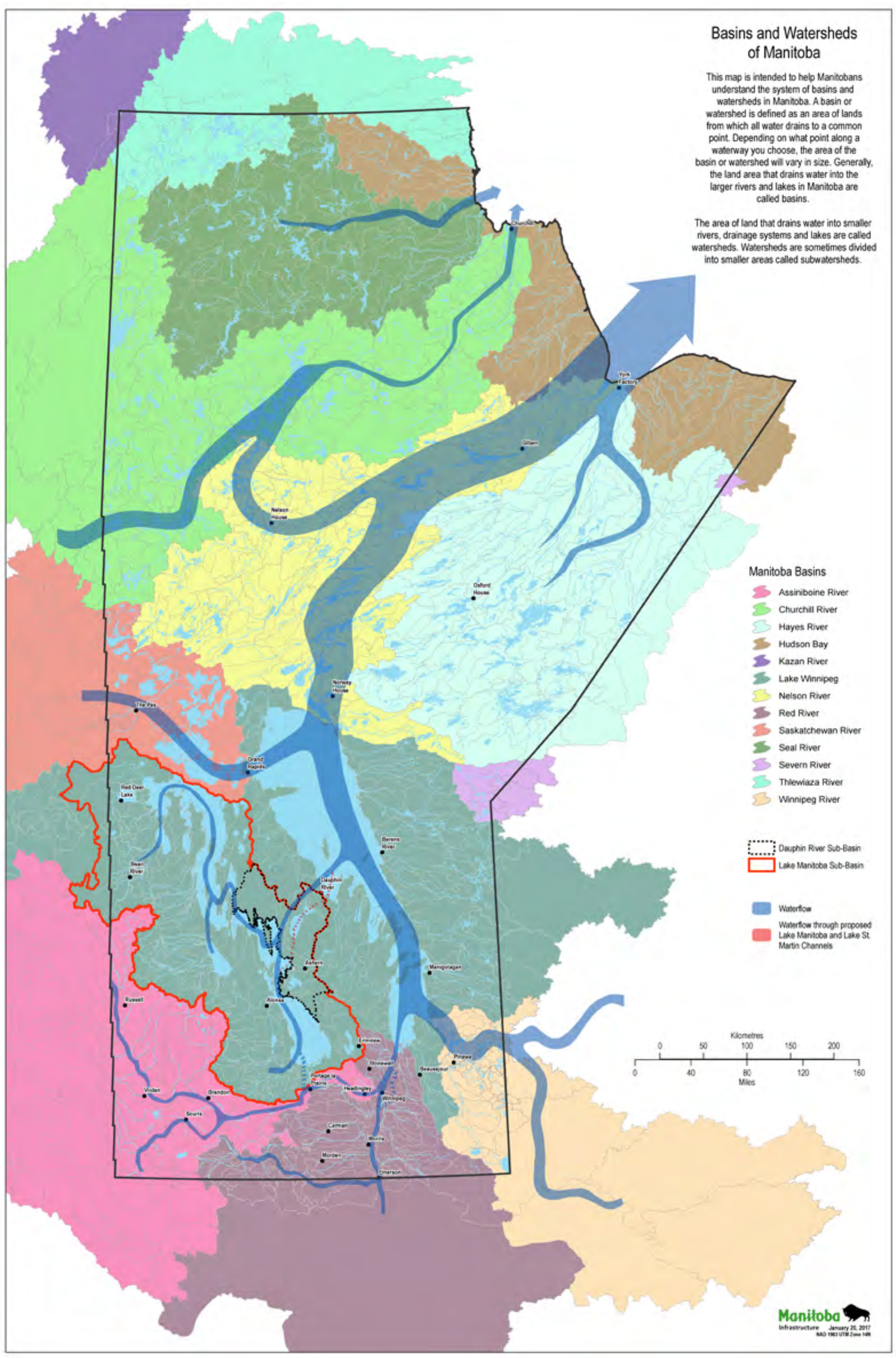
You can look at the watersheds on a landscape at many scales, from locally to continentally. The watershed of a tiny stream will be much smaller than that of a river; the river's watershed is made up of all the watersheds of its tributaries (streams that feed the river) combined. Canada has five continental 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

© Government of Manitoba

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.

MEASURING STREAM FLOW

Information about **water levels** and **discharge** (rate of flow) is essential for wise management of water resources. For example, flow information can be used to

- allocate water among various users (government, industry, individuals, etc.)
- design and construct stream-related structures, such as bridges, canals, culverts, roadways, water supplies, and irrigation facilities
- minimize the impacts of extreme flows (e.g., flood protection and irrigation)
- plan and conduct environmental programs and assessments related to water quality and habitat for aquatic organisms

Environment Canada's Water Survey of Canada, along with many contributing agencies, measures the rate of flow in streams at more than 2600 locations in Canada.

Water level is tracked using both manual measurements (gauge boards), and instruments that continuously measure and record water level. Measurement of discharge requires numerous measurements to be made, including channel depth, width, and flow velocity to calculate the discharge for a given water level. Measurements can be made from a structure across the river (e.g., bridge), by wading into a stream, by boat, etc. In winter, the measurements are made through the ice.

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).

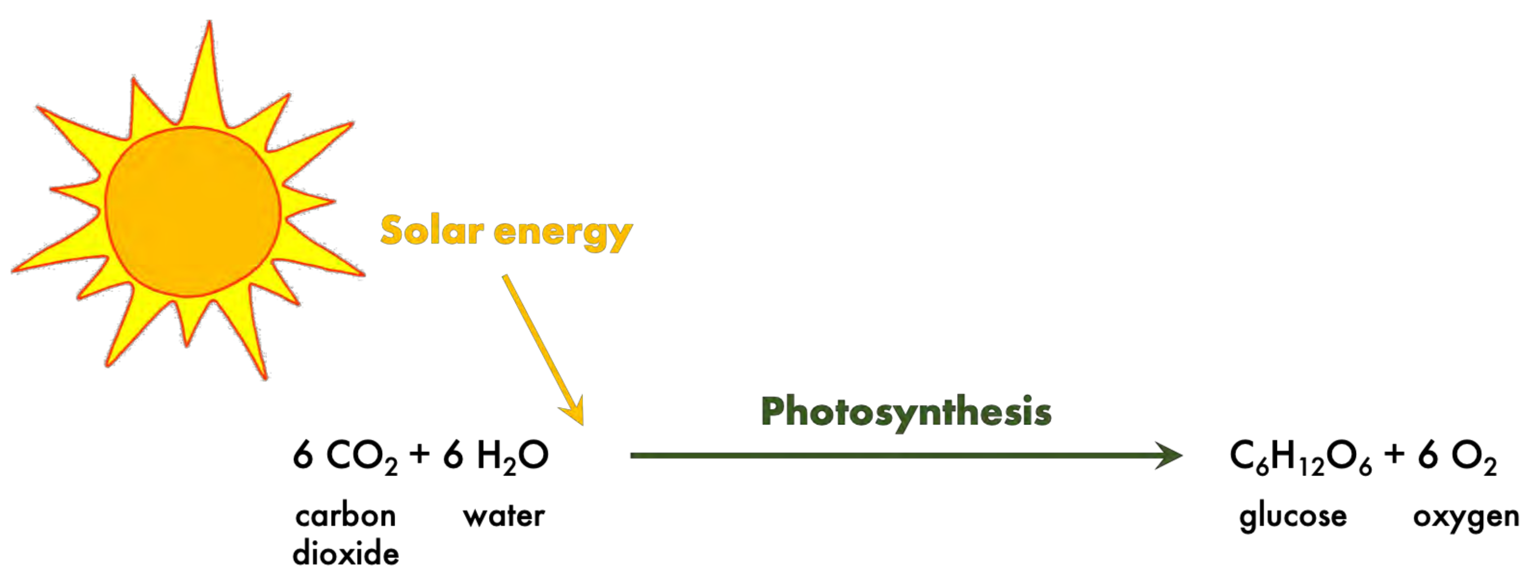
Biotic (living) characteristics of habitats also impact the organisms found within them. Interactions between species, competition for resources (food, habitat), predation, and parasitism, all impact species abundance and diversity.

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.

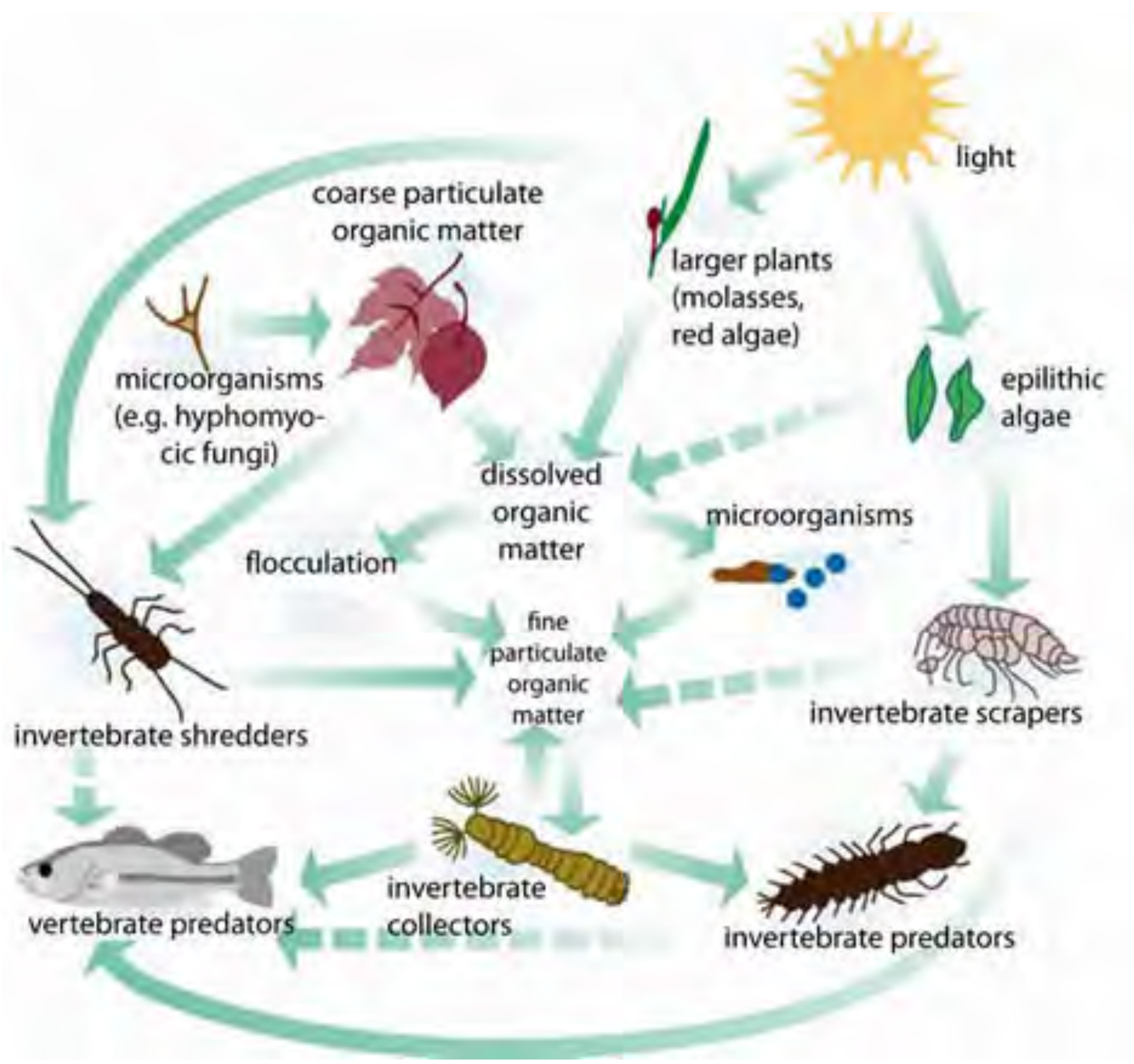


BIOLOGICAL COMMUNITIES

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

- **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
    - additional information is provided about each type of organism in the section "Food webs" below



Example of an aquatic (stream) food web
© 1998 Stream Corridor Restoration

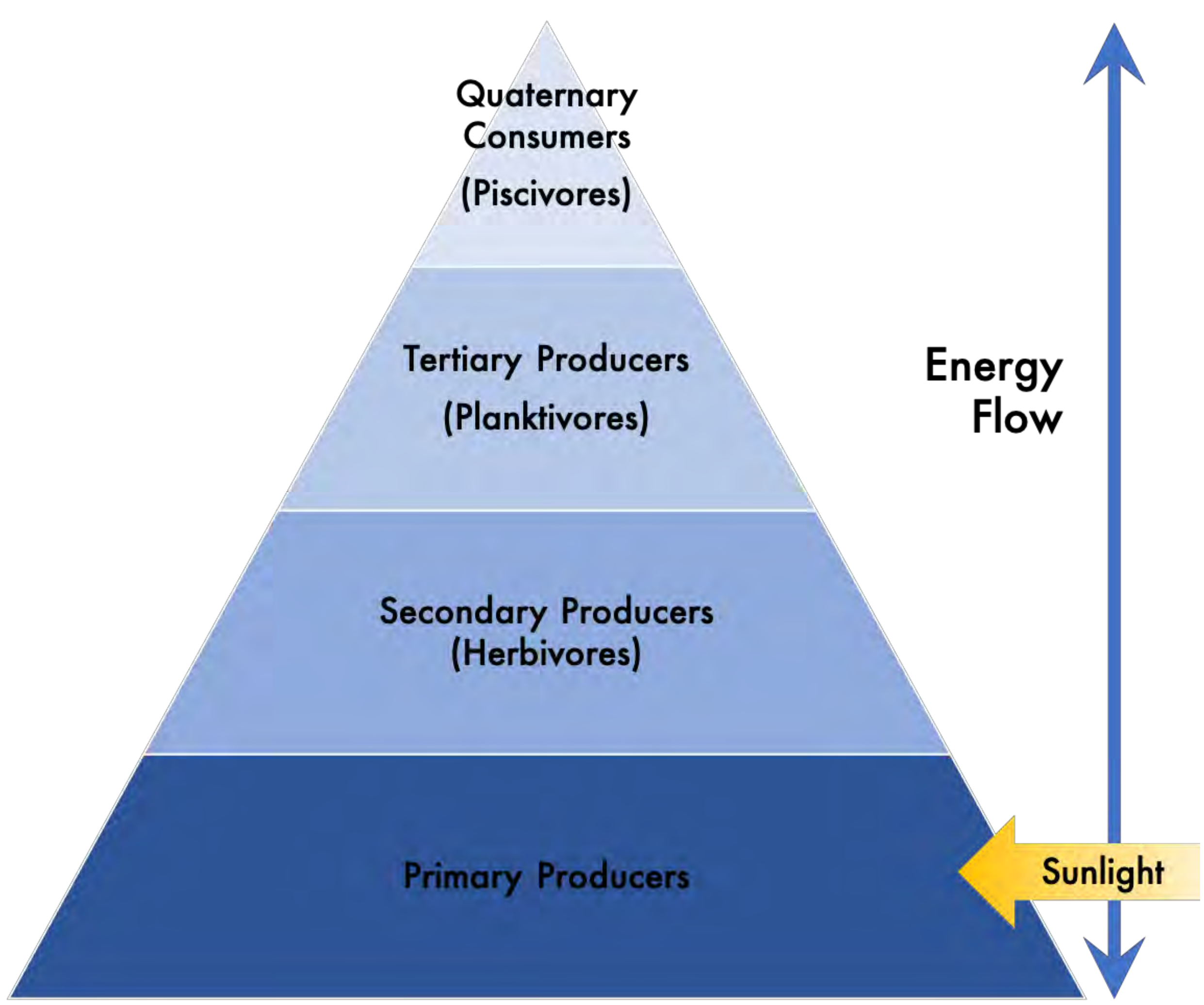
TROPHIC LEVELS

Food webs consist of several **trophic levels**, with each level indicating the position of the organism in the food web and the flow of energy to and from that organism. There may be several trophic levels within a system, including primary producers, primary consumers, secondary consumers, and beyond.

- **Primary producers** form the "base" of the food web, and are the most abundant food source and **biomass** (total weight) available. Without the conversion, through photosynthesis, of inorganic nutrients and minerals to organic matter there would be no new biomass produced within the ecosystem to support other life forms. The greater the primary production within an ecosystem, the more living biomass that can be supported within the food web.

- **Primary consumers**, who consume primary producers, are the next level "up" the food web, and the second most abundant group of organisms in terms of biomass.

- **Secondary, tertiary and quaternary (etc.) consumers** represent the smallest groups of organisms. The amount of energy/biomass present in each trophic level is reduced with every additional level (see below).



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.

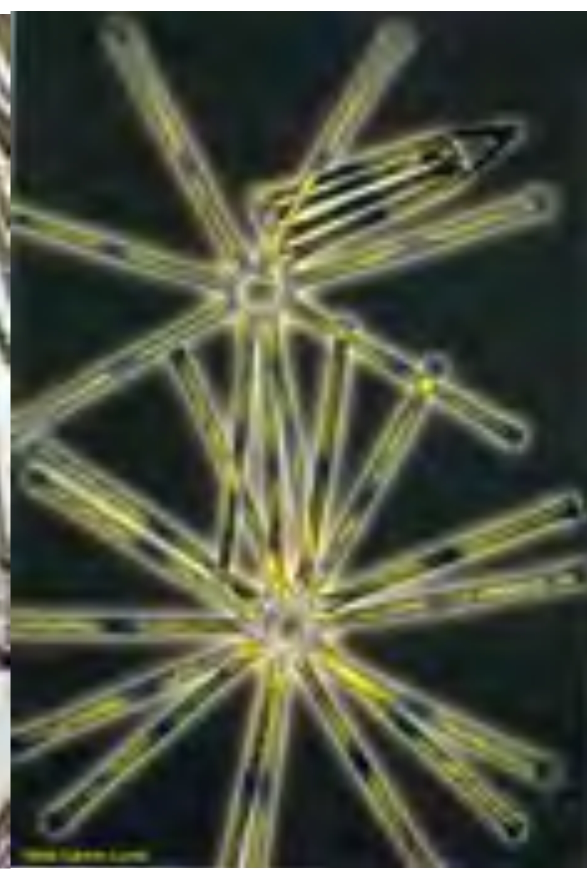
- Most algae are unable to survive in **anoxic** (no oxygen) conditions, meaning that plants and algae are not typically found in deep water where oxygen is low and the light can't reach.
- Carbon dioxide is almost always available as it has a variety of sources: diffusion from the atmosphere, weathering 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**).

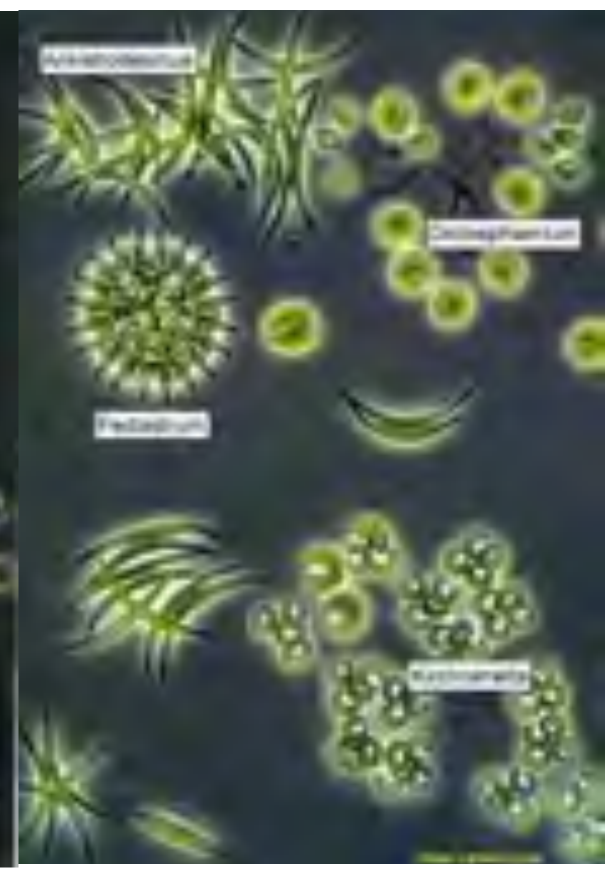
Algae are exceptionally diverse. Each algal group consists of hundreds of species, and hundreds of different species may occur in a lake. Each group and species are adapted to certain conditions of nutrient availability, water temperature, solar energy, and other environmental factors. Thus, some species will commonly occur in certain types of waterbodies, or at certain times of year, or under certain special conditions. If conditions are ideal for a species, it will be present in high numbers and other algal species in the lake will be less abundant. If conditions change significantly, other species better adapted to the new conditions may outcompete the original species and begin to dominate the phytoplankton community.

Among the major freshwater algal groups are chlorophytes (green algae), diatoms, euglenophytes, dinoflagellates, and chrysophytes. “Blue-green algae” or cyanophytes (more properly called **cyanobacteria**) are grouped with the other algae but are not closely related. Several types of algae are shown below.

A mixture of filamentous cyano- bacterial colonies and dinoflagellates



Diatom colonies



A mixture of chlorophyte species

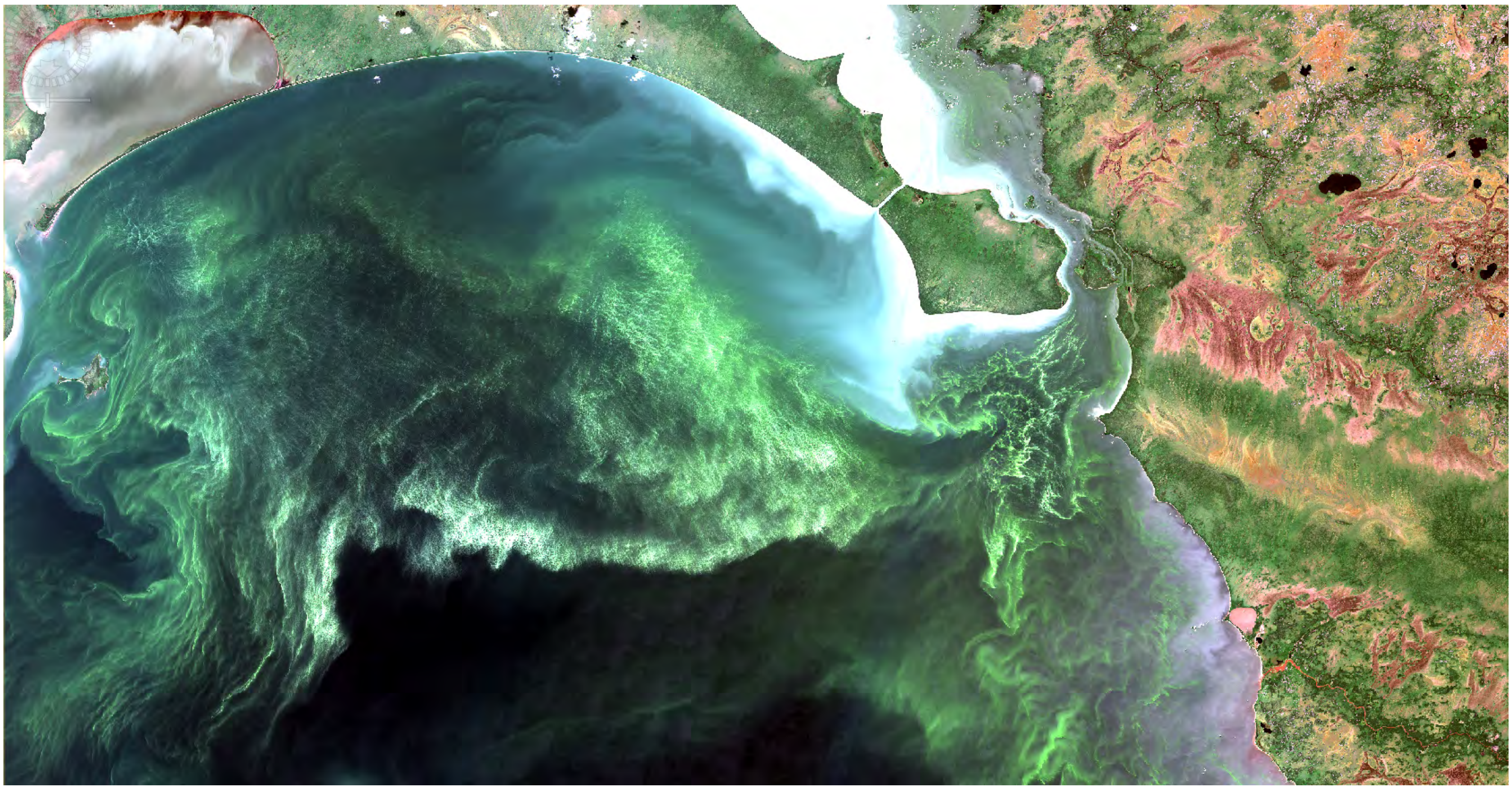
Chrysophytes

Cyanophytes

Chrysophytes, such as *Dinobryon* sp., are typically found in boreal shield lakes where nutrient concentrations are low. With limited availability of key nutrients such as phosphorus, these species will dominate, but the overall biomass of the community will be low. On the other hand, cyanophytes such as *Anabaena* sp. are generally adapted to warm, nutrient-rich water, such as is found in many prairie lakes. If phosphorus is abundant, these algae will grow and multiply at a rapid pace and quickly dominate the phytoplankton community.

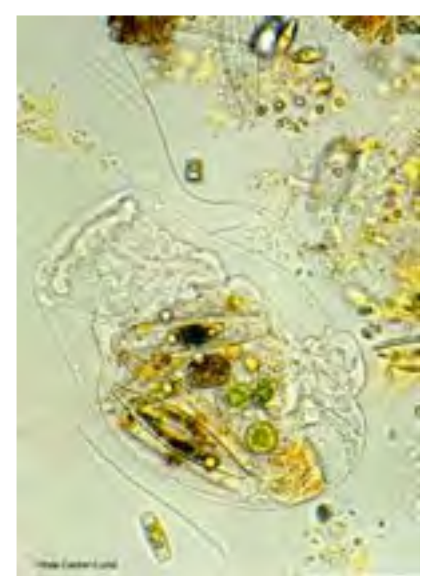
Algal blooms

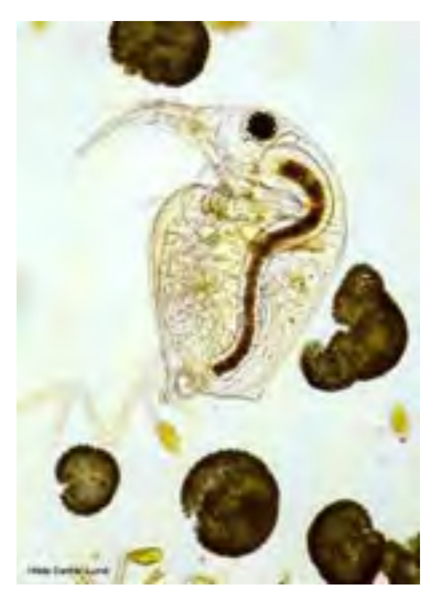
Some cyanobacteria species can form chains of specialized cells which allow them to grow rapidly. Gas vacuoles keep the chain floating at the surface where sunlight is strongest, and heterocysts allow the algae to take in nitrogen (an essential nutrient) from the atmosphere. The result is the formation of massive surface "blooms" that can block sunlight from reaching other species deeper in the water. When the cells forming the bloom die off, they leave large quantities of decomposing biomass in the water. Bacteria carrying out this decomposition may remove much of the dissolved oxygen from the water, sometimes killing fish and other organisms that require oxygen. Some cyanobacteria species also produce toxins such as microcystin, a hepatoxin (liver toxin), that can be fatal to animals if ingested.



Algal bloom on the north basin of Lake Winnipeg during the summer of 2017

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

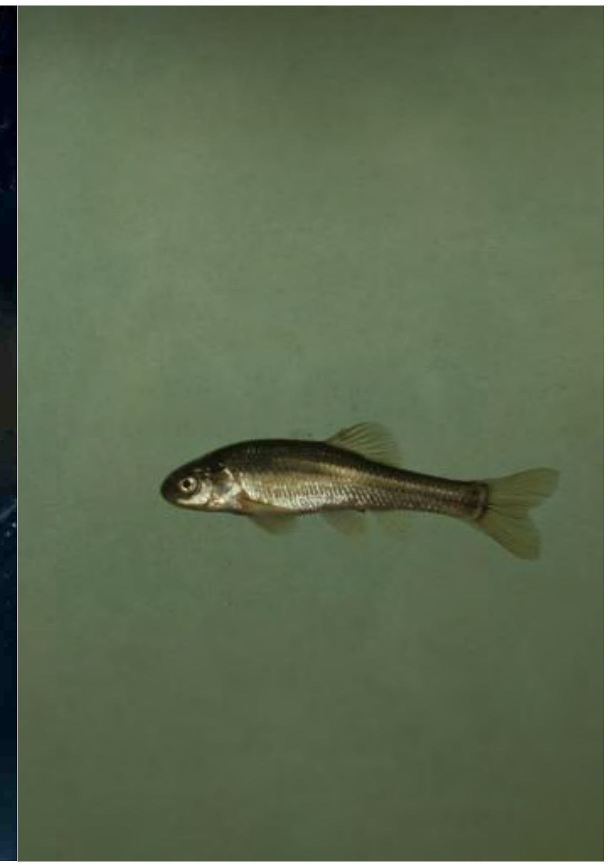
Many primary consumers are **invertebrates** such as zooplankton, insect larvae, and molluscs. **Small fish**, including minnows and the young of larger species, also feed directly on algae and plants. Not all algae are equally edible; some algal species have spines and other structures that make their 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.

Glassworm (*Chaoborus* sp.)

Mysis sp.



Fathead Minnow

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) 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.

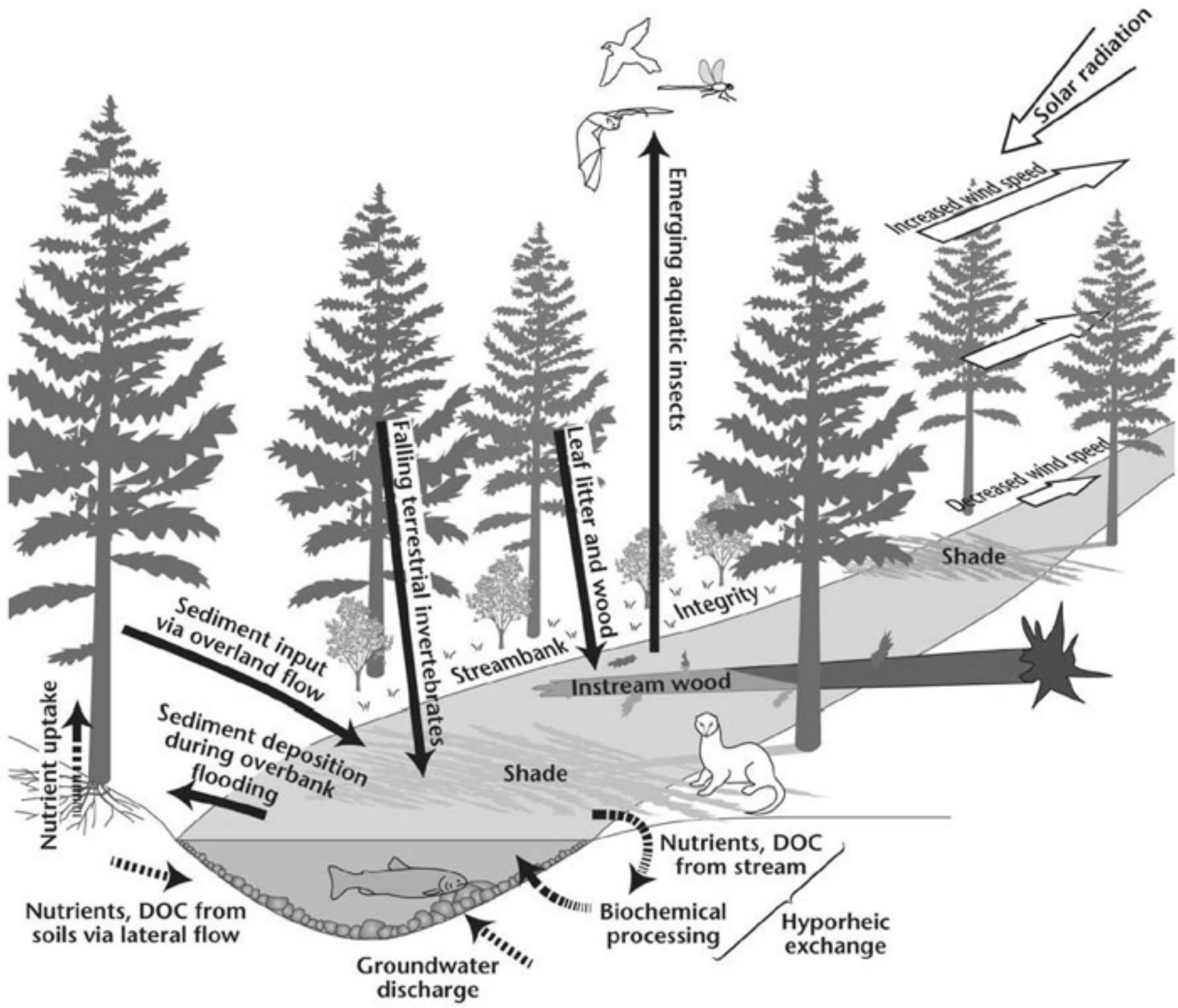
Rivers are closely tied with the atmosphere. Gases from the air, like oxygen, carbon dioxide, and nitrogen dissolve into the water. The colder the water is, or the more it churns as it flows downhill, the more gases there will be in it.

STREAM LIFE

Every stream also carries organisms and the habitats in which they live. Bacteria, fungi, plants, invertebrates, fishes, mammals, birds and many other life-forms live in and use streams. Diversity is key to the survival of a stream's life-forms. **Genetic diversity** must be present within each species. **Species** and **biological diversity** must be present as well. None of these types of diversity can be created or fostered by humans. They are the products of millions of years of evolution by trial-and-error. Once they are lost, they cannot be re-fashioned by scientists. **Habitat diversity** is also essential. Each stream contains many different habitats and microhabitats. A single species may require several different habitats to carry out its life functions, and each habitat is inhabited by its own species that cannot live elsewhere. **Keystone species** are those species whose functions are so intertwined with the lives of other animals in a system that their disappearance will cause the system to become imbalanced or even collapse. The beaver is a perfect example of a keystone species. It dams rivers, creating ponds and wetlands that support an entire system of stream organisms. When beavers are removed from a stream, many of those stream organisms are displaced or die.

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. Riparian zones are discussed in more detail later in this document.



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.

HUMAN IMPACTS ON STREAMS

Dams and water storage

People dam rivers in order to store water countless uses, including generation of electricity, to control flooding, agricultural practices, and household and recreational uses. Damming rivers changes their ecology forever. Each stream has its own biological community, all members interacting with each other in a complex fashion, all depending on each other for their survival. Dams change these communities by changing flows, temperatures, and water clarity. Many fish species migrate up rivers in order to reproduce; if they can't get all the way up a river, or if their offspring can't get all the way back down, reproduction fails. Soon, there are fewer and fewer of them, and ultimately, they will disappear forever. Many dams have fish ladders, but even with these in place dams can be very physically damaging to fish.

Channelizing streams

When a stream is prone to flooding, or to meandering out of control and across property lines or roads, it may be **channelized**. Sections of stream are cut off so it can be transformed into a tidy, straight line of water. The stream's banks may be lined with concrete or riprap (large boulders). Channelization ultimately “kills” the stream through destruction of stream and riparian habitat. A channelized stream becomes poor in nutrients and habitat. Without periodic flooding, its riparian zone is starved of water and nutrients. Stream inhabitants depend on the riparian zone for food, shade, and debris. Channelization creates artificial river banks without variation, while stream inhabitants depend on natural variations such as backwaters, riffles, and large woody debris for cover, protection, and food.

Ironically, the more you try to channelize a river, the more out of control it becomes. Erosion, a minor irritant before, threatens property, buildings, and roads. Flooding becomes more catastrophic when streams are channelized. Water gathers energy as it flows downhill. When a stream meanders, it creates banks. The water then pushes against the banks, and swirls in eddies. In both cases, the energy of the flowing water is decreased. When a stream is channelized, however, there is nothing to prevent it from gathering more and more destructive energy as it flows downhill. Secondly, a healthy **floodplain** acts as a sponge, soaking up floodwaters, while channelized rivers simply forward the extra water downstream until it overwhelms dams, dikes, or walls. Finally, when streams are channelized, people are encouraged to live on floodplains, risking lives and property in the event of a catastrophic flood. The inevitable response to catastrophic flooding is, unfortunately, to increase channelization, which leads to even more catastrophic flooding (another positive feedback loop).

Development

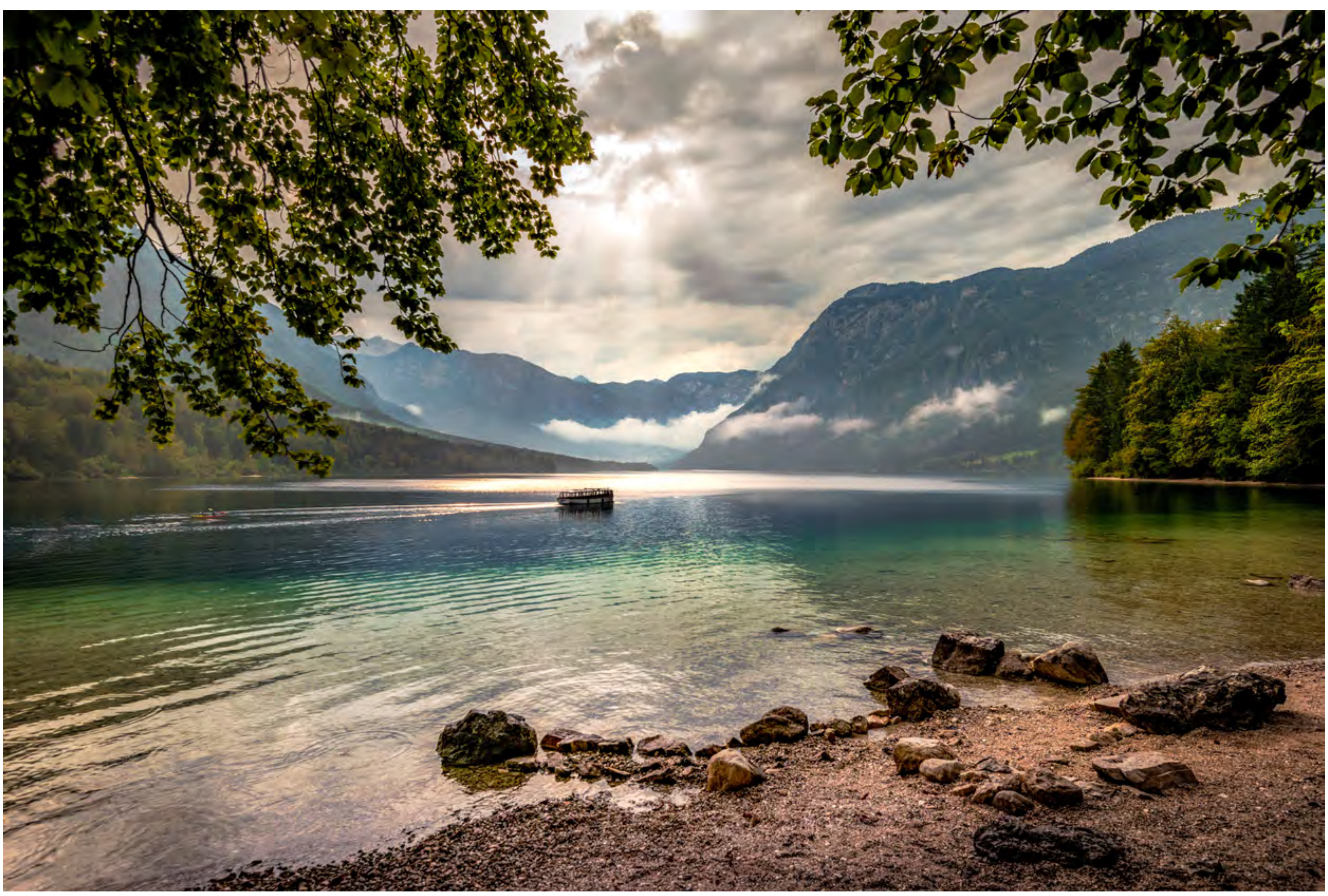
We also change our streams by changing the land around them. If we pave land or remove vegetation from it, rainwater runs directly off of it instead of soaking into the earth. This **urban runoff** carries pollutants like car oil and pesticides instead of nutrients. When we change the vegetation around a stream, we change its chemistry. For instance, a developer may cut down all the trees around a stream in order to place a big neighbourhood of houses next to it. This has many effects, among them that no more leaves will fall into the stream, taking out the very base of the stream's food web. Tree branches will no longer shade the stream and it will become too warm for the fish that belong there and choked with algae. In addition, without overhanging branches, bugs will no longer fall from them to feed fish. The trees themselves were critical to that stream because they were providing nutrients to it, as well as shade for the growth of other important stream side vegetation. And finally, without the roots of vegetation to anchor stream side soil, the soil will become eroded away by the stream--forcing homeowners to channelize the stream.

Mobilization of sediment

Many human activities increase the sediment load of streams, including logging (especially the creation of logging roads), farming, and other types of development. Streams that run through clay-rich soils are particularly susceptible to increased sediment loads. When silt is dislodged from the land and washes into streams, it makes the water cloudy. **Turbidity** is a measure of the amount of particulates present in the water column; a stream with lots of sediment will have high turbidity. High turbidity blocks light from entering the water, reducing the ability of plants and algae to photosynthesize and altering the base of the food web.

Sediment that falls to the bottom of the stream fills in the spaces between the gravel and cobbles of the stream bed, thus eliminating the habitat of many aquatic insects. It also hinders the maturation of fish eggs. Salmonid (salmon and trout family) eggs spend their early lives buried in stream bed cobbles, sheltered from the river's current and hidden from predators. They live off their yolk sacs until they are large enough to fend for themselves, and then emerge into the water column to feed. While they are still in the gravel, water must flow rapidly over them to bring them fresh, dissolved oxygen and to carry their wastes away. When silt from development fills in the spaces between the rocks, the fish can no longer grow there.

LAKE ECOLOGY



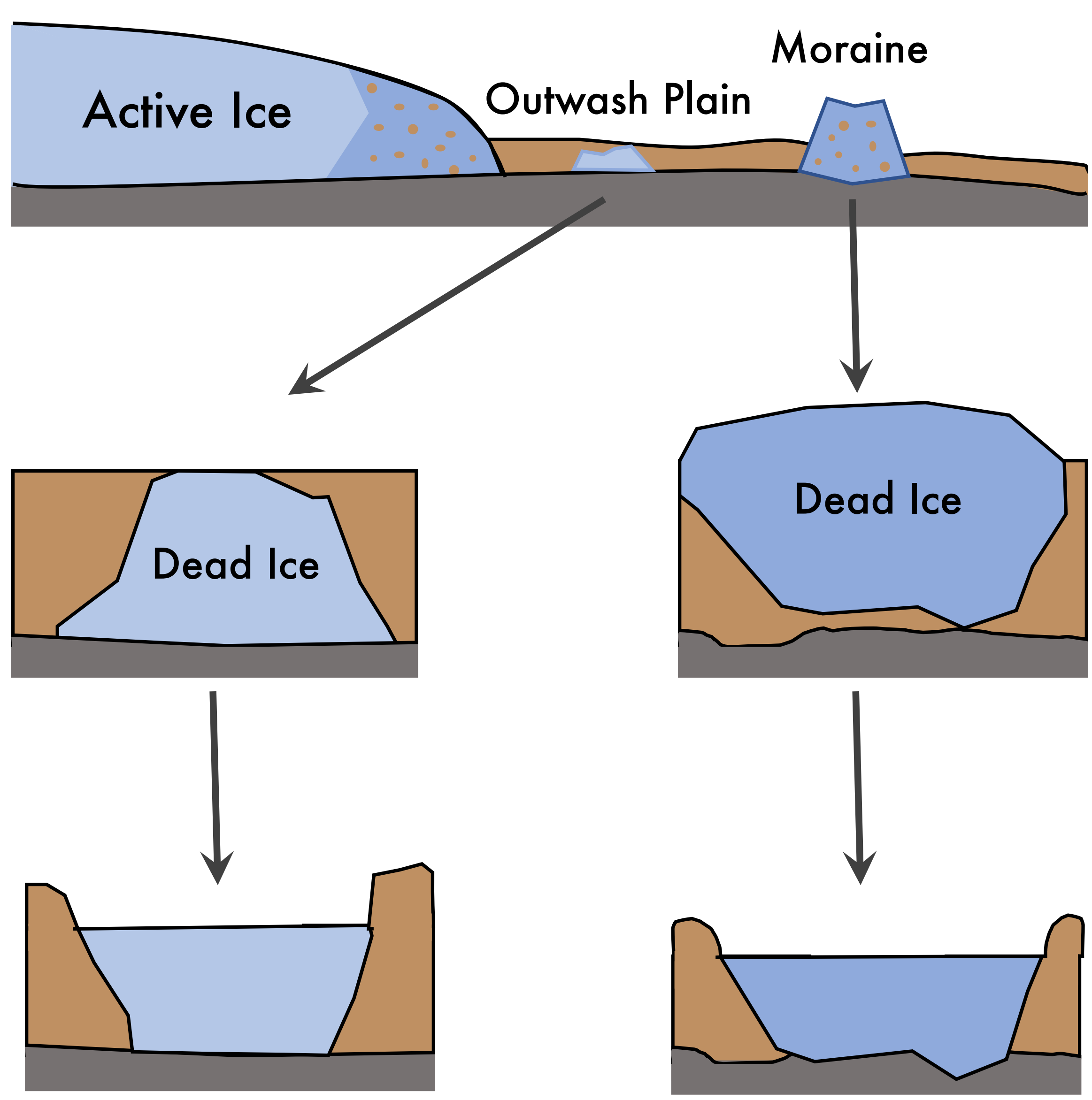
A lake is a sizeable water body surrounded by land and fed by streams and local runoff. Lakes provide us with a wide range of benefits. Much of our domestic, agricultural and industrial water requirements come from surface water and much of this surface water is contained in lakes. Lakes also provide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

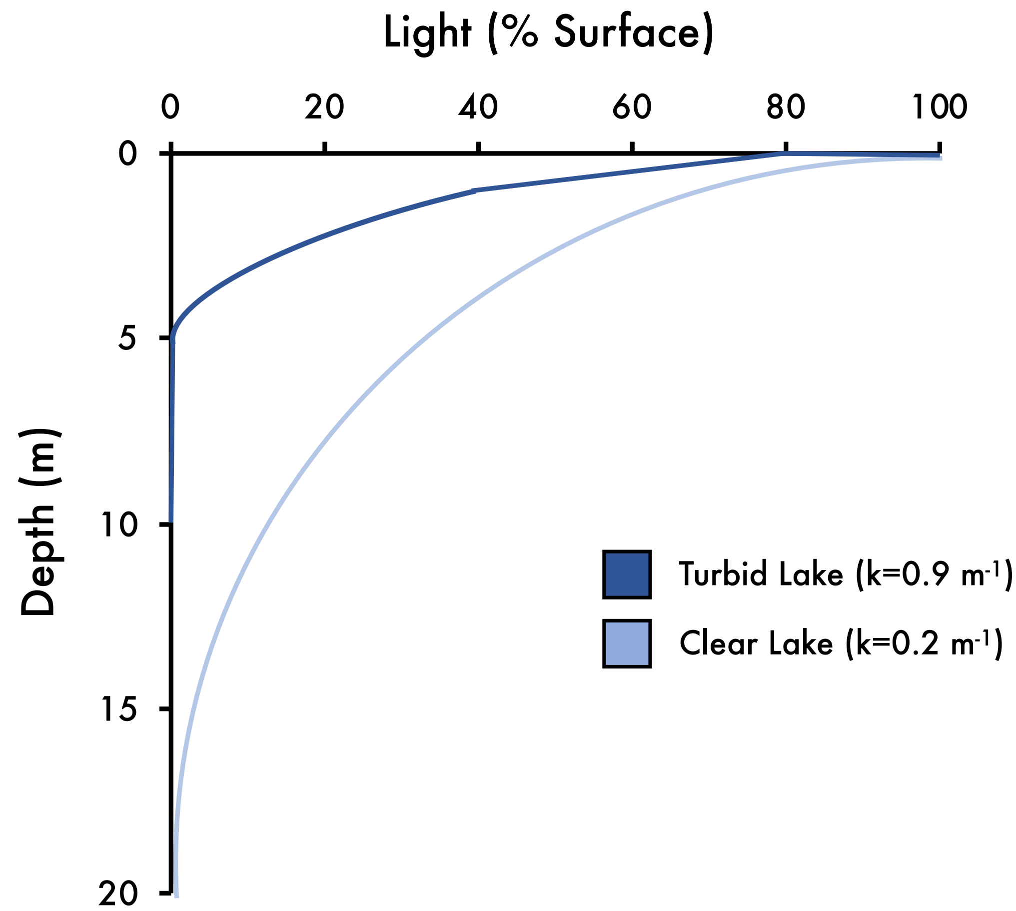
Lakes are often visualized uniform masses of water like a full bathtub that is evenly mixed. In fact, lakes are extremely **heterogeneous**. Lakes vary **physically** in terms of light levels, temperature, and water currents. They vary **chemically** in terms of nutrients, major ions, and contaminants. 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 more light attenuation, whereas lakes with lots of particulates in them (high turbidity) or with a dark colour (high dissolved organic carbon) will have lower 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.

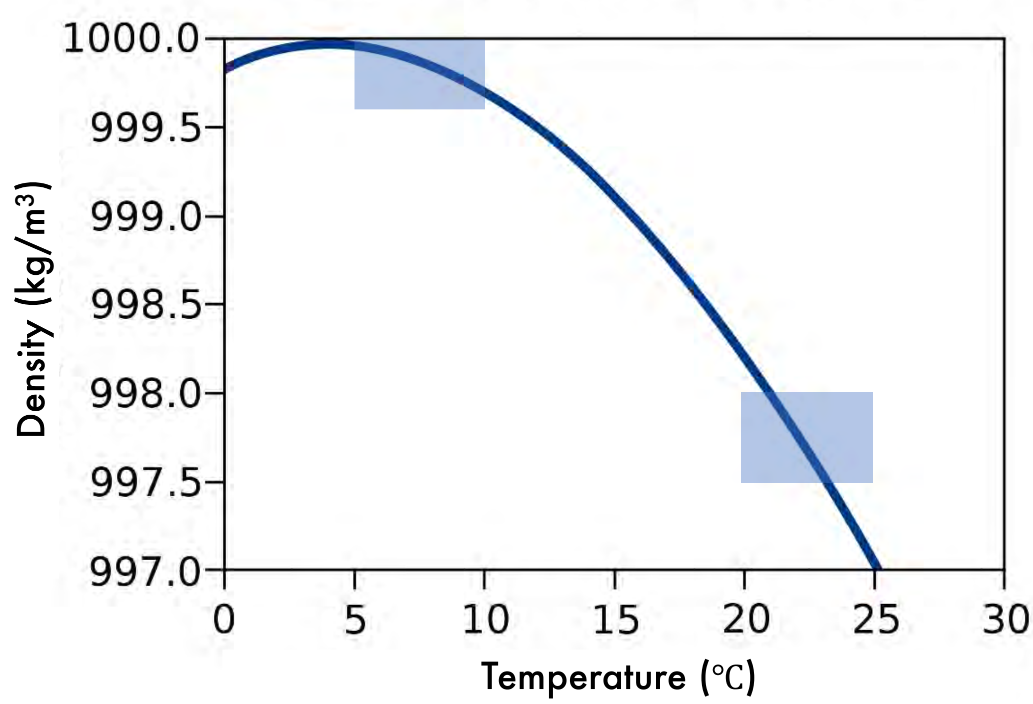


Light versus depth profiles for both a clear lake and turbid lake

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/Temperature relationship for distilled water

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 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.

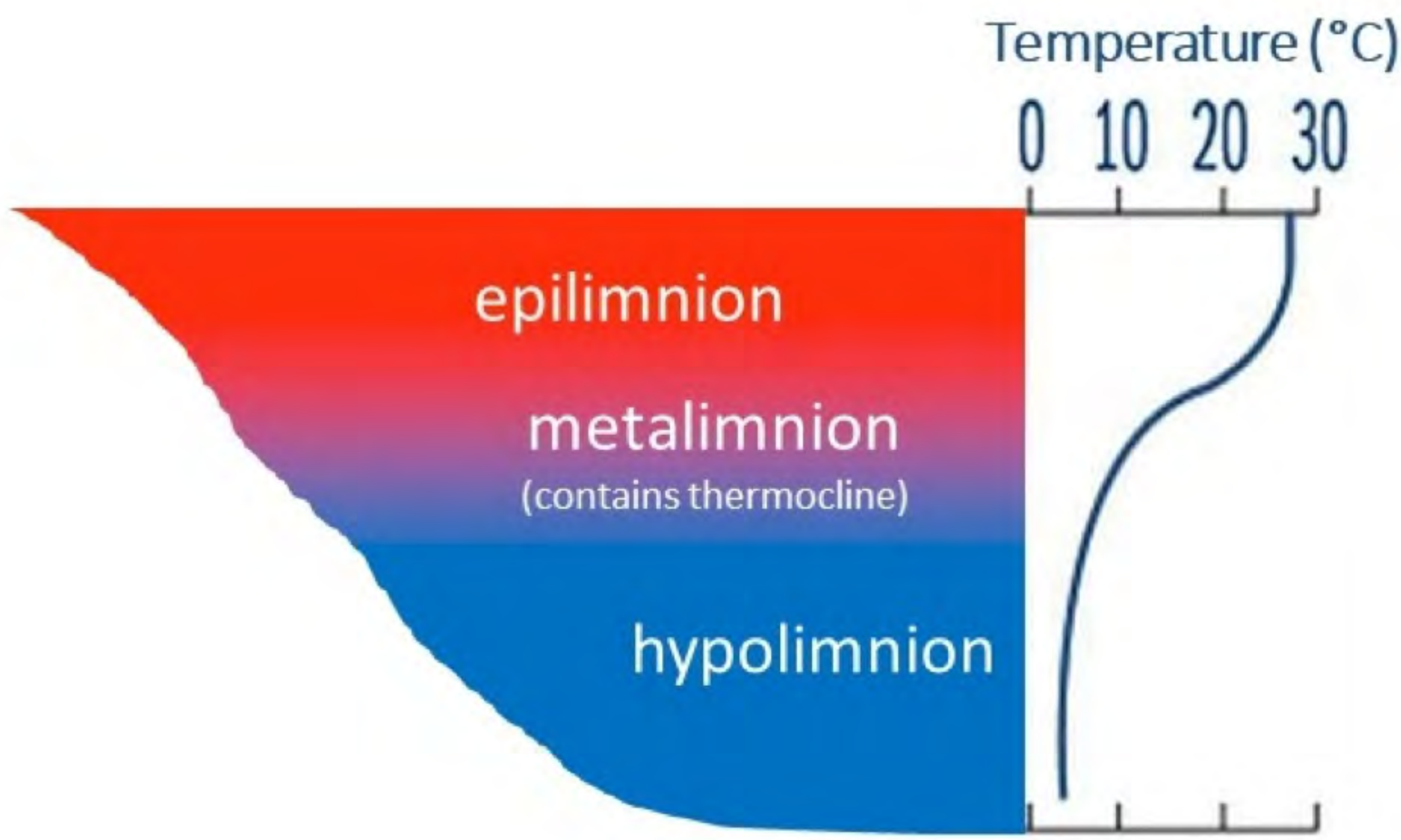
It is useful to visualize a more extreme example of density stratification. Imagine a bottle of salad dressing containing vegetable oil and vinegar. The oil is lighter (more buoyant) than the vinegar. When you shake it up you are supplying the energy to overcome the buoyant force, so the two fluids can 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** (see below).

- **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

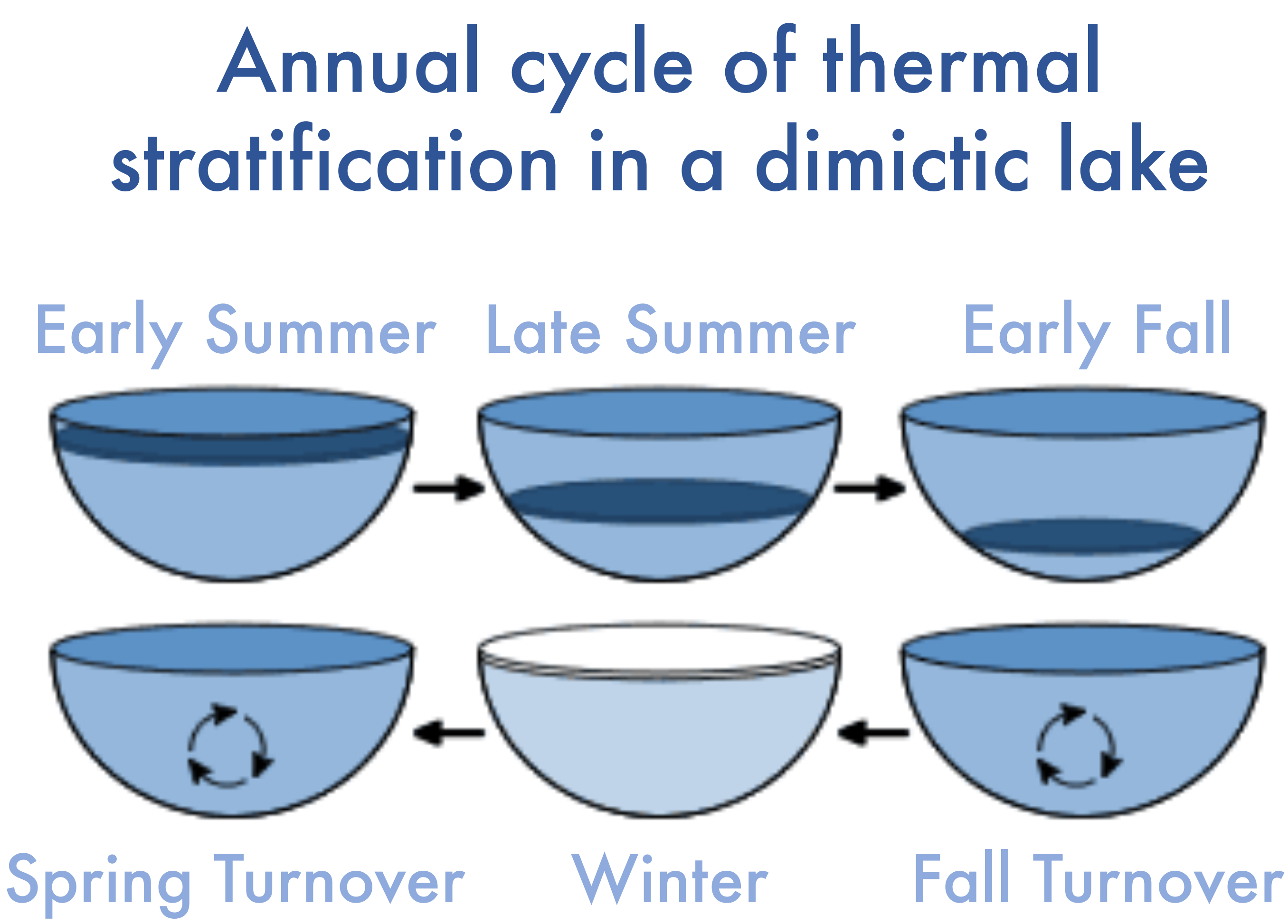
Autumn (mixed)

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 WATERSHEDS

A lake reflects its watershed. More specifically, a lake reflects the watershed's size, topography, geology, land use, soil fertility and erodibility, and vegetation. Comparing the surface area of the lake to the surface area of the watershed (**watershed:lake ratio**) can be a useful tool for understanding the condition of the lake. Typically, water quality decreases with an increasing ratio of watershed area to lake area. This is obvious when one considers that as the watershed to lake area increases there are additional sources of runoff to the lake. In larger watersheds, there is also a greater opportunity for water from precipitation to contact the soil and pick up minerals and other contaminants before reaching the lake. Conversely, a large lake with a small watershed will receive relatively less input from its watershed, meaning that its water quality is likely to be better.

Lakes with small watersheds that are maintained primarily by groundwater flow are known as **seepage lakes**, while lakes fed primarily by inflowing streams and local runoff are known as **drainage lakes**. In keeping with the watershed:lake area relationship, seepage lakes tend to have good water quality compared to drainage lakes.

Land use in a watershed has an important impact on the quality and quantity of water entering a lake. The amount of water a lake receives after a storm differs greatly among land uses. For example, the high proportion of impervious surfaces in urban areas prevents absorption of rainwater by the soil and increases the rate of surface water flow to the lake. The high flushing rates from urban areas increase erosion of stream banks and provide sufficient force to carry large particles to the lake. Thus, water quantity affects water quality. Additionally, as water flows over roads, parking lots and rooftops, it accumulates nutrients and contaminants in both dissolved and particulate form.

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.

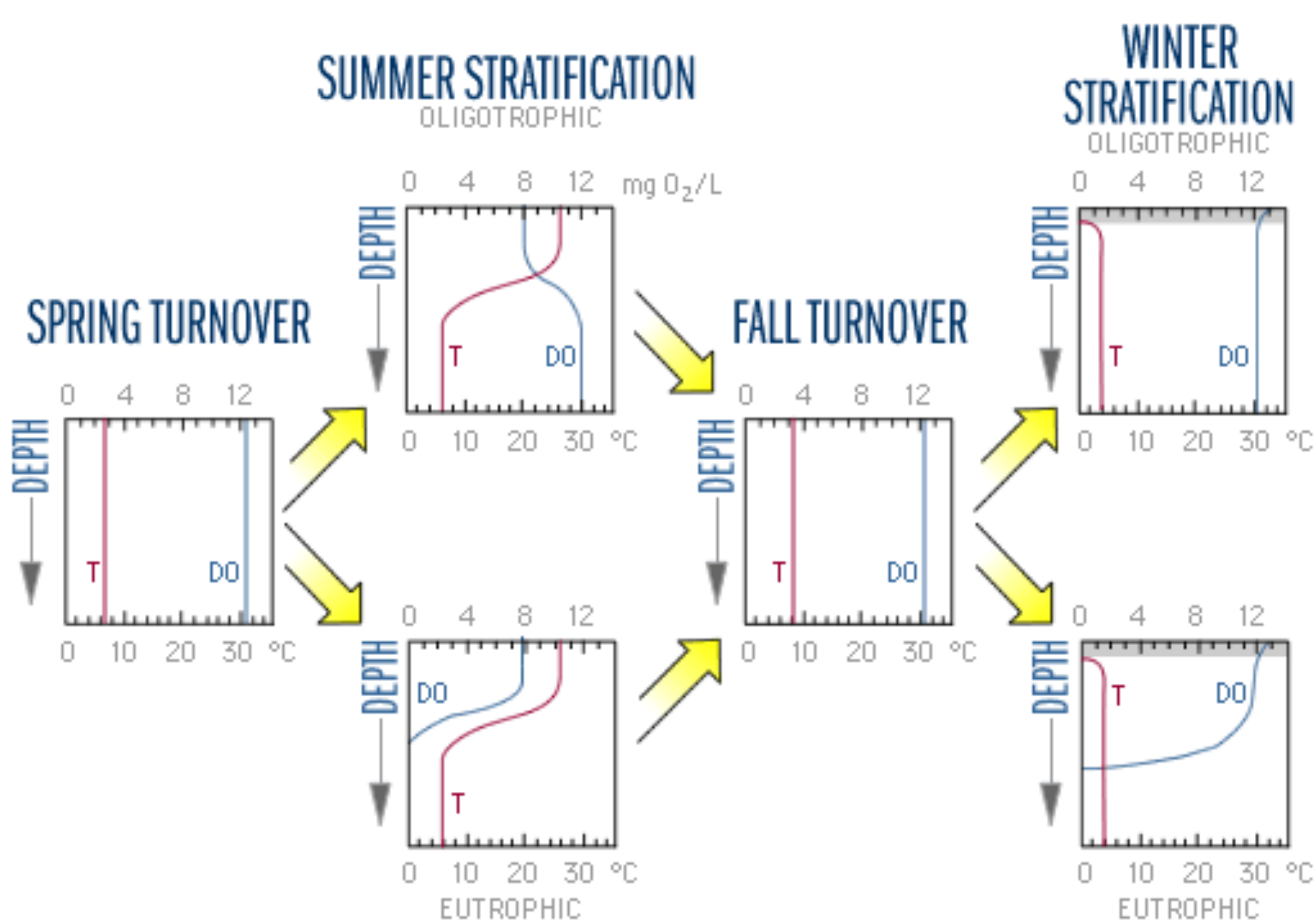
Dissolved Oxygen (DO)

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).

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.

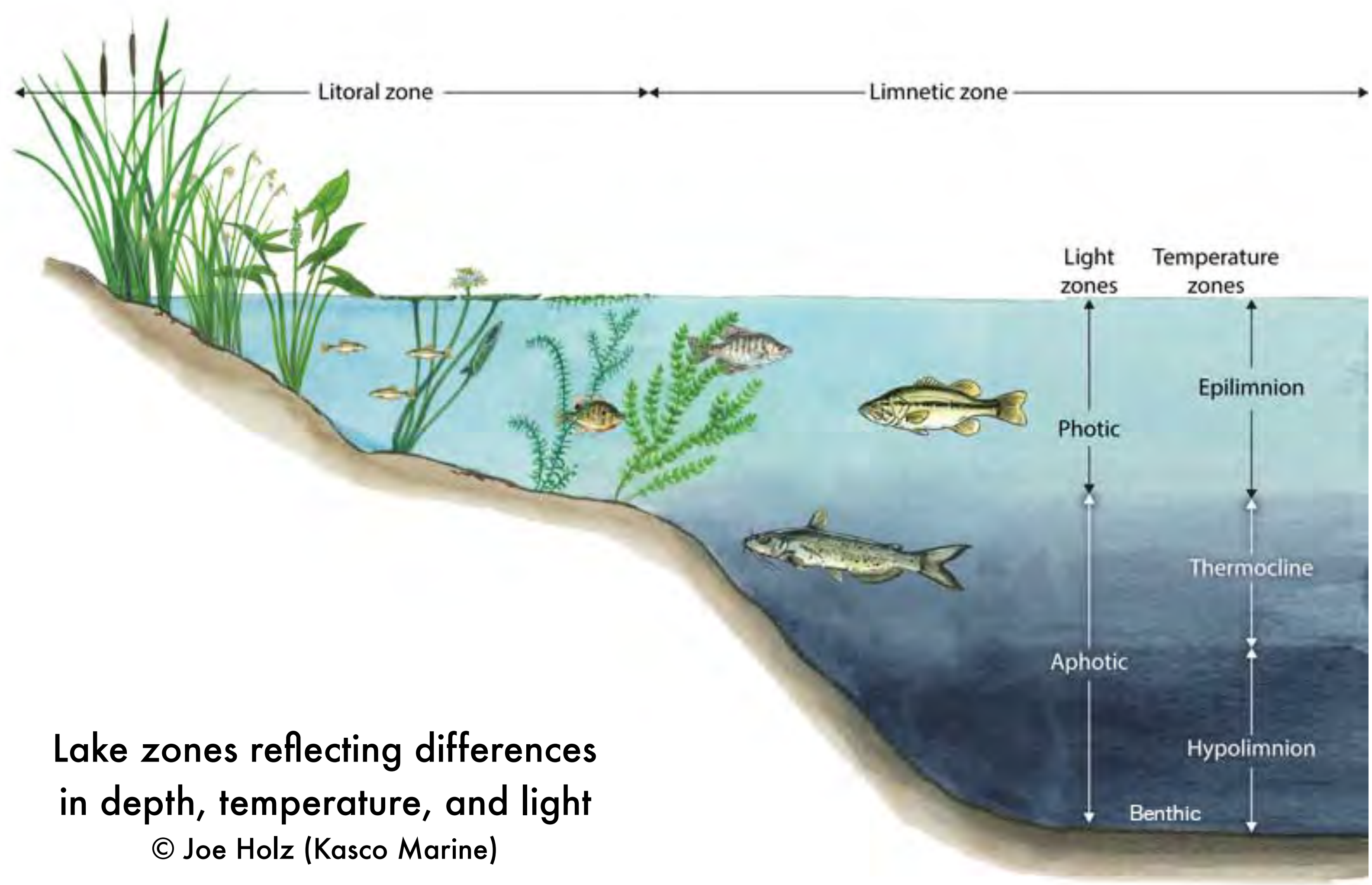
- In eutrophic (more productive) lakes, hypolimnetic DO declines during the summer because it is cut-off from all sources of oxygen, while organisms continue to respire and consume oxygen. The bottom layer of the lake and even the entire hypolimnion may eventually become **anoxic**.
- In oligotrophic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



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

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.

PHYSICAL STRUCTURE OF LAKES



Lake zones reflecting differences in depth, temperature, and light
© Joe Holz (Kasco Marine)

Spatial zones

The **littoral zone** is the near-shore area where sunlight penetrates all the way to the sediment and allows aquatic plants (macrophytes) to grow. The littoral zone is typically highly productive and home to a wide variety of organisms, including plants, invertebrates, and fishes. The higher plants in the littoral zone, in addition to being a food source and a substrate for algae and invertebrates, provide a habitat for fish and other organisms that is very different from the open water environment. The **limnetic** or **pelagic zone** (either name is appropriate) is the off-shore (open water) area in which light does not generally penetrate all the way to the bottom. This zone is subject to turbulent winds and will be home to floating organisms such as phytoplankton and zooplankton. The bottom sediment, known as the **benthic zone**, has a surface layer abundant with organisms. This upper layer of sediments may be mixed by the activity of the benthic organisms that live there, often to a depth of 2-5 cm in rich organic sediments. Most of the organisms in the benthic zone are invertebrates, such as dipteran insect larvae (midges, mosquitoes, black flies, etc.) or small crustaceans.

The **productivity** of sediments in the littoral and benthic zones depends upon the organic content of the sediment, the amount of physical structure, and the amount of light received (littoral sediments only). Sandy sediments contain relatively little organic matter (food) for organisms and poor protection from predatory fish. Higher plant growth is typically sparse in sandy sediment, because the sand is unstable and nutrient deficient. A rocky bottom has a high diversity of potential habitats offering protection (refuge) from predators, substrate for attached algae (periphyton), and pockets of organic matter (food). A flat mucky bottom offers abundant food for organisms but is less protected and may have a lower diversity of structural habitats unless it is colonized by higher plants.

Light zones

The **euphotic zone** (also called the photic zone) exists between the surface of the water down to the depth at which light levels are 1% of surface values, below which light is too low for photosynthesis to occurs. The 1% light boundary generally also defines the maximum depth of the littoral zone. Parts of the lake below the 1% light boundary are in the **aphotic** (no light) zone.

In most lakes, the sunlit euphotic zone occurs within the epilimnion. In unusually transparent lakes, however, photosynthesis may occur well below the thermocline into the perennially cold hypolimnion. For example, in western Lake Superior summer algal photosynthesis and growth can persist to depths of at least 25 meters, while the mixed layer, or epilimnion, only extends down to about 10 meters.

TROPHIC STATUS OF LAKES

Lakes are often classified according to their **trophic state**, which are based on lake fertility (nutrient levels). While lakes may be categorized into a few trophic classes, each lake has a unique constellation of attributes that contribute to its trophic status.

Several factors regulate the trophic state of a lake:

- **Rate of nutrient supply** from watershed, which is dependent on watershed geology, vegetation, and human land use/management.
- **Climate** (sunlight, temperature, precipitation, etc.)
- **Hydrology** (movement of water across landscape).
- **Residence time of water** in lake (how long it takes for all water in the lake to be replaced)
- **Lake morphometry** (shape of lake basin)
  - Depth (maximum and mean)
  - Volume
  - Surface area
  - Watershed to lake surface area ratio

Lakes can be classified into three basic trophic states: **oligotrophic, mesotrophic,** and **eutrophic**, based on their nutrient levels.

Oligotrophic lakes

Oligotrophic lakes have few nutrients ('oligo' means 'very little'), and can be characterized by deep, clear (good light penetration) water, rocky and sandy bottoms, and little algae. Oxygen is found at high levels throughout the water column because cold water can hold more dissolved oxygen than warm water (the deep region of oligotrophic lakes stays cold).

Populations of algae and the animals that feed on them are less dense in oligotrophic lakes because of low nutrient concentrations, thus, the water remains clear. Decay of the relatively small amount of organic matter in oligotrophic lakes does not completely deplete the hypolimnetic supply of dissolved oxygen. Therefore, lack of oxygen does not restrict animals from living in the hypolimnion of oligotrophic lakes. Lake trout, for example, require cold, well-oxygenated water and primarily live in the hypolimnion of oligotrophic lakes.

Extremely deep oligotrophic lakes have hypolimnia that remain completely saturated with oxygen the entire year. Moderately deep lakes may develop anoxia in the lower hypolimnion during late summer, but may still be classified as oligotrophic because of their very low nutrient concentrations, low algal abundance, and relatively high transparency/clarity. These lakes may have a two-story fish community, with warm and cool water fish in the epi- and metalimnion and cold-water fish in the cold, oxygen rich portion of the hypolimnion. The cold-water fish community is very sensitive to increased inputs of organic matter and nutrients and the resulting increase in algal and macrophyte production because these factors will accelerate the rate and extent of hypolimnetic oxygen depletion in the summer.

Eutrophic lakes

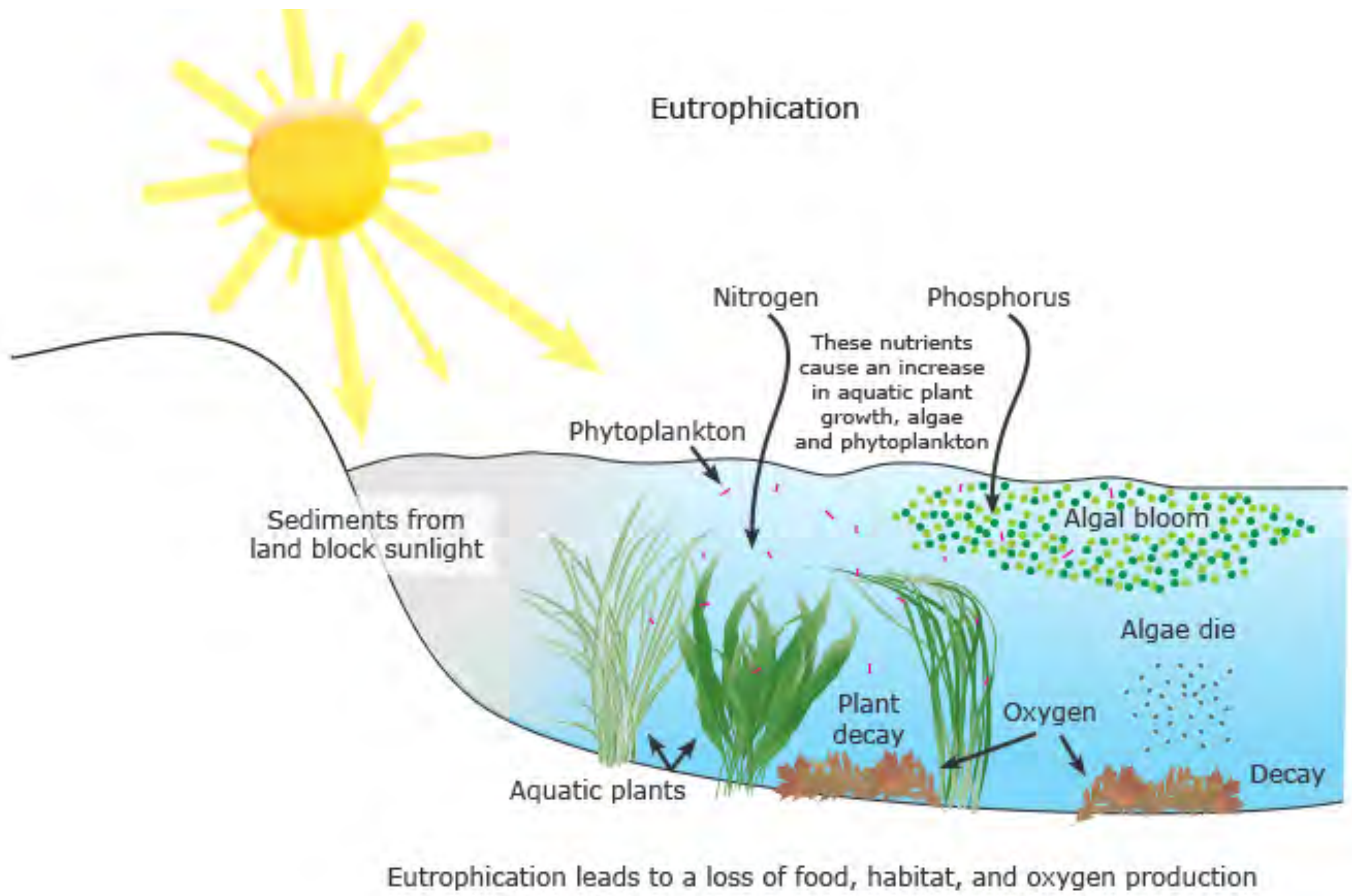
Eutrophic have high levels of nutrients ('eu' means 'true'). Do not confuse "**eutrophic**" with "**euphotic**". Eutrophic lakes are often shallow and have murky water and mucky, soft bottoms. They also have a lot of plants and algae. Eutrophic lakes tend to be situated in landscapes that can provide them with lots of nutrients, which are carried into the lake in runoff. Eutrophic lakes can support high densities of algae, fish, and other aquatic organisms. The high amount of **biomass** (total matter in all organisms), means lots of decomposition occurs at the bottom of this type of lake (organisms are continually dying and dropping to the bottom of the lake). The process of decomposition uses up oxygen and can lead to the bottom of the lake becoming **anoxic**. Occasionally the entire lake may become anoxic leading to large die offs of fish and other species (typically only happens in shallow lakes).

Mesotrophic lakes

Mesotrophic lakes fall somewhere in between eutrophic and oligotrophic lakes ('meso' means 'middle'). These lakes are typically characterized by clear water with lots of submerged macrophytes and moderate levels of nutrients.

Eutrophication

Eutrophication is the alteration of the production (trophic status) of a lake from oligotrophic or mesotrophic to eutrophic. This state is characterized by excessive plant and algal growth due to increased availability of one or more of the factors needed for photosynthesis, such as nutrients that are typically **limiting** (e.g., phosphorus), sunlight, and carbon dioxide. An increase in phosphorus inputs is the most important contributor to eutrophication of lakes.

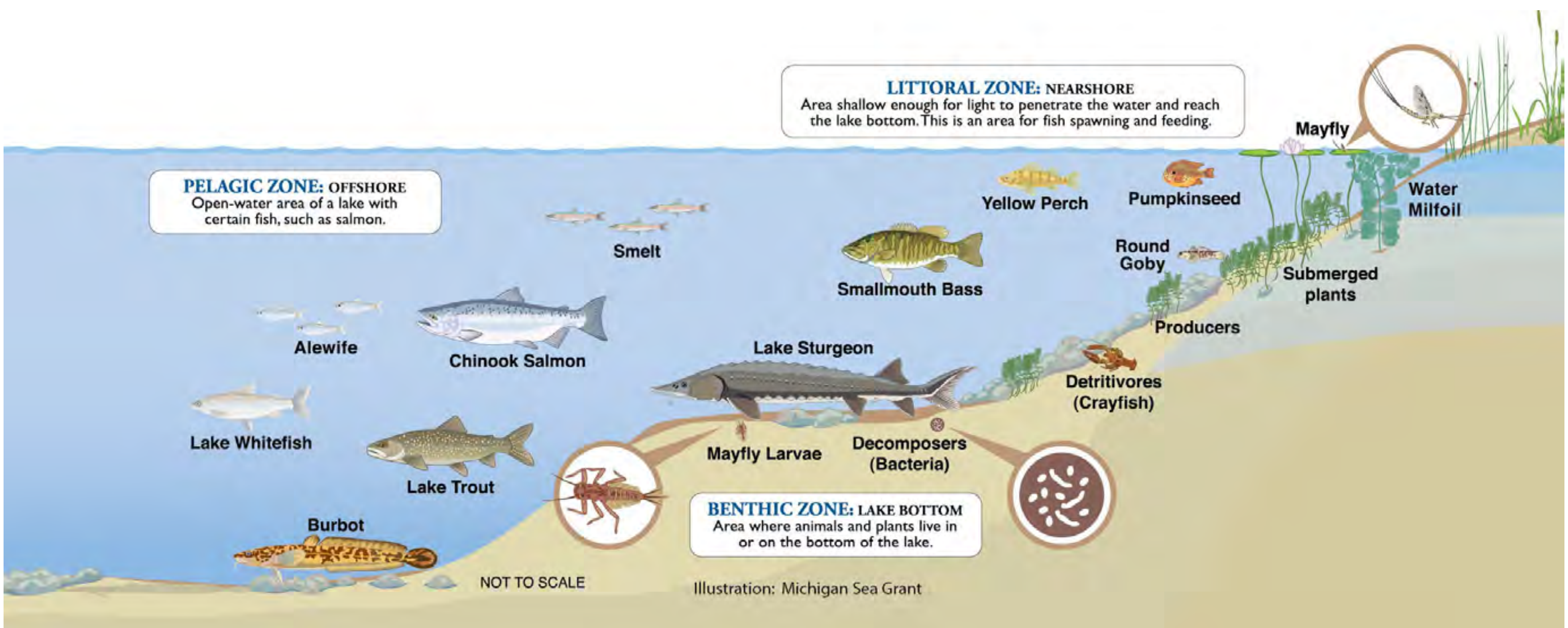


Eutrophication process in an aquatic system

Eutrophication leads to the creation of dense mats of phytoplankton (called **algal blooms**) that reduce water clarity and quality. As seen in Lake Winnipeg, eutrophication can have severe consequences for the entire aquatic community. Algal blooms decrease light penetration into the water body, reducing growth and causing die-offs of plants in littoral zones while also lowering the success of predators that need light to pursue and catch prey. The large amounts of algae eventually die and decompose, which severely depletes the oxygen in the water, which can lead to fish-kills.

Eutrophication is largely a human-caused problem and remains the single-most widespread and serious pollution problem facing lakes across the globe. Worldwide, millions of lakes have been, and continue to be, eutrophied. Human activities can hugely increase the rate and extent of this process through both **point-source** (e.g., sewage treatment plants) and **non-point source** (e.g., agricultural runoff) additions of limiting nutrients (especially phosphorus) into aquatic ecosystems. Decreasing the amount of phosphorus that enters a lake is the best way to limit the problems associated with eutrophication. For example, in the 1970s phosphate was banned as an ingredient in detergents (laundry, dish soap, personal hygiene products, etc.) to reduce eutrophication of lakes (at the time it was in response to the eutrophication of Lake Erie).

LAKE BIOLOGY



An example of a lake food web
© Michigan Sea Grant

Different organisms utilize the different regions, or **ecological niches**, within a lake. Many of the larger organisms can move about freely within, or even between, large regions of a lake (e.g., fish, amphibians, larger zooplankton), while smaller organisms tend to drift with lake currents or settle with gravity. Attached organisms, such as rooted plants and periphyton, attach to substrates where conditions are suitable for them.

Primary producers in lake ecosystems algae and macrophytes (aquatic plants). Together, they create the organic material required by other organisms for nutrients and energy. The majority of macrophytes grow in the littoral zone, while algae may be located throughout the epilimnion. The macrophyte community can include large algae, such as *Chara*, *Nitelle*, or *Cladophora*. In shallow, clear lakes, macrophytes may account for the majority of the photosynthesis. There may be few macrophytes in lakes where the bottom is too rocky/

sandy for the plants to anchor themselves, wave action too severe, water too deep, or areas in which algae and/or silt concentrations are high and block sunlight.

Macrophytes and algae are eaten by **primary consumers**, the second trophic level. This link in the food chain typically involves zooplankton, benthic invertebrates, and larval fish grazing on algae and plants. **Secondary consumers**, such as small fish and larger invertebrates, eat the primary consumers. Still larger consumers such as large fish, birds, and mammals (including people) are **tertiary consumers**. Thus, energy and nutrients originating from the photosynthetic production of biomass and energy cascade through the food web.

Decomposers are found in all lake zones and are the dominant forms in the lower hypolimnion where there is an abundance of dead organic matter. Decomposers are sinks for plant and animal wastes, but they also recycle nutrients required for photosynthesis (carbon). The amount of dead material in a lake far exceeds the living material. **Detritus** is the organic fraction of dead material, including small fragments of plants and animals and dissolved organic material. In recent years, scientists have recognized that zooplankton grazing on detritus and its associated bacterial community represent an additional important trophic pathway in lakes.

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
© Sparky Stensaas

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
© Itasca Soil and Water Conservation District

WETLANDS AND WILDLIFE

Wetlands provide food and shelter for many species of animals that either live permanently within the wetland or visit periodically. Almost every part of a wetland, from the bottom up, is important to wildlife in some way. Each species has adapted to using the wetland and its surrounding area in a specific way. Some examples include:

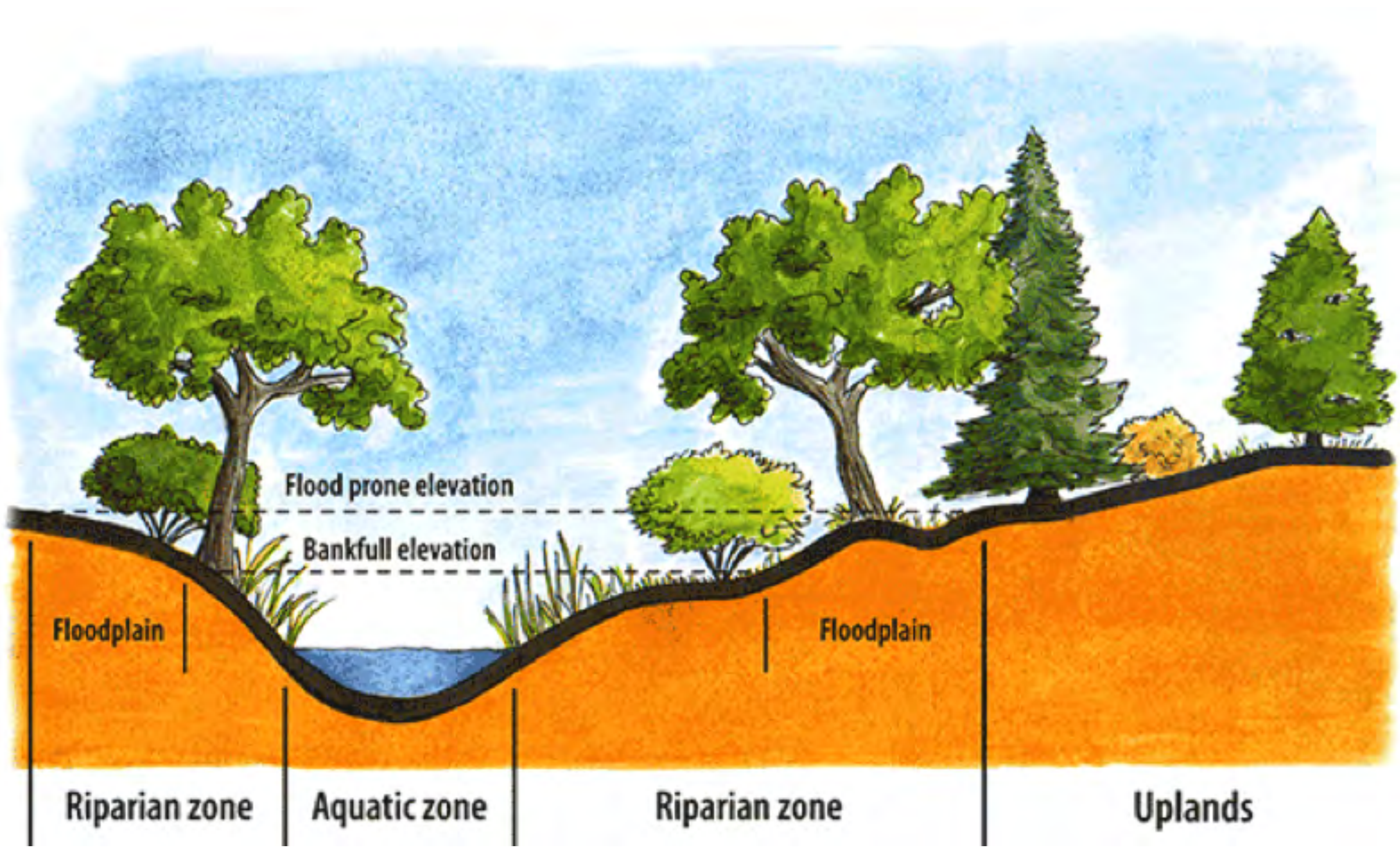
- frogs bury themselves in the muddy substrate to survive the winter
- some insects use bottom debris to form a protective covering

- fish swim and feed in wetlands, often eating the eggs of insects that have been deposited in the water
- wetland vegetation provides nesting materials and support structures to several bird species and is a major source of food to mammals, even those as large as moose
- small mammals use the lush vegetation at the edge of wetlands for cover and as a source of food, and they themselves are a food source for birds of prey

WETLANDS AND GROUNDWATER

Wetlands have very close connections with the groundwater system. Some wetlands, for example potholes in higher ground, may serve as important groundwater recharge areas. Others, especially those in low-lying areas, may be the receptors for significant amounts of groundwater discharge. If the underlying groundwater is contaminated, detrimental consequences will be felt by the wildlife and all other resources dependent on that wetland.

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

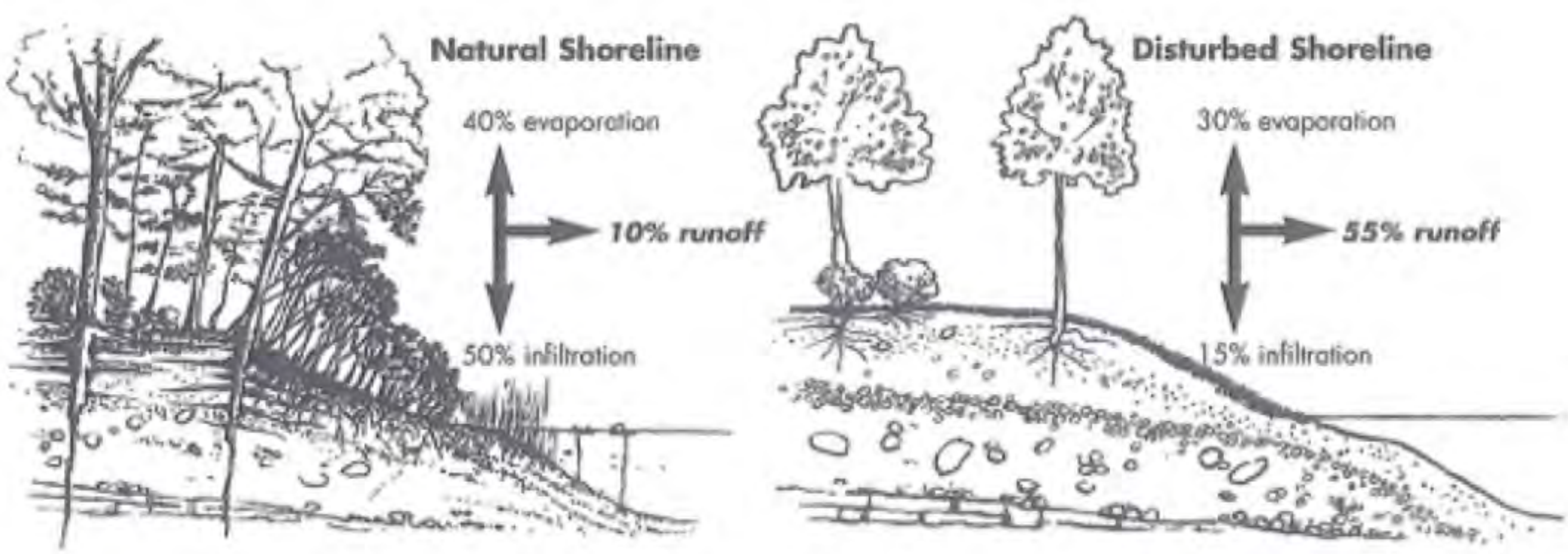
Protection of water supply

- 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



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

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 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

ESTUARY ECOLOGY

An estuary is a partially enclosed, costal water body where the fresh water streams mixes with salt water from the ocean. Estuaries are influenced by tides but are protected from wind, storms, and ocean waves by land, such as islands and peninsulas. Estuaries are some of the most productive ecosystems on earth, creating more organic material annually than the same sized area of forest, grassland, or agricultural land. These sheltered water bodies support unique communities of plants and animals.

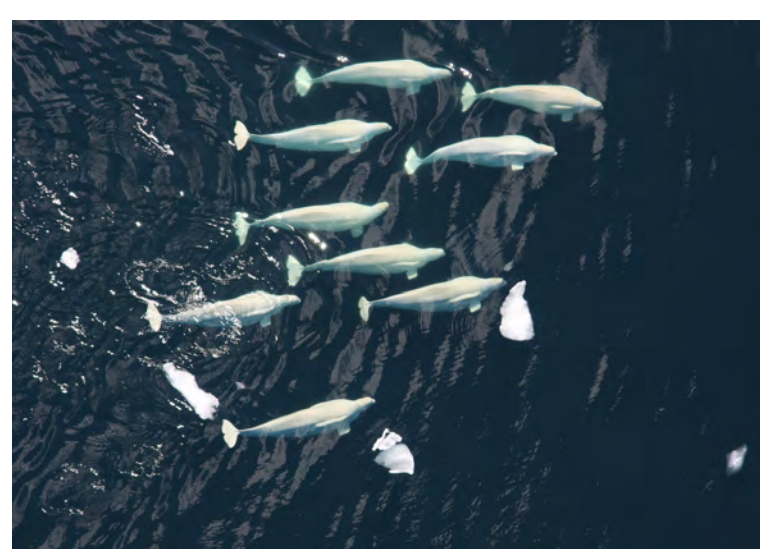
Many habitat types can be found within and around estuaries, including shallow open waters, fresh- and saltwater marshes, swamps, sandy beaches, mud and sand flats, rocky shores, oyster reefs, mangrove forests, river deltas, tidal pools, and seagrass beds.

Thousands of bird, mammal, fish, and invertebrate species depend on these fluctuating habitats. Many marine organisms depend on estuaries at some point within their development (in fact, estuaries are often called the 'nurseries of the sea'). Since estuaries are extremely biologically productive, they provide ideal areas for migratory birds to rest and eat during migration.

Estuaries perform many important biological and physical processes. Water draining from uplands carries sediments, nutrients, and other pollutants into estuaries. As the water flows through wetlands that are a part of these ecosystems, much of these sediments and pollutants are filtered out. As such, cleaner and clearer water enters the marine environment. Estuarine plants help to stabilize shorelines, prevent erosion, and protect costal habitats and communities from severe weather, such as flooding and storm surges.

MANITOBA ESTUARIES AND BELUGA WHALES

The Seal, Churchill, and Nelson River estuaries in northern Manitoba attract large aggregations of beluga whales annually (~57,000 animals total). As soon as the ice in the Nelson, Churchill and Seal estuaries breaks up (mid-June), belugas enter them by the thousands and occupy these estuaries in large numbers until the sea ice begins to form again (late-September). (Matthews *et al.* 2017). Every day, pods of belugas move in and out of the estuaries with the tide. Scientists are not sure why the belugas gather in such numbers within the estuaries, but some ideas included:



A pod of beluga whales
© NOAA/NMFS/National Marine Mammal Laboratory

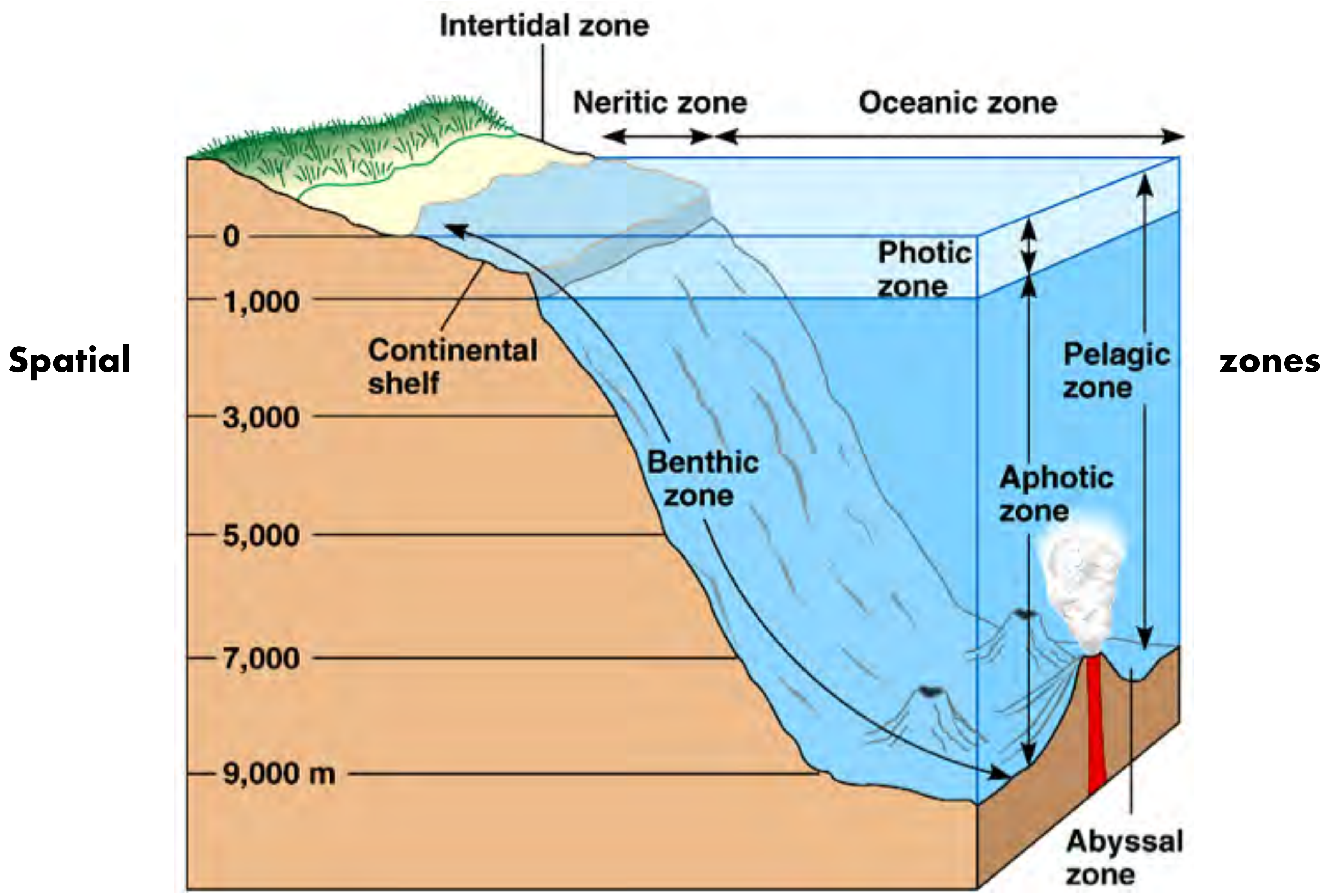
- Females give birth and care for their newborns in the estuaries
- Calves conserve energy in the relatively warm water
- Warm, low-salinity water of estuaries promotes skin molt
- Estuaries provide protection from predators
- Estuaries provide food for belugas
- Belugas are there to socialize

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.



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.

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

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.

Bay of Fundy, New Brunswick
© Jared Rover

OCEAN BIOLOGY

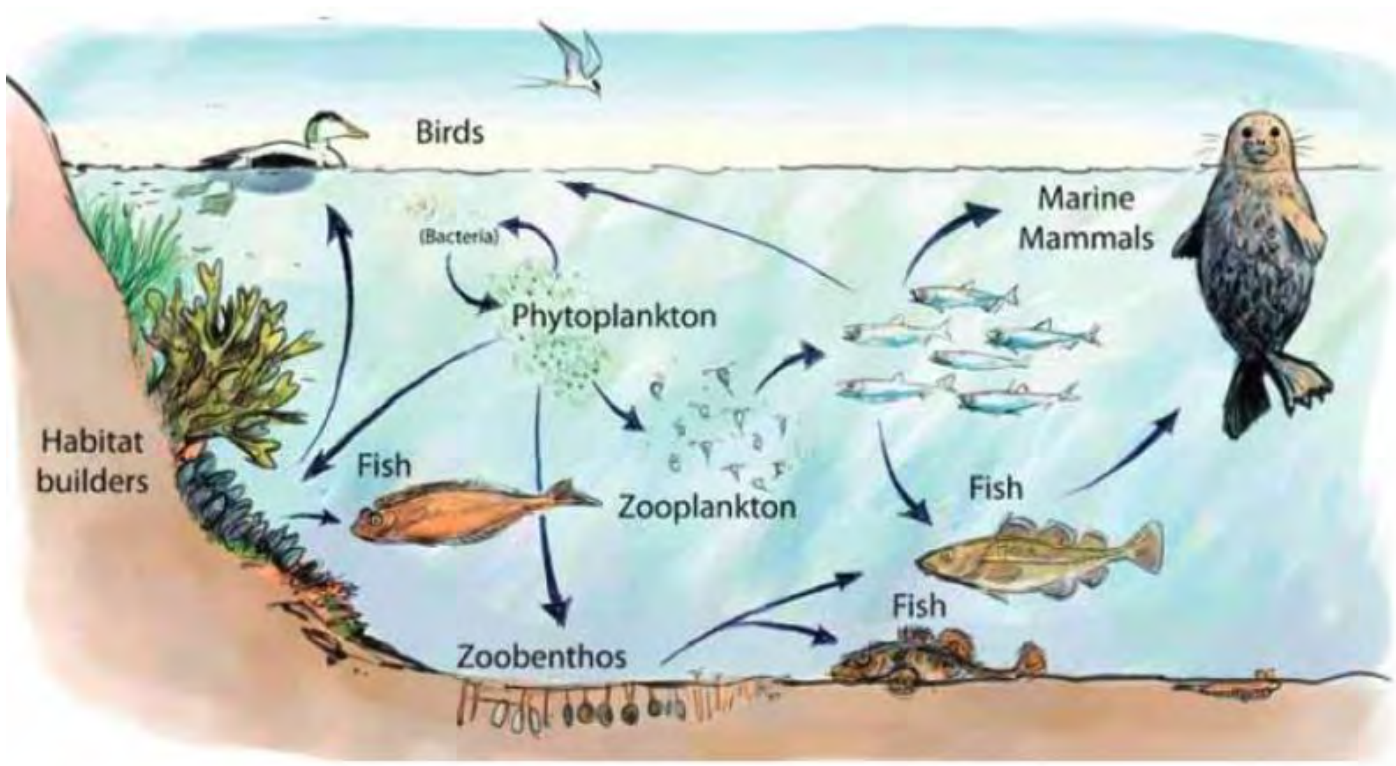
Primary Production

In most ocean ecosystems, sunlight provides the main source of energy. Photosynthesis by phytoplankton, macroalgae (sea weeds), and bacteria feeds the rest of the food web. Organisms in areas below the photic zone are dependent on food dropping from the surface zone, from **marine snow** (tiny clumps of bacteria and decomposing microalgae) to large items like dead marine mammals.

Chemosythesis is a form of energy production that is observed in some parts of the aphotic zone. Chemosynthetic bacteria produce food from CO_2 (and sometimes water) using energy from the metabolism of inorganic materials found around them rather than sunlight. Large ecosystems in the deep sea, such as **hydrothermal vent systems**, are dependent on chemosynthetic bacteria using sulfur and methane to produce food.

Heterotrophs

The ocean has a huge variety of animals, including bacteria, invertebrates (sponges, jellies, sea anemones, crustaceans, molluscs, nematodes, and flatworms), fish (including sharks), mammals (seals, dolphins, walruses, whales), and many others. Most of these species live within the top two zones of the ocean where they have access to food. The deep ocean (aphotic zone) contains some organisms, including some of the most unusual animals on earth (e.g., angler fish, which uses a phosphorescent lure to attract prey to its mouth).

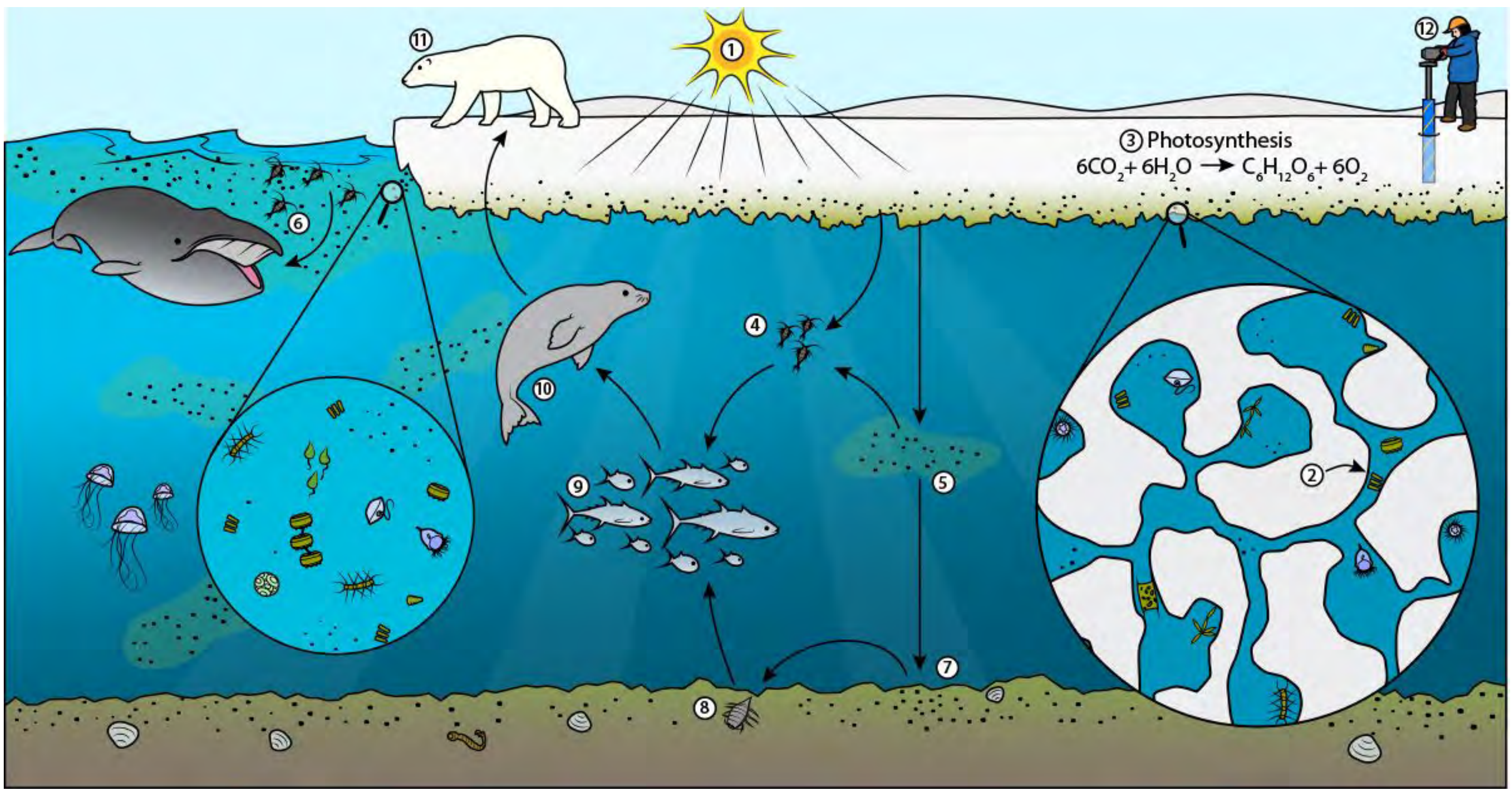


Simplified food-web structure of a near-shore ocean ecosystem
© HELCOM 2010

SEA ICE

Sea ice provides a complex habitat for many species. In some areas of the arctic, sea ice persists throughout the year (**multi-year ice**), and in others it melts in spring. As the ice melts it transports organisms, nutrients, and pollutants into the ocean. Partial melting of the ice produces openings in the ice called polynyas that have their own communities of animals. The interface between sea ice and water helps to protect some organisms from predators. For example, Arctic cod use these regions as nursery grounds, and in turn they are an important food source for many marine mammals and birds.

Sea ice is riddled with a network of tunnels called brine channels. These tunnels range from microscopic to more than 3 cm in diameter and are inhabited by primary producers such as diatoms and algae. In spring as the ice melts these species are released into the ocean and provide food for other organisms including invertebrates (e.g., amphipods, worms, etc.) and larval fish. Large algal masses also form under the ice and provide additional food. On average, over 50% of the primary production within Arctic regions comes from the single-celled algae living in this layer, making them critical for the ocean community.



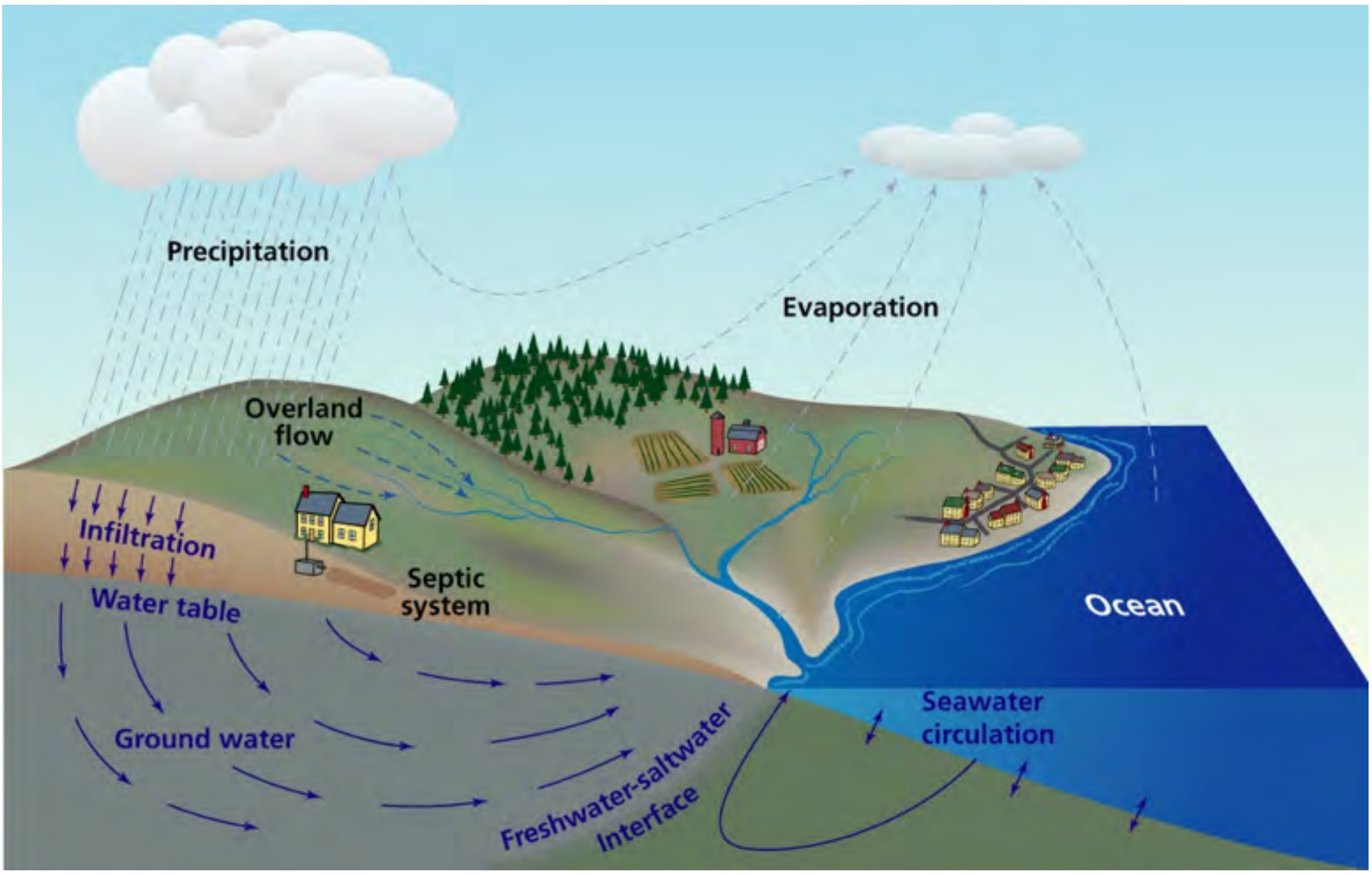
Arctic Sea Ice Community: Sunlight (1) shines on the microscopic algae (2) in the sea ice. The sea ice algae convert carbon dioxide (CO2) to sugars through photosynthesis (3) algae in the ice are eaten by small zooplankton such as copepods (4). Some of the algae in the ice are not eaten and melt out of the ice and sink into the water (5) where they can be eaten by the small animals (4) or whales (6). Some of the algae are heavy and sink to the sea floor (7) where they can be eaten by bottom-feeding animals such as isopods (which are crustaceans, (8)). The small animals in the water (4) and on the seafloor (8) are in turn eaten by fish (9). Fish are the food choice of seals (10). Seals are a preferred food of polar bears (11), which inhabit the area and roam on top of the ice in search of food. Researchers study sea ice and marine ecosystems to better-understand how they work (12).

GROUNDWATER

PROPERTIES OF GROUNDWATER

It is sometimes thought that water flows through underground rivers or collects in underground lakes. Groundwater is not confined to a few channels or depressions in the same way that surface water is concentrated in streams and lakes. Rather, it exists almost everywhere underground. It is found in the spaces between particles of sand and soil, or in crevices and cracks in rock, and is usually within 100 metres of the surface. Much of the earth's fresh water is found in these spaces. At greater depths, because of the weight of overlying rock, these openings are much smaller, and therefore hold considerably smaller quantities of water.

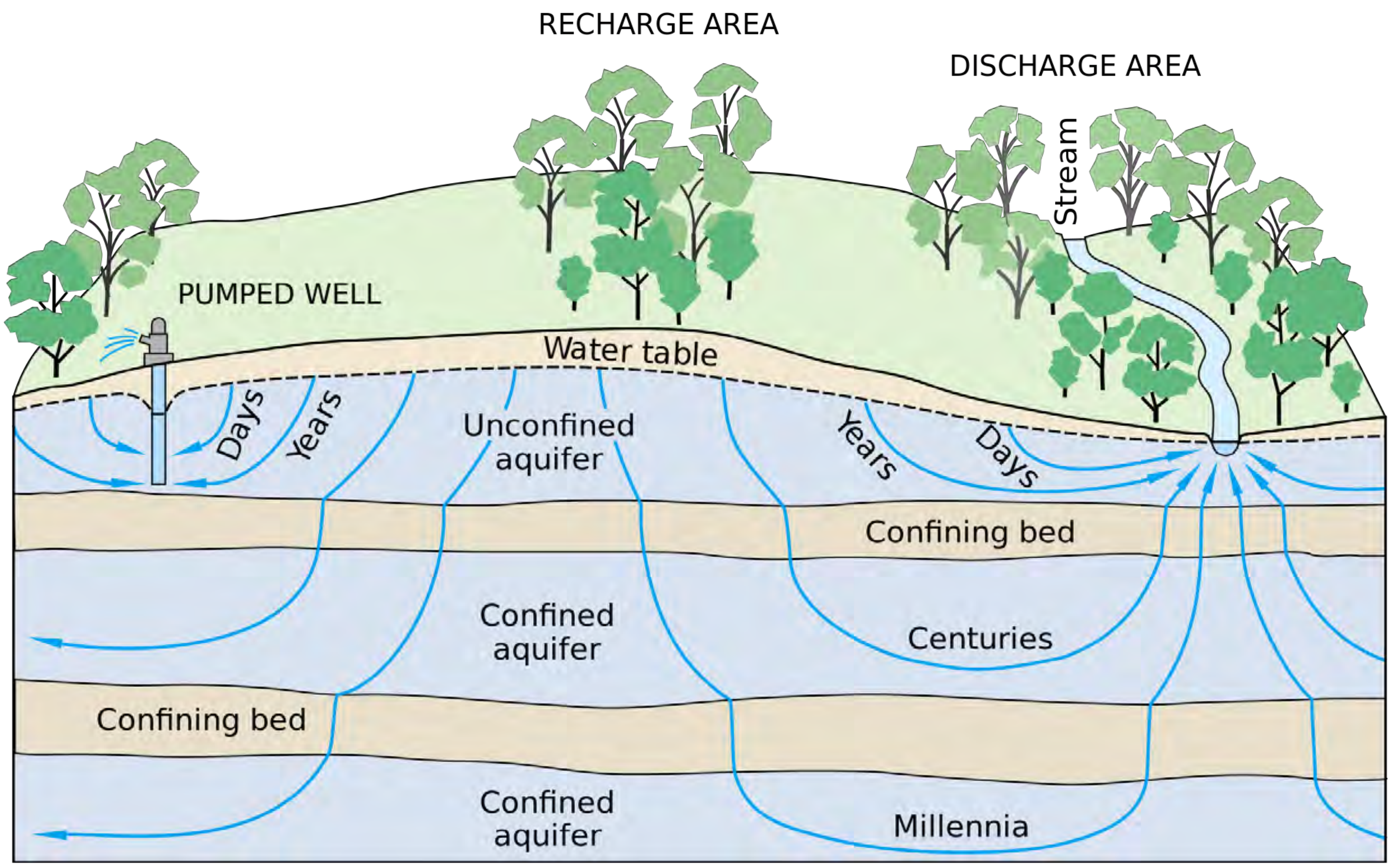
The depth of soil below which all spaces are filled with water is called the **water table**. Above the water table lies the **unsaturated zone** where spaces in rock and soil contain both air and water (called **soil moisture**, not ground water). The entire region below the water table is called the saturated zone, and water in this saturated zone is called **groundwater**.



Groundwater flow with saltwater intrusion

Aquifers

Although groundwater exists everywhere under the ground, some parts of the saturated zone contain more water than others. An **aquifer** is an underground formation of permeable rock or loose material that can produce useful quantities of water when tapped by a well. Aquifers come in all sizes and their origin and composition is varied. They may cover a small area (a few hectare) or a very large area (underlying thousands of square kilometres of the earth's surface). They may be only a few metres thick, or they may measure hundreds of metres from top to bottom. Groundwater usually flows downhill with the slope of the water table. Like surface water, groundwater flows toward, and eventually drains into streams, rivers, lakes and the oceans. Groundwater may move in different directions than water flowing on the surface.



Groundwater flow through an ecosystem

© Wikimedia Commons

Many important Canadian aquifers are composed of thick deposits of sands and gravel previously laid down by glacial rivers. The Carberry aquifer in Manitoba is an old delta lying on what was formerly Glacial Lake Agassiz. It is well developed as a source of irrigation water. The Winnipeg and Montreal aquifers that are used for industrial water supply are composed of fractured rocks.

Fractured aquifers are rocks in which groundwater moves through cracks, joints or fractures in otherwise solid rock (such as granite or basalt). Limestone aquifers are often fractured, but here the cracks and fractures may be enlarged by water dissolving the rock, forming large channels or even caverns. Limestone terrain where solution has been very active is termed **karst** and consists of many large caverns. Porous media such as sandstone may become so highly cemented or recrystallized that all the original space is filled such that the rock is no longer a porous medium. If it contains cracks it can still act as a fractured aquifer.

Unconfined aquifers are those bounded by the water table and are easily accessible from the surface (e.g., by a well).

Confined aquifers (also called **artesian aquifers**) lie beneath layers of impermeable materials and rarely interact with the surface/atmosphere.

GROUNDWATER AND THE HYDROLOGIC CYCLE

Groundwater does not stay underground forever, but instead circulates as part of the hydrologic cycle. The **residence time** of groundwater, i.e., the length of time water spends in the groundwater portion of the hydrologic cycle, varies immensely. Residence times of tens, hundreds, or even thousands of years are not unusual. By comparison, the average turnover time of river water, or the time it takes the water in rivers to completely replace itself, is about two weeks.

When precipitation falls on the land surface, part of the water runs off into the lakes and rivers. Some of the water from melting snow and from rainfall seeps into the soil and percolates into the saturated zone. This process is called **recharge**. Eventually, groundwater circulates back to the surface at various **discharge** points, including streams, rivers, marshes, lakes and oceans, or it may discharge in the form of springs and flowing wells. While the **rate of discharge** determines the volume of water moving into streams, the **rate of recharge** determines the volume of water running over the surface. When it rains, for instance, the volume of water running into streams and rivers depends on how much rainfall the underground materials can absorb. When there is more water on the surface than can be absorbed into the groundwater zone, it runs off into streams and lakes. Groundwater discharge can contribute significantly to surface water flow. In dry periods, the flow of some streams may be supplied entirely by groundwater.

After it has been discharged, groundwater becomes surface water. From the surface, all water returns to the atmosphere through evaporation and transpiration.

GROUNDWATER QUALITY

The chemical nature of water continually evolves as it moves through the hydrologic cycle. The chemistry of groundwater depends on:

- Precipitation and recharge water chemistry
- Rock and soil formations it flows through
- Residence time
- Temperature and pressure conditions

Near coastlines, precipitation contains higher concentrations of sodium chloride, and downwind of industrial areas, airborne sulphur and nitrogen compounds make precipitation acidic.

In its passage from recharge to discharge area, groundwater may dissolve substances it encounters, or it may deposit some of its constituents along the way. In general, faster flowing water dissolves less material. One of the most important natural changes in groundwater chemistry occurs in the soil. Soils contain high concentrations of carbon dioxide which dissolves in groundwater, creating a weak acid capable of dissolving many silicate minerals.

As groundwater flows through an aquifer it is naturally filtered. This filtering, combined with the long residence time underground, means that groundwater is usually free from disease-causing microorganisms. A source of contamination close to a well, however, can defeat these natural safeguards. Natural filtering also means that groundwater usually contains less suspended material and undissolved solids than surface water.

GROUNDWATER CONTAMINATION

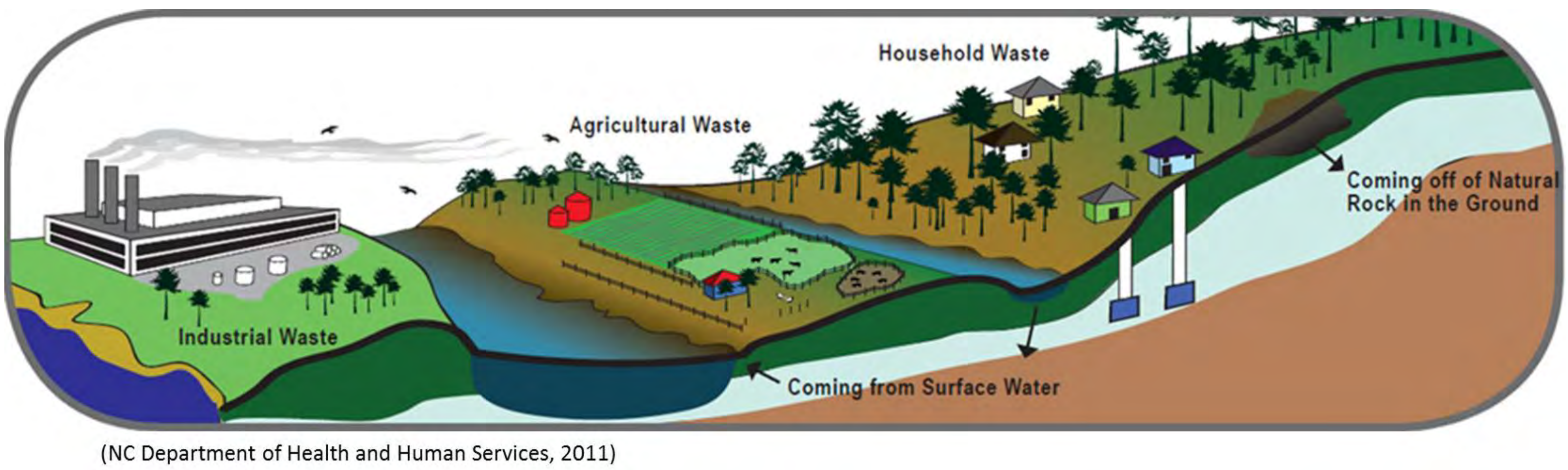
Groundwater is an essential resource for about 25% of Canadians, acting as their sole source of water for drinking and washing, farming and manufacturing, indeed, for all their daily water needs. Our image of Canada is of a land of sparkling lakes, rivers and glaciers. Groundwater, which exists everywhere under the surface of the land, is not part of this picture. Not surprisingly, therefore, concerns of Canadians about water quality focus primarily on surface waters. The less visible, but equally important, groundwater resources have received much less public attention historically.

In recent years several events affecting groundwater quality have contributed to a heightened public awareness and concern about the importance and vulnerability of the resource. Media reports about contamination of wells from leaking gasoline storage tanks, dry-cleaning solvents, industrial waste, and landfill runoff have raised public concerns about groundwater quality.

Contamination is any addition of unwanted materials to groundwater caused by human activities. It has often been assumed that contaminants left on or under the ground will stay there; unfortunately, this has been shown to be wishful thinking. Groundwater often spreads the effects of dumps and spills far beyond the site of the original contamination.

Groundwater contamination is extremely difficult, and sometimes impossible, to clean up.

Groundwater contaminants fall into two categories: **point sources** (such as landfills, leaking gasoline storage tanks, leaking septic tanks, and accidental spills) and **non-point sources** (such as infiltration from farm land treated with pesticides and fertilizers).



Groundwater Contamination
© 2011 NC Department of Health and Human Services

GROUNDWATER, GEOLOGY, AND ENGINEERING

Engineers must consider groundwater when planning almost any kind of structure, either above or below the ground (particularly, but not limited to, dams, tunnels, mines, etc.). Ignoring potential effects of groundwater on slope stability can be costly and dangerous. Groundwater must also be considered when devising measures to control flooding. In all of these situations, groundwater flow and fluid pressure can create serious geotechnical problems.

Geologists see groundwater as a major force in geological change. The fluid pressures exerted by groundwater, for example, play an important role in the occurrence of earthquakes. Geologists also know that the movement of water through underground geologic formations controls migration and accumulation of petroleum and formation of some ore deposits.

OVERDRAFTING

Problems result from the excessive use of groundwater. **Overdrafting** occurs when people draw water out of an aquifer faster than nature can replenish it. The most obvious problem created is a **shortage of water**, but overdrafting can also create significant geotechnical problems. Although not an issue in Canada, overdrafting has led to land subsidence in many locations around the world, which leads to severe engineering difficulties. Parts of Mexico City, for instance, have subsided as much as 10 metres in the past 70 years, resulting in a host of problems in its water supply and sewerage system. Land subsidence may also occur when the water table is lowered by drainage.

WATER USE

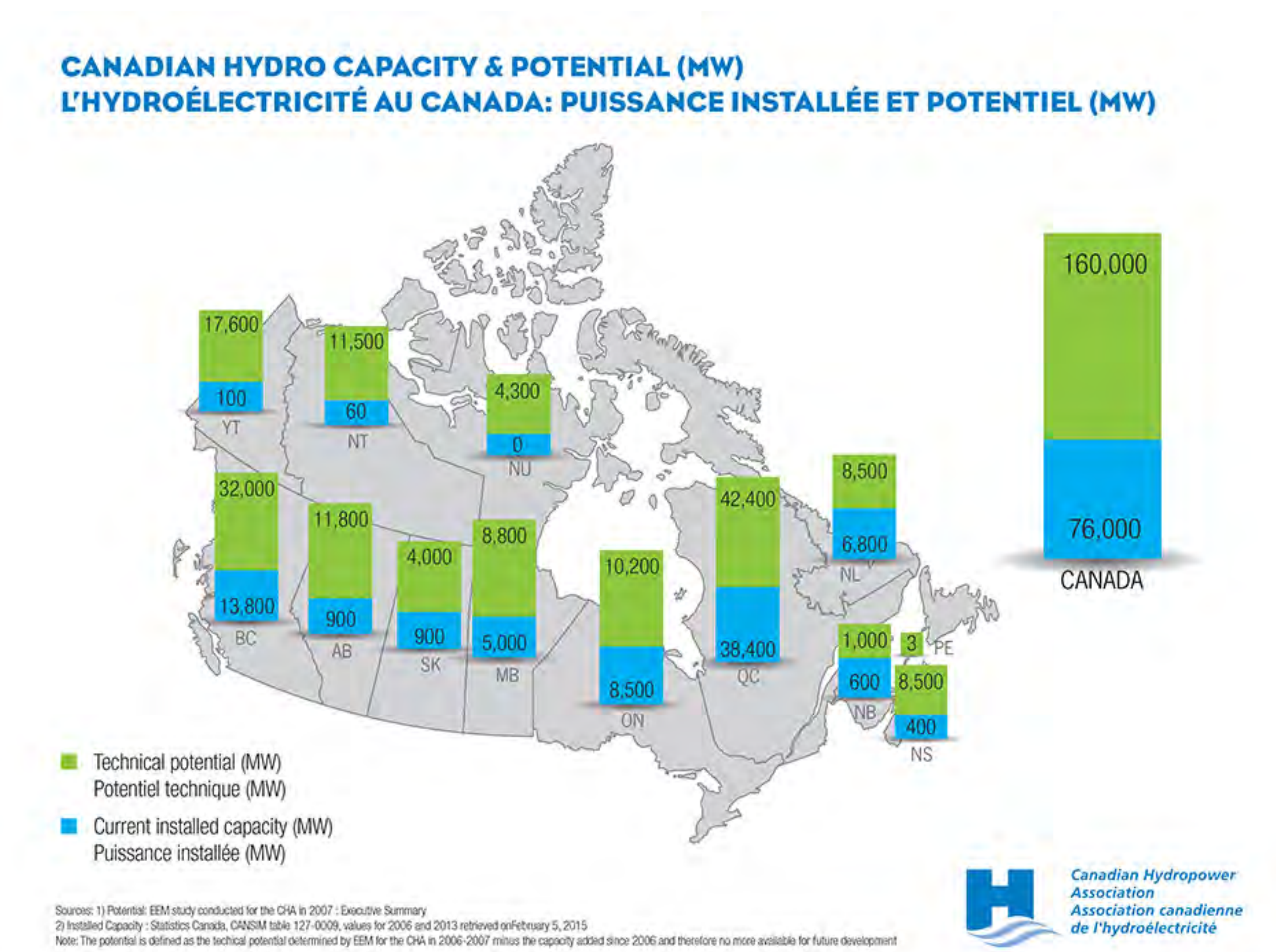
INSTREAM USES

The most obvious and immediate water usages occur within water bodies themselves; these are called **instream uses**. Human instream uses include any way that humans interact with water in its natural setting, such as hydroelectric power generation, shipping, and water-based recreation. Instream uses are not always harmless. For example: oil leaking from outboard motors and freighters can cause pollution, and large reservoirs needed for hydroelectric power generation remove water by evaporation and completely change the river regime for downstream users and migrating species. Proper management of instream uses is essential for the health of aquatic ecosystems.

Instream uses cannot be quantitatively measured as the water is not removed from its natural environment. Instead, instream uses are described by certain characteristics of the water, such as water levels, flow rates, and water quality. If these characteristics change, it means that the instream use is having a significant impact on the ecosystem. For example, hydroelectric development affects aquatic life, wildlife, water supply and water transportation. If a reservoir is used to store water rather than allowing it to flow according to natural patterns, it removes the natural variability of stream flows on which many life processes depend, in particular, the highly productive ecosystems of deltas, estuaries and wetlands. **To make the best use of our water, all uses must be carefully assessed and considered.**

Hydroelectric Power Generation

Hydroelectric energy is produced by the force of falling water. The capacity to produce this energy is dependent on the available flow and the height from which it falls. Building up behind a high dam, water accumulates potential energy, which is transformed into mechanical energy when the water rushes through a turbine and turns the blades. The turbine's rotation spins electromagnets which generate current (electrical energy) in stationary coils of wire. Finally, the current is put through a transformer where the voltage is increased for long distance transmission over power lines. In Canada, hydroelectric plants satisfy 63% of electricity demands.



Hydroelectric power potential

Water Transport

Inland waterways in Canada have historically played a major role in moving goods and raw materials. Some traditional uses, such as log driving, have now disappeared, however, water transport by ship is still the most economical means of moving the bulky raw materials which are our main exports: wheat, pulp, lumber, and minerals. Reliable and predictable lake and river levels are very important for this use. Water transportation is typically used in large bodies of water such as the Great Lakes and the ocean, and is less typical on smaller bodies of water.

Waste Disposal

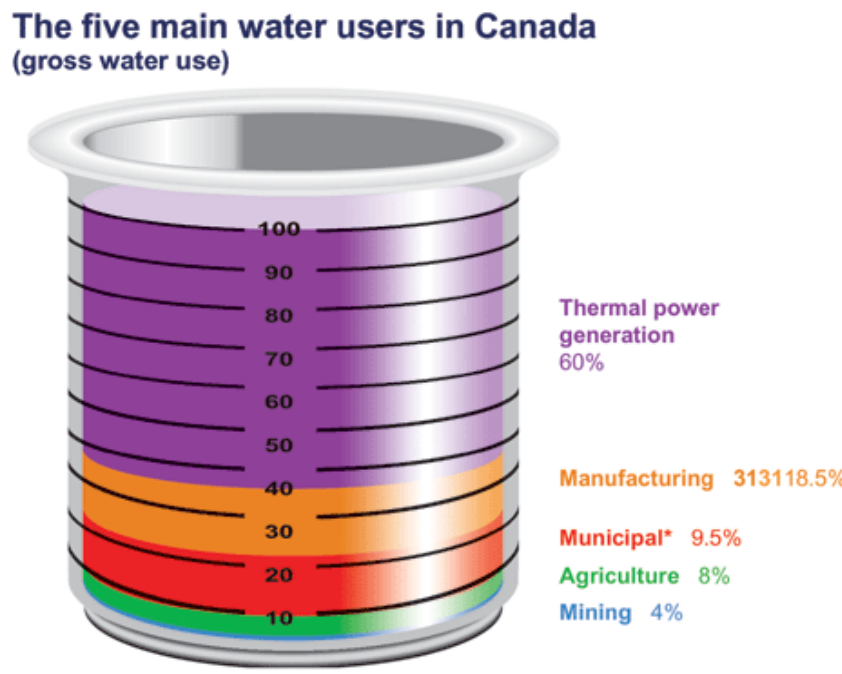
Human and industrial wastes are commonly dumped into lakes, streams, and oceans with or without treatment. While water is capable of diluting and processing these wastes to some extent, there are limits to what each water body can absorb. The degree to which water bodies can absorb contaminants depends on factors including the nature of the contaminant, the ratio of contaminant volume to water volume, how long the contaminant stays in the water, the temperature of the water, and the rate of flow. Many of our waterways are now overloaded with wastes but this problem can sometimes be resolved by increased regulation and/or monitoring. Proper treatment of wastes prior to disposal is essential for reducing their impacts on aquatic ecosystems. For example, removing nutrients and pharmaceuticals from sewage, and using tailings/settling ponds for industrial waste.

WITHDRAWAL USES

Withdrawal uses are those in which water is removed from its source (well or water body) and transported elsewhere; they represent the greatest number and variety of water uses. Water is piped or channelled to many locations and users, and then is collected again for return to a water body or into the ground (but not necessarily the same place it was withdrawn from). Household and industrial uses, thermal and nuclear power generation, irrigation and livestock watering are all considered withdrawal uses.

Water **intake volume** is the amount of water withdrawn from the source over time. This measure is important because it represents the **demand** imposed by that particular use at a given location. The amount of water returned to the landscape, either at or away from its source, it is called **discharge volume**.

Water **consumption** is the difference between water **intake** and water **discharge**. Consumption removes water from a river system and makes it unavailable for further use downstream. The irrigation of crops is by far the largest consumptive use in the world, followed by evaporation in large open water reservoirs and cooling ponds. However, because evaporation is difficult to measure, it is seldom recognized in water consumption budgets.

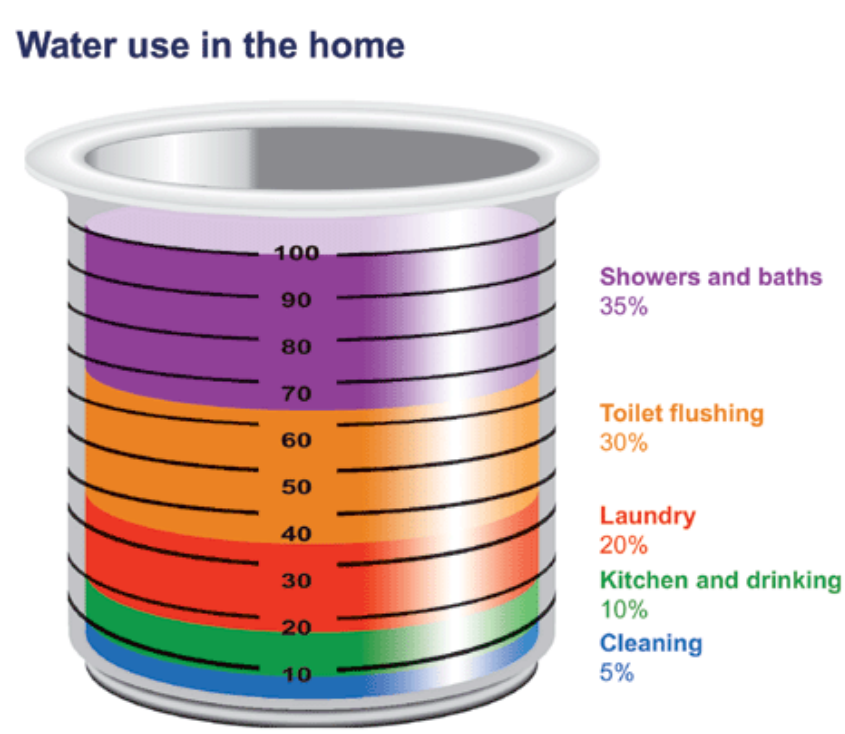


The five main water users in Canada

The **efficiency** of water usage in a process or economic sector is quantified with the help of two additional measurements: **gross water use** and the amount of water that is **recirculated**. Gross water use represents the total amount of water used in a process. The difference between gross water use and water intake is the amount recirculated, which can be expressed as a recycling rate. This is the number of times that the water is recirculated and indicates how efficient a water use is.

Municipal Use

Municipal water use includes residential, commercial, and public uses. Residentially, we use it for drinking, cooking, watering gardens, and for other household needs. In 2011-2016, Canadians, used **251-329 litres of water per person per day** (about 65% of which occurred in the bathroom). Water is also used publicly (e.g., to fight fires, fill public swimming pools), and commercially (e.g., water parks, by businesses), among many other uses.



Water use in the home

Agricultural Use

Water is withdrawn mainly for irrigation (86.4%) and livestock watering (9.8%). Irrigation is needed mainly in the drier parts of Canada, such as the southern regions of Alberta, British Columbia, Saskatchewan, and Manitoba. Irrigation is also used in Ontario and the Maritimes for frost control. Since so much of the water used in irrigation evaporates, only a small fraction is returned to its source. **Irrigation is a highly consumptive use.** Canadian agricultural producers used just over 2 billion cubic metres of water for irrigation in 2016, about 22% higher than in 2014.

Mining

This category includes metal mining, non-metal mining, and the extraction of coal. Water is used by the mining industry to separate ore from rock, to cool drills, to wash ore during production, and to carry away unwanted material. Mining recirculates its water to a greater extent than any other sector, so although the mining industry had a gross use equal to about half of that used in agriculture, mining accounted for only 1% of all water intake in 2005 (compared to 9% in the agricultural sector). Mining activities have great potential to **contaminate** water with harmful pollutants, so even if the water is technically returned to its source, it may not be fit to support aquatic organisms.

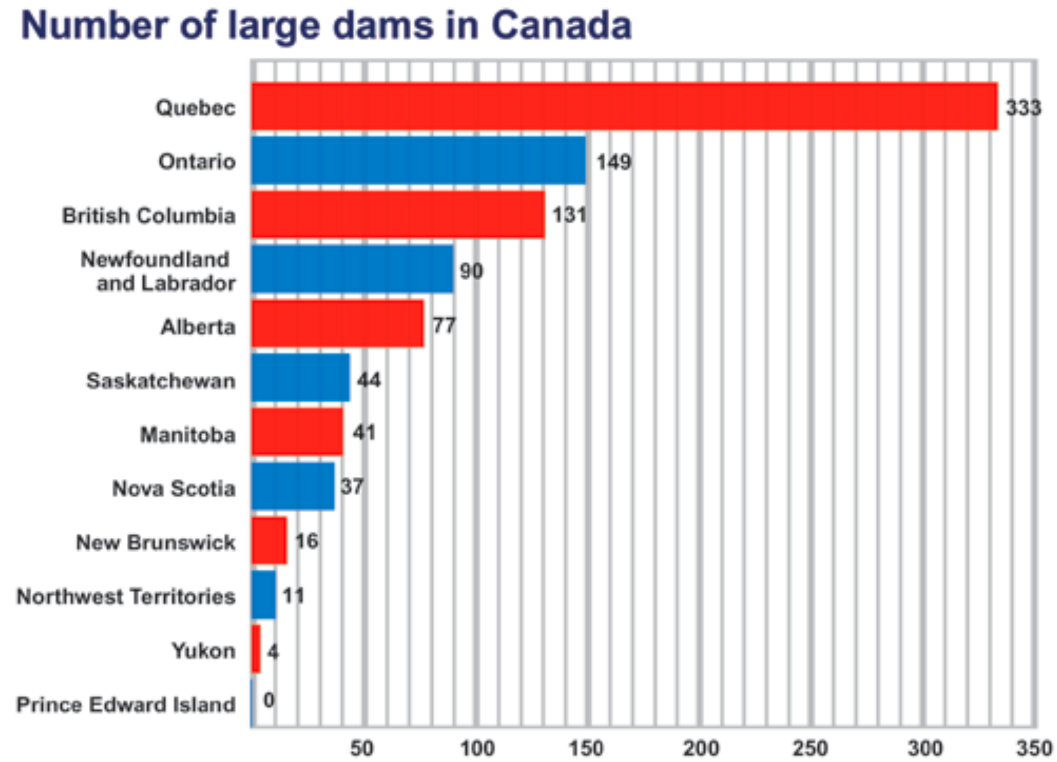
DAMS AND DIVERSIONS

Water can be diverted away from or into a water body, changing flow rates, flow patterns, and water levels, and significantly impacting downstream areas. Diverting water permanently (e.g., a diversion channel) or temporarily (e.g., when fixing a bridge) can significantly affect the natural character of a waterway and the surrounding habitat.

For example, storm water drains and pipes discharge water and its associated contaminants into water bodies, thereby increasing flow and turbidity.

Water can be diverted using **instream barriers** such as dams, weirs, culverts, canals, and pipes. **Dams** hold back flows of surface or underground streams for controlled release (to provide maximum power generation or to control the destructive power of storm water). Canada ranks as one of the world's top ten dam builders. **Reservoirs** (large flooded areas upstream) created by dams not only suppress floods but also provide water for activities such as irrigation, human consumption, industrial use, aquaculture, and navigability.

Dams and their resulting reservoirs impact the water quality and biotic community of a stream system. The land upstream of the dam is flooded, which may mean the loss of valuable wildlife habitat, farmland, forests, or town sites. Accumulation of sediments in the reservoir can have a negative impact on water quality (turbidity), and decomposition of flooded vegetation can lead to the release of huge amounts of greenhouse gases (methane, carbon dioxide) and mercury. Fish in reservoirs are often highly contaminated with mercury due to the enhanced availability of mercury in the ecosystem. Eutrophication may also occur at a faster rate and adversely affect water quality.



The number of large dams in Canada by province

© Environment Canada

Diversions redirect water flow to an alternate location (e.g., changing the pathway of a river, or draining a portion of a lake), and are frequently used in mining and other industrial activities. Historically, diverting flow from one basin to another has been done for energy generation, irrigation, and industrial output. Inter-basin (between watersheds) diversions can have undesirable social and environmental consequences. For example, the amount of water removed in relation to the amount of water available, existing water demand and uses, quality of water transferred, and potential for introduction of invasive species and pathogens, can all have significant impacts. Major diversions and transfers have been used to fulfill water resource and economic development objectives, but it is widely recognized that we have moved away from the era of large-scale diversions and transfers in North America because of environmental and social considerations.

Manitoba dams and diversions

Northern Manitoba has many dams for the generation of hydroelectric power. Hydroelectric development has played a prominent and controversial role in the last 100 years of Manitoba history. Manitoba Hydro's complex has three major components: Churchill River diversion, Lake Winnipeg regulation, and the major generation stations.

Manitoba's two largest rivers (Nelson and Churchill) drain into Hudson Bay. Manitoba Hydro diverted the Churchill River in 1976, directing flow toward the Nelson, which allowed them to gain power from both rivers in one series of dams (along the Nelson). This diversion results in the ongoing flooding of 837 km^2 at Southern Indian Lake and along the diversion route. Annual flows along this route are roughly nine times greater than they would be without the diversion. Three major dams on the Nelson river, the Limestone, Kettle, and Long Spruce, generate about 70% of Manitoba Hydro's total production.

The Jenpeg dam regulates the flow of Lake Winnipeg into the Nelson river. Water is held back in Lake Winnipeg to be released into the Nelson river during winter when energy demands in Manitoba are higher.

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.

Scientists, 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.

WATER QUALITY DRIVERS

Many factors impact water quality. Dust, volcanic gases, and gases in the air (carbon dioxide, oxygen, and nitrogen), are all dissolved or entrapped in rain. When other substances such as sulphur dioxide, toxic chemicals, or lead are in the air, they are also collected in the rain as it falls to the ground.

Rain reaches the ground and, as runoff, flows over and through the landscape, dissolving and picking up other substances. For example, if the soils contain high amounts of soluble substances, such as limestone, the runoff will have high concentrations of calcium carbonate (dissolved from the limestone). If water flows over rocks high in metals, such as ore bodies, it will dissolve those metals. In urban regions, water collects debris from streets and takes it to the receiving water body. Urban runoff can increase concentrations of nutrients, sediments, animal wastes, petroleum products, and road salts.

Industrial, farming, mining, and forestry activities also affect the quality of water bodies and groundwater. Farming can increase nutrients, pesticides, and suspended sediments. Industrial activities can increase concentrations of metals and toxic chemicals, add suspended sediment, increase temperature, and lower dissolved oxygen in the water. Each of these effects can have a negative impact on the aquatic ecosystem and/or make water unsuitable for established or potential uses.

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

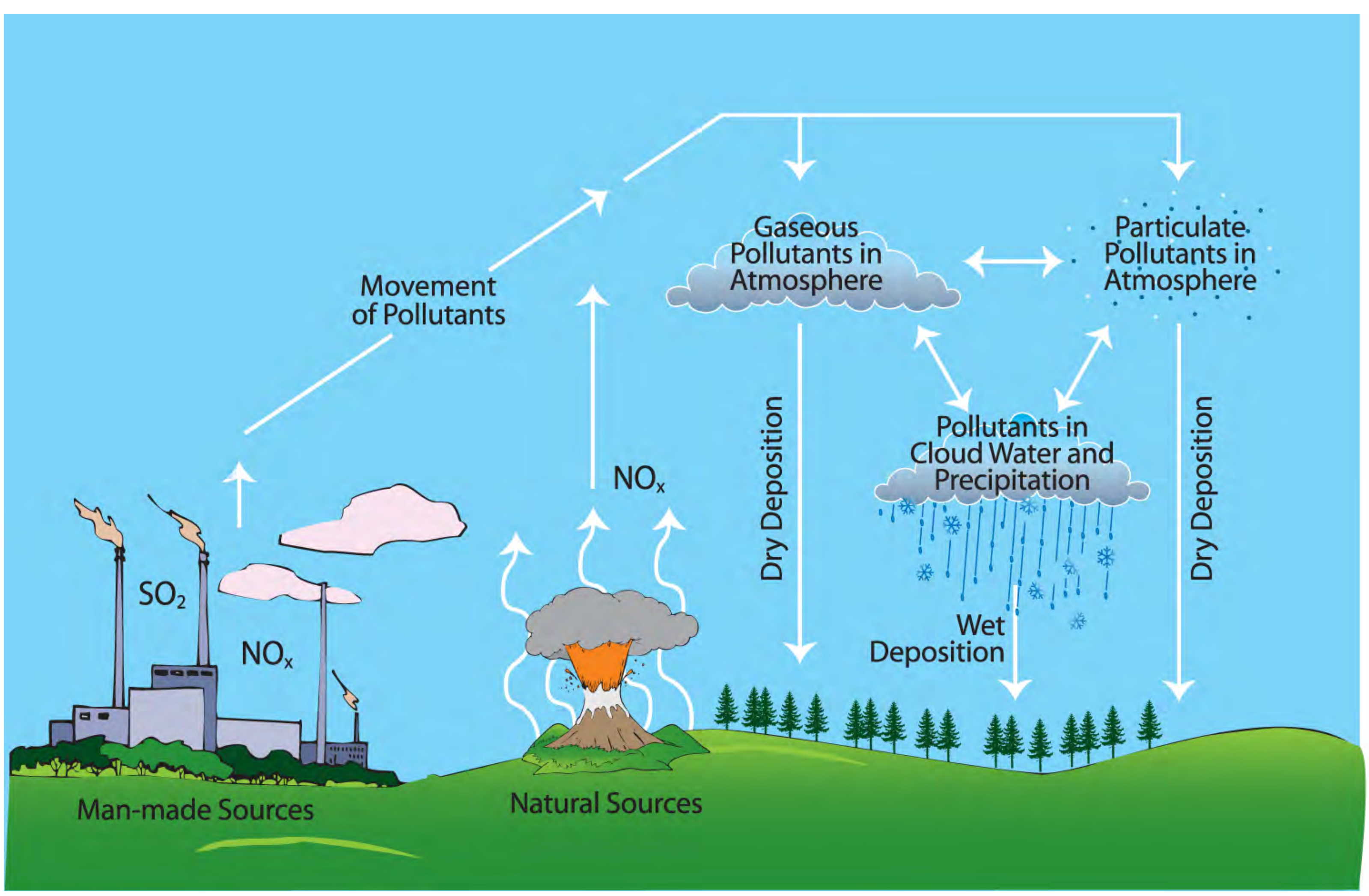
More harmful		Less harmful		Beneficial			Less harmful		More harmful	
Few, if any fish can survive for more than a few hours. Some plants and invertebrates can live at this level	Lethal to salmonids (salmon and trout)	Few fish, frogs, or insects can survive	Most fish eggs will not hatch	Bottom-dwelling bacteria begin to die. Plankton disappears and there are few snails and clams. Toxic metals such as aluminum and lead are released	Most fish and plant life survive	Optimal for most organisms	Not directly harmful to fish, but some chemicals, such as ammonia, become more toxic at higher pH levels	Harmful to salmonids and perch	Lethal to salmonids; harmful to carp and perch	Rapidly lethal to all species of fish
3.0–3.5	3.5–4.0	4.0–4.5	4.5–5.0	5.0–5.5	5.5–6.5	6.5–8.2	8.2–9.0	9.0–10.5	10.5–11.0	11.0–11.5

pH level

ACIDIC | NEUTRAL | ALKALINE

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.

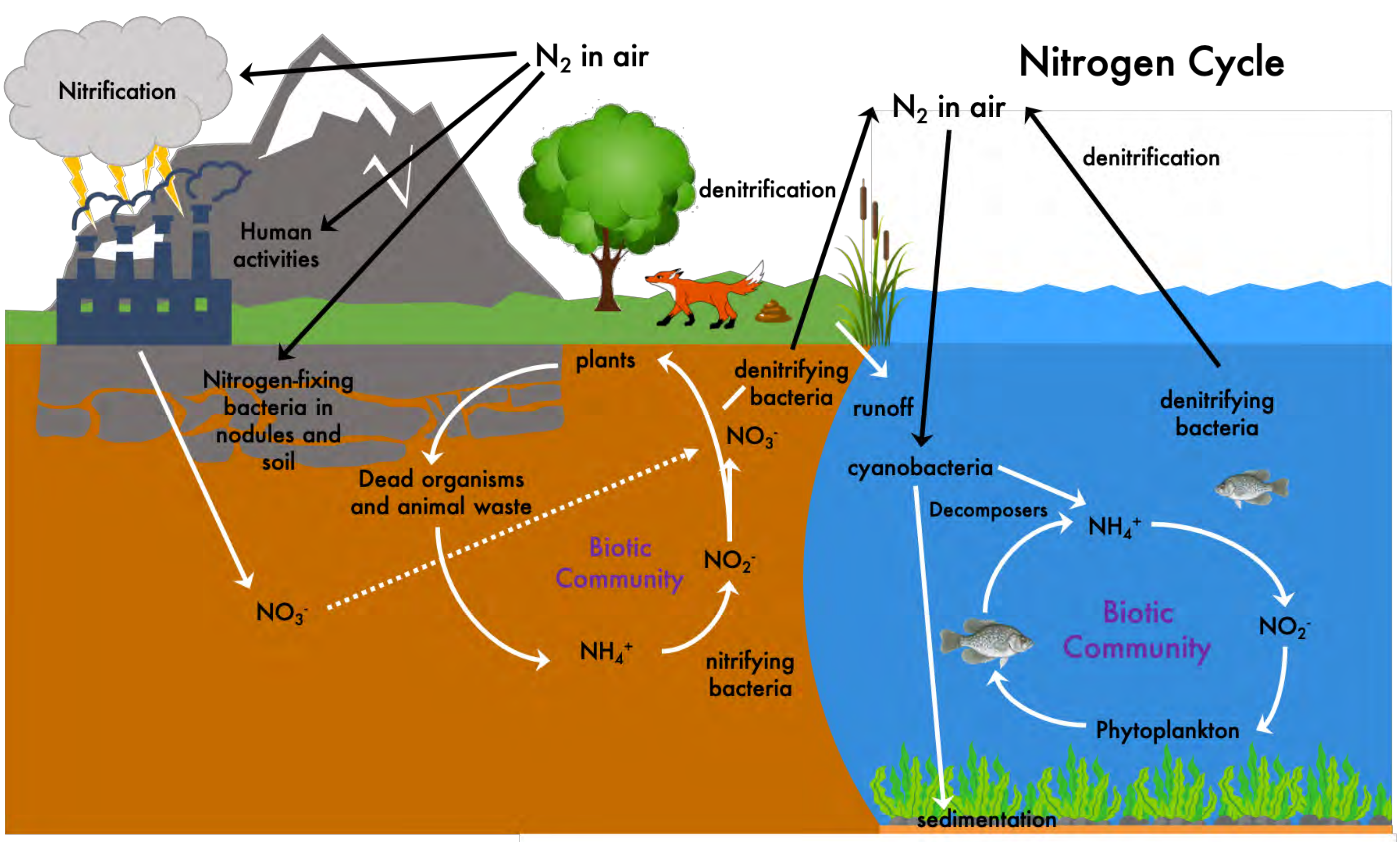
Phosphorus

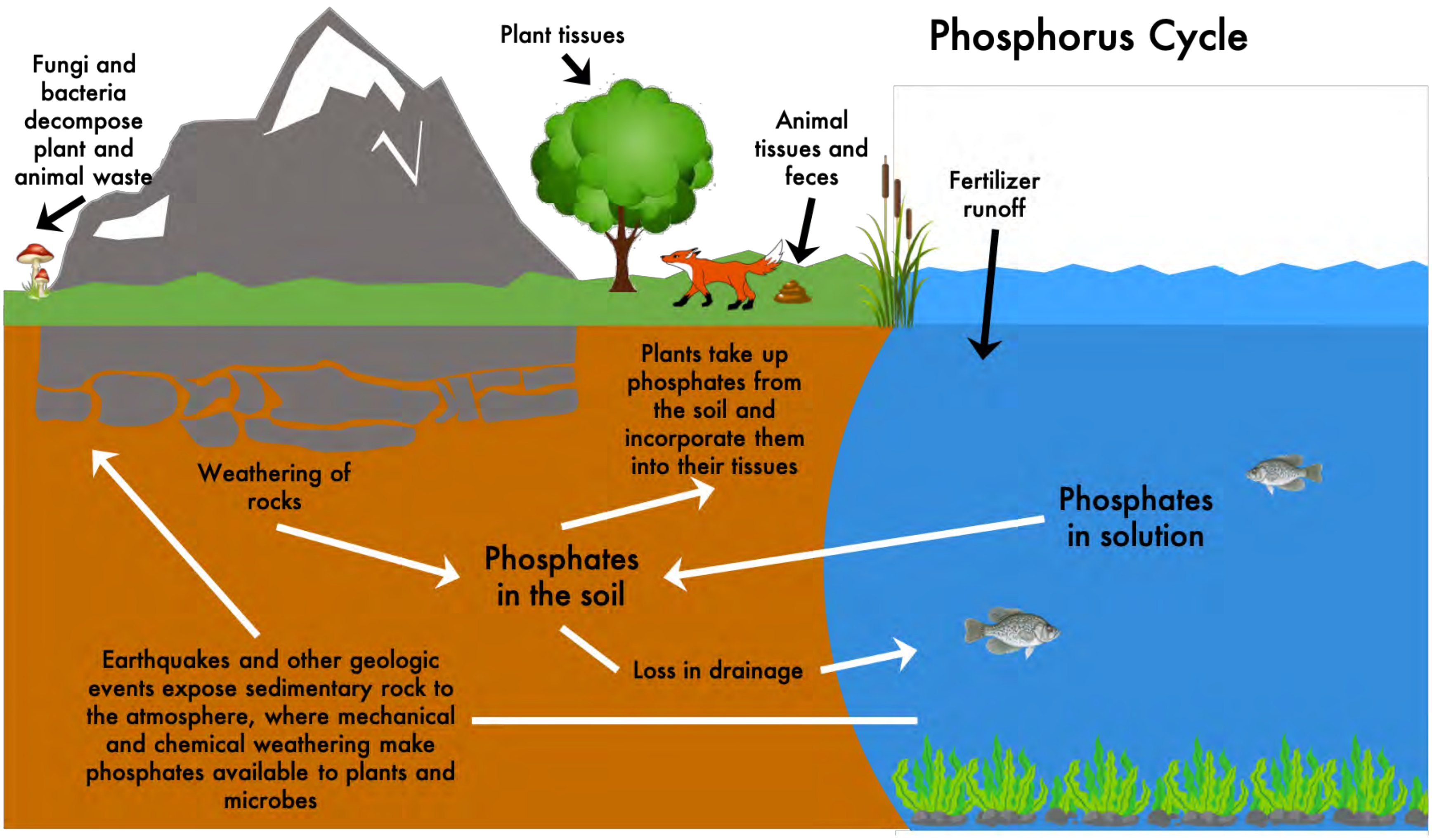
Phosphorus is another substance that is essential for life. Phosphorus often combines with four oxygen atoms, forming a phosphate ion (PO_4). Algae and larger aquatic plants rapidly take up this ion for metabolic reactions and growth. Animals need phosophorus for similar reasons, but they uptake phosphorus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

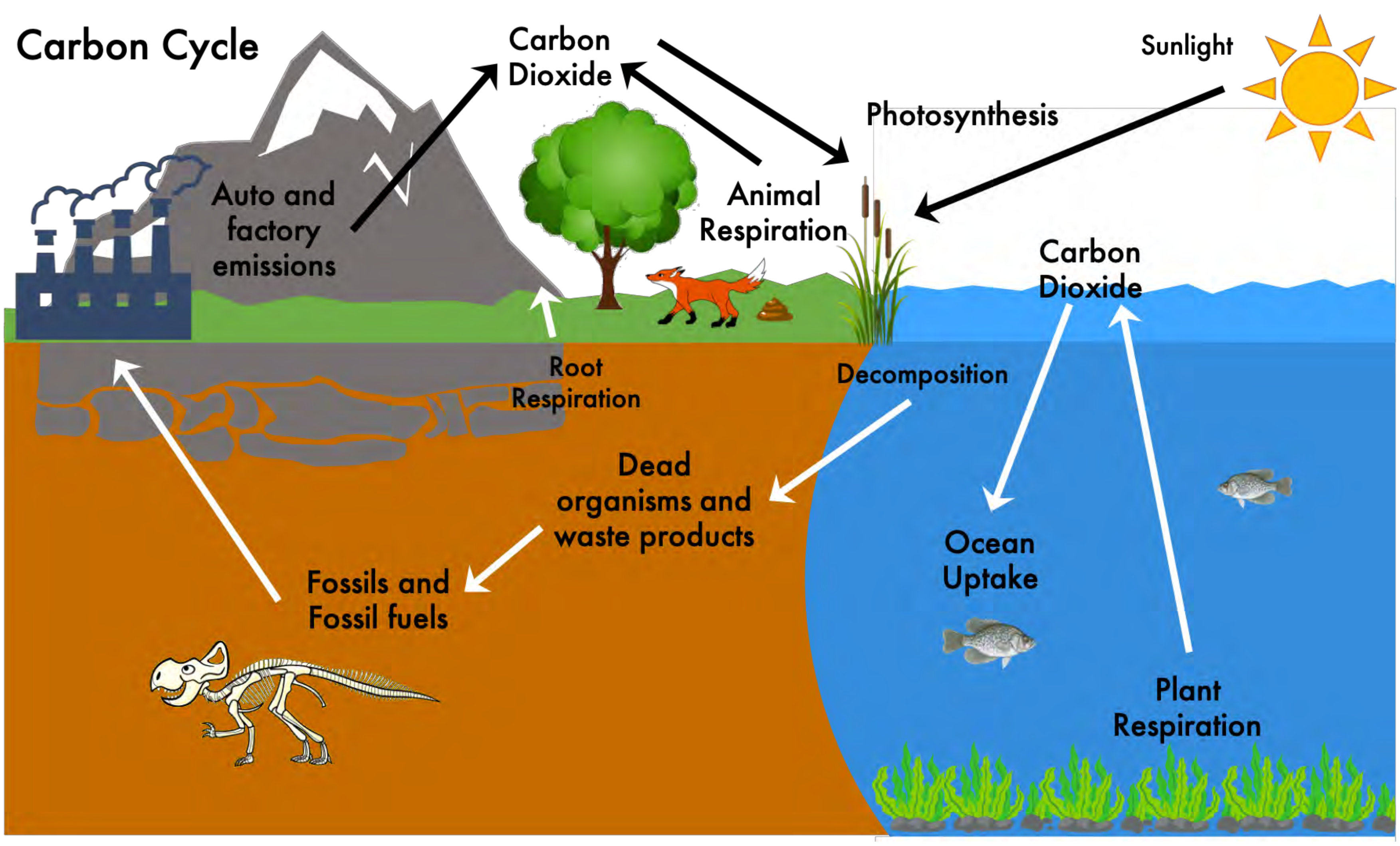
Phosphate that is not combined with any molecules in organisms is called "**orthophosphate**", meaning "straight phosphate". Orthophosphate, the reactive form of phosphate, is the easiest to test for in the environment. In most water bodies, orthophosphate is found in very low concentrations. Therefore, 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




Phosphorus Cycle
Fungi and bacteria decompose plant and animal waste
Plant tissues
Animal tissues and feces
Fertilizer runoff
Plants take up phosphates from the soil and incorporate them into their tissues
Weathering of rocks
Phosphates in the soil
Phosphates in solution
Loss in drainage
Earthquakes and other geologic events expose sedimentary rock to the atmosphere, where mechanical and chemical weathering make phosphates available to plants and microbes


Carbon Cycle
Carbon Dioxide
Sunlight
Photosynthesis
Auto and factory emissions
Animal Respiration
Carbon Dioxide
Root Respiration
Decomposition
Dead organisms and waste products
Ocean Uptake
Fossils and Fossil fuels
Plant Respiration

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.

CHLOROPHYLL – A MEASURE OF ALGAE

An in-depth microscopic count of the dozens of species of algae present in a water column each time a lake is sampled is prohibitively costly and technically impossible for most monitoring programs. Further, in many lakes a large portion of the algal biomass may be unidentifiable by most experts (these are appropriately called LRGTs or LRBGTs -- little round green things and little round blue-green things). However, measuring the concentration of chlorophyll-a is simple and provides a reasonable estimate of algal biomass. Chlorophyll-a is the green pigment responsible for a plant's ability to convert sunlight into the chemical energy needed to fix CO_2 into carbohydrates (phososynthesis). It is important to examine the algal community microscopically on occasion in addition to chlorophyll-a measurements, since the mix of species may influence lake management decisions.

To measure chlorophyll-a, a volume of water is filtered through a fine glass-fiber filter to collect all of the particulate material greater than about 1 micron (1/1000th of a millimeter) in size. The chlorophyll-a in this material is then extracted with a solvent (acetone or alcohol) and quantified using a spectrophotometer or a fluorometer.

Secchi depth (see Aquatic Sampling Techniques section) has also been used to estimate algal biomass in lakes, but it is a much cruder method and is easily influenced by factors other than chlorophyll-a (suspended solids, water colour).

TOTAL DISSOLVED SOLIDS (TDS) AND SALINITY

Water can dissolve a wide range of substances, including calcium, sodium, phosphorus, iron, sulfate, carbonate, nitrates, chlorides, and other ions. Some of these solids are essential for the health of aquatic organisms. Phytoplankton depends on dissolved nitrates and phosphates, but high concentrations of these ions can lower water quality.

High solid concentration can increase water **turbidity** (opacity), which can decrease the rate of photosynthesis. High TDS can increase water temperature through increased absorption of infrared radiation, and solids can also bind with toxic compounds and heavy metals.

Freshwater, brackish water, and sea water differ primarily in their total dissolved solid levels due, primarily, to differences in salt content (**salinity**). For example, freshwater contains up to 1 part per thousand (ppt) of dissolved solids. Brackish water contains 1-35 ppt, and sea water contains 35 ppt.

TURBIDITY

Turbidity is the cloudiness or opacity of a fluid and is caused by suspended solid particles that scatter light (plankton, sediment, organic materials, eroded soil, industrial waste, sewage, etc.). Turbidity is quantified by determining how much light passes through the water.

Although clear water may appear cleaner than turbid water, it is not necessarily healthier. On the other hand, high turbidity could be a symptom of other problems.

Effects of Turbidity

- Block sunlight (flows photosynthesis; plants may die if too much light is blocked)
- Increase water temperature (suspended particles absorb the sun's heat)
- direct impacts on fish: clog gills, stunt growth, and decrease disease resistance
- Pathogenic bacteria may increase

Causes of Excessive Turbidity

- Weather and seasons (e.g., heavy rains or spring snow melts can stir up soil and sediments)
- Contamination from sewage, industrial waste, or urban runoff
- Algal blooms can be caused by excess nitrogen

TOTAL COLIFORM BACTERIA

Coliform bacteria are a group of non-pathogenic (do not cause disease) bacteria living in the environment. Coliform bacteria can serve as an indicator of the presence of disease-causing (pathogenic) bacteria. If you find coliform bacteria in water, it is likely that you can find other bacteria or viruses, some of which may cause disease.

Testing for specific pathogens in water can be difficult and time consuming. Testing for coliform is fairly easy and a reliable indicator of the presence of other bacteria or viruses.

Sources of Coliform

- Combined sewage systems (from toilets, washers, and sinks)
- Agricultural and rural runoff
- Improperly working septic tanks and cesspools can allow untreated wastewater to enter groundwater

PROTECTING WATER QUALITY

In the face of this planet's overwhelming environmental problems, each individual effort to protect water quality is vital. **Together, individual actions can and do make a difference to water quality and the environment as a whole**. You can start by:

Avoid hazardous household products

Most proprietary household chemicals are safe to use and environmentally friendly when used according to the directions on the package. However, some have a harmful cumulative effect when they are over-used or incorrectly disposed of. Buy only those environmentally hazardous products you really need and buy them in quantities you will be able to completely use up, so that you will not have to worry about disposing of the leftovers later. When you buy environmentally-friendly products, make sure you read the label to see what their actual properties are – it's easy to make a product look "green" without having any environmental protection properties (this is called **green washing**).

Misuse of sewage systems

Don't throw waste down the drain just because it's convenient. Toxic household products can damage the environment and return to us through water and food. If you're unsure of how to dispose of something, look up a waste management company in your area, or call your local municipality.

Pesticide and hazardous materials

Instead of using chemical pesticides, adopt alternative pest control methods:

- Hand pull weeds
- Snip and discard infested leaves
- Dislodge insects with soap (regular liquid soap (not detergent) mixed with water 40 parts water, 1 part soap) or a water hose
- Practice companion planting
- Set ant and roach traps instead of using chemical sprays, or use natural insecticides such as diatomaceous earth
- Fertilize with natural materials such as bone meal or peat instead of chemical fertilizers

AQUATIC ECOSYSTEMS AND CLIMATE CHANGE

Throughout its history, Earth's climate has varied, reflecting the complex interactions and dependencies of the solar, oceanic, terrestrial, atmospheric, and living components that make up planet Earth's systems. Human activities, such as burning fossil fuels and deforesting large areas of land, have had a profound influence on Earth's climate. The accelerated climate change we are experiencing today will have a profound impact on all parts of the earth's ecosystems.

Water in its various forms (solid, liquid, vapour), is always on the move in the hydrologic cycle. Higher average global temperatures and more extreme, less predictable, weather conditions caused by climate change, are already having a measurable impact on this cycle, altering the amount, distribution, timing, and quality of available water. It is predicted these changes will also impact water quality. These changes will have wide-ranging consequences for human societies and ecosystems.

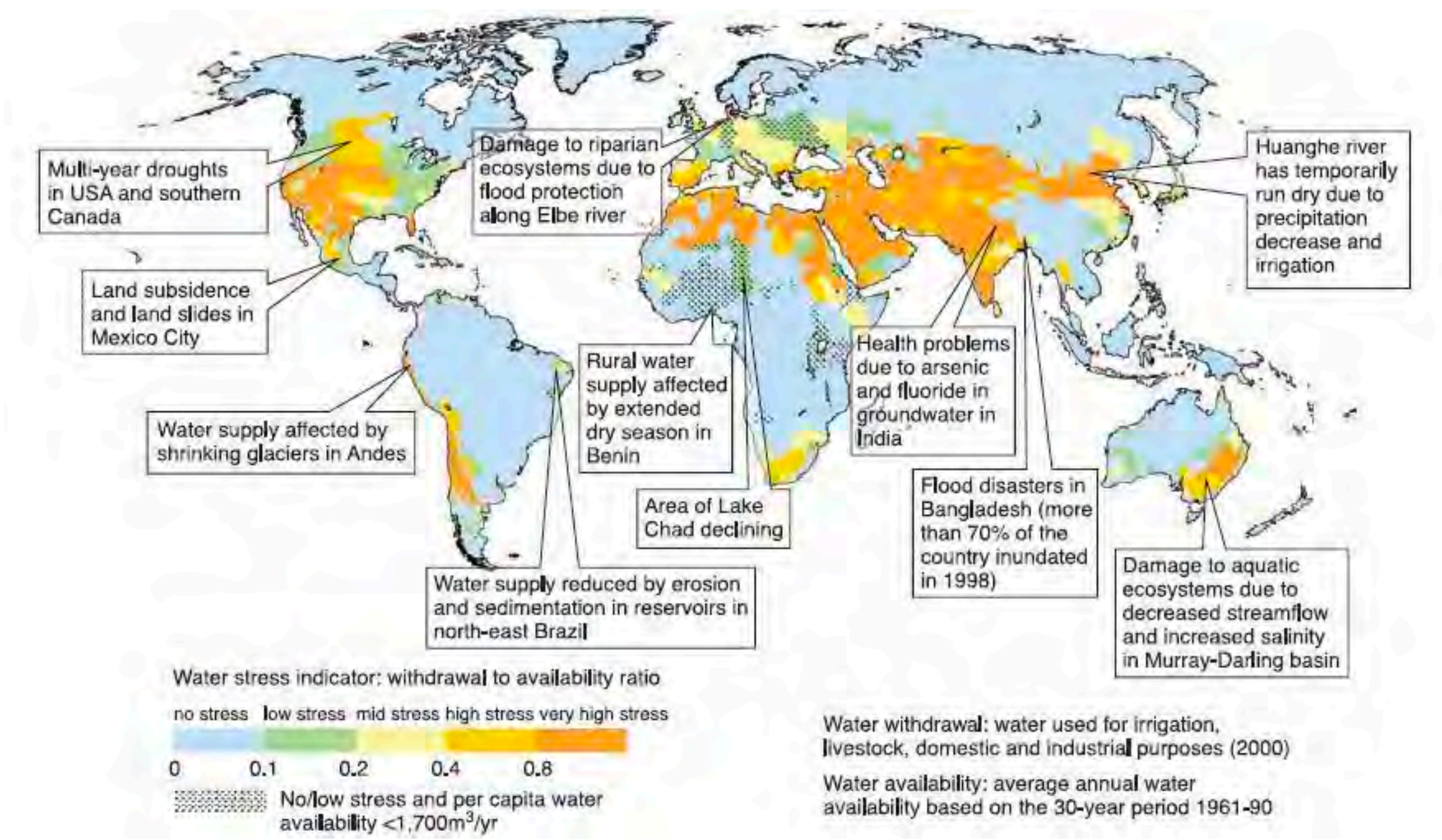
Observed warming over the last several decades have been linked to alterations in the hydrological cycle.

- Increased water vapour in the atmosphere
- Changing precipitation patterns, intensity, and extremes
- Reduced snow cover and melting of ice
- Changes in soil moisture and runoff

Other predictions include:

- Increased precipitation at higher latitudes and parts of the tropics and decreased in other areas
- Increased annual average river runoff and water availability in some areas (high latitudes and wet tropical areas) and decreased in others (mid-latitudes and dry tropics).
- Increased precipitation intensity and variability, leading to increased risk of flooding and drought in many areas

- Declines in glaciers and snow cover, reducing water storage
- Reduction in overall water quality due to higher water temperatures and changes in extreme weather (storms, flooding, etc.)
- Changes in food availability, stability and access due to changes in water quality
- Function and operation of existing water infrastructure (hydropower, flood defences, drainage and irrigation systems) and water management practices will be negatively impacted

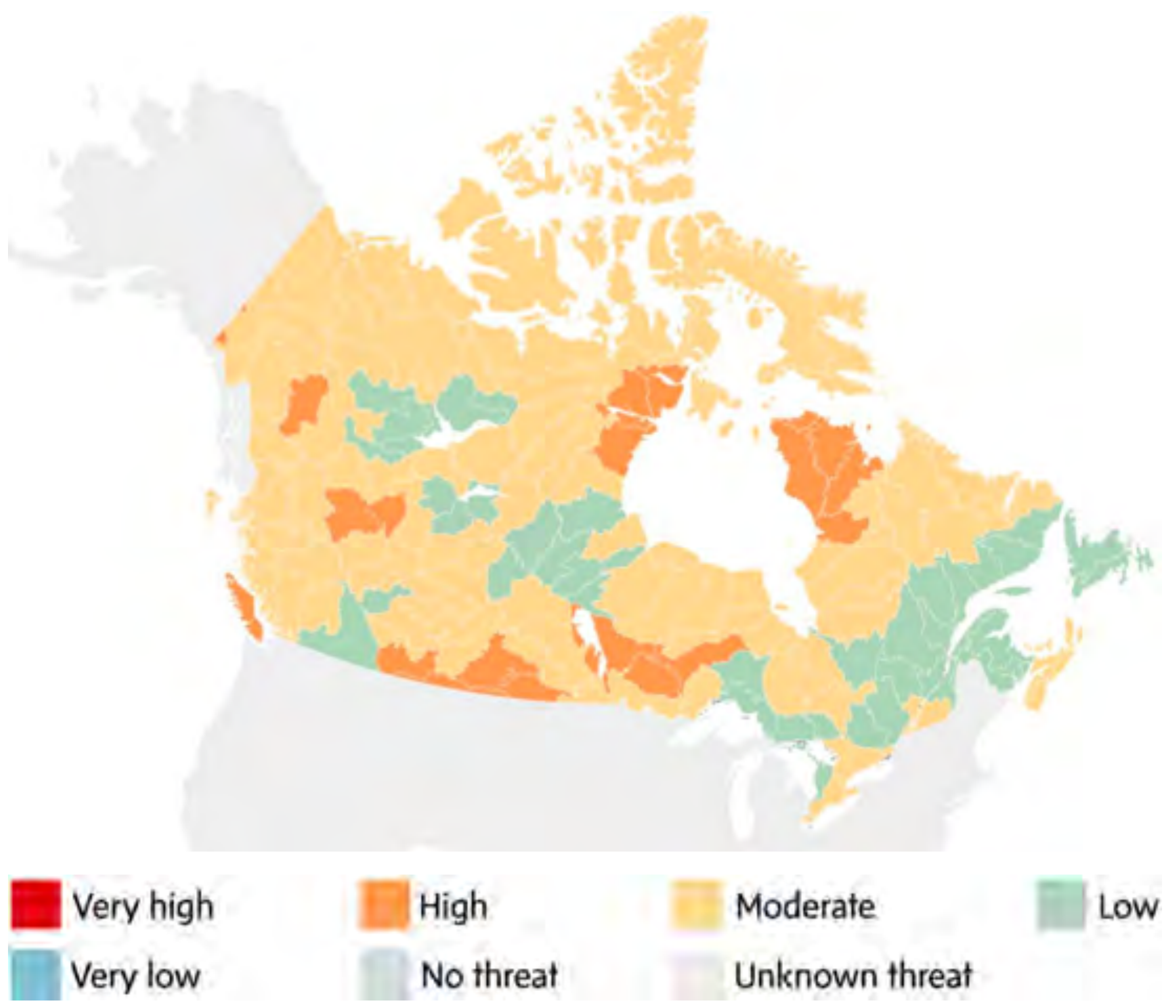


Worldwide water stress linked to climate change

Climate change adaptation options need to be designed to ensure safety and health of water supply during normal and drought conditions. **Mitigation** measures should be put in place to reduce the impacts of climate change on water resources. Finally, many gaps in knowledge exist on the consequences of climate change on our aquatic ecosystems. Further **research** needs to be conducted so that we can properly prepare and understand these changes.

CANADA'S TROUBLED WATERS: WATERSHEDS AND CLIMATE CHANGE

Although climate change currently represents a moderate risk to watersheds across most of Canada, it is likely to play a major role in future watershed health. Small shifts in temperature and precipitation can translate into profound effects on flow rates and the way ecosystems function. Climate change is also expected to become important as an amplifier of other threats. 21 sub-watersheds in Canada are already enduring high impacts from climate change, a further 105 sub-watersheds have been moderately impacted, and another 41 are experiencing some degree of impact from climate change.



Impacts of climate change on Canadian watersheds
© 2017 Trish McAlaster/The Globe and Mail/WWF Canada

OCEANS AND CLIMATE CHANGE

The world's oceans cover over 70% of the planet's surface. Although the water is salty and undrinkable, it is difficult to over-estimate the value of this vast mass of water. It helps regulate global climate and to ensure that a constant flow of vital nutrients is cycled throughout the biosphere. Climate change impacts in the world's ocean will have global effects. Marine and coastal ecosystems may collapse, creating a disastrous domino effect of extinction and loss. Marine animals, plants and invertebrates are not the only creatures in danger. **Humans have much to lose if the world's oceans falter under the added burden of climate change**.

Sea-level rise

Climate warming will lead to the thermal expansion of water and melting of glacial and polar ice, together causing a rise in sea level. Rising oceans would permanently flood highly populated coastal cities all over the world and submerge the atoll nations of the Pacific and Indian Oceans. Precious marine wetland habitats such as mangrove forests and coastal wetlands would be lost to the rising waters.

Disease and toxic algal blooms

In waters already choked with algae fertilized by nutrient pollutants, warmth only encourages algal growth. Algae can be a reservoir and amplifier of dangerous diseases such as cholera, a serious threat for countries with poor water and sanitation. Off the East Coast of Canada, the deaths of humpback whales and dolphins have been attributed to algae blooms and viruses. Some algal blooms, such as red tides and some cyanobacteria (e.g., Microcystis), are also toxic to humans.

Storms, erosion and sediment

An increase in the number and severity of storms and storm surges would have serious consequences for coastal habitats, as well as fishery and aquaculture industries. Increased sea levels and storms would interact to erode beaches, damage coral reefs, and overwhelm coastal wetlands and settlements. Higher storm surges would also pull more sediments and pollutants into the water, increasing the turbidity and likelihood of algal blooms.

Ocean circulation

Winds are created by the unequal warming of the earth's surface. Many climate change scenarios predict that polar regions will experience higher temperatures, reducing the thermal gradient between the poles and the equator. Major ocean surface currents generated by the drag of strong wind on water would weaken or even change. Patterns of vertical water movement would also be altered, devastating marine life that depend on the upwelling of nutrient-rich waters and the downwelling of oxygen-rich waters. Since the 1950's, zooplankton in the California current have decreased by 70% as the sea surface has warmed. This may explain the mass starvations of seabirds such as sooty shearwaters and Cassin's auklets in recent years.

Marine life in jeopardy

The world's oceans support a dazzling array of life forms, from massive marine mammals to microscopic crustaceans. Climate change is already disrupting marine food webs. In the Antarctic, penguins are starving for lack of krill, tropical coral reefs are bleaching and breaking, Pacific salmon are moving north, and polar bears in Manitoba cannot gain enough weight to raise their cubs.

CLIMATE CHANGE IN MANITOBA

In Manitoba, we are expecting a variety of climate change related impacts on our water systems:

- Manitoba will likely experience more flooding in winter. Warmer temperatures will increase rain-to-snow precipitation and the frequency of winter thaws.
- Spring flooding is also predicted to increase
- Summer river flows are expected to decrease as a result of the declining water supply from snowmelt
- Water quality will be reduced as more sediment is released into water ways through shoreline and overland erosion
- Water temperature increases will impact fish spawning, allow the introduction of invasive species and intensify algal blooms

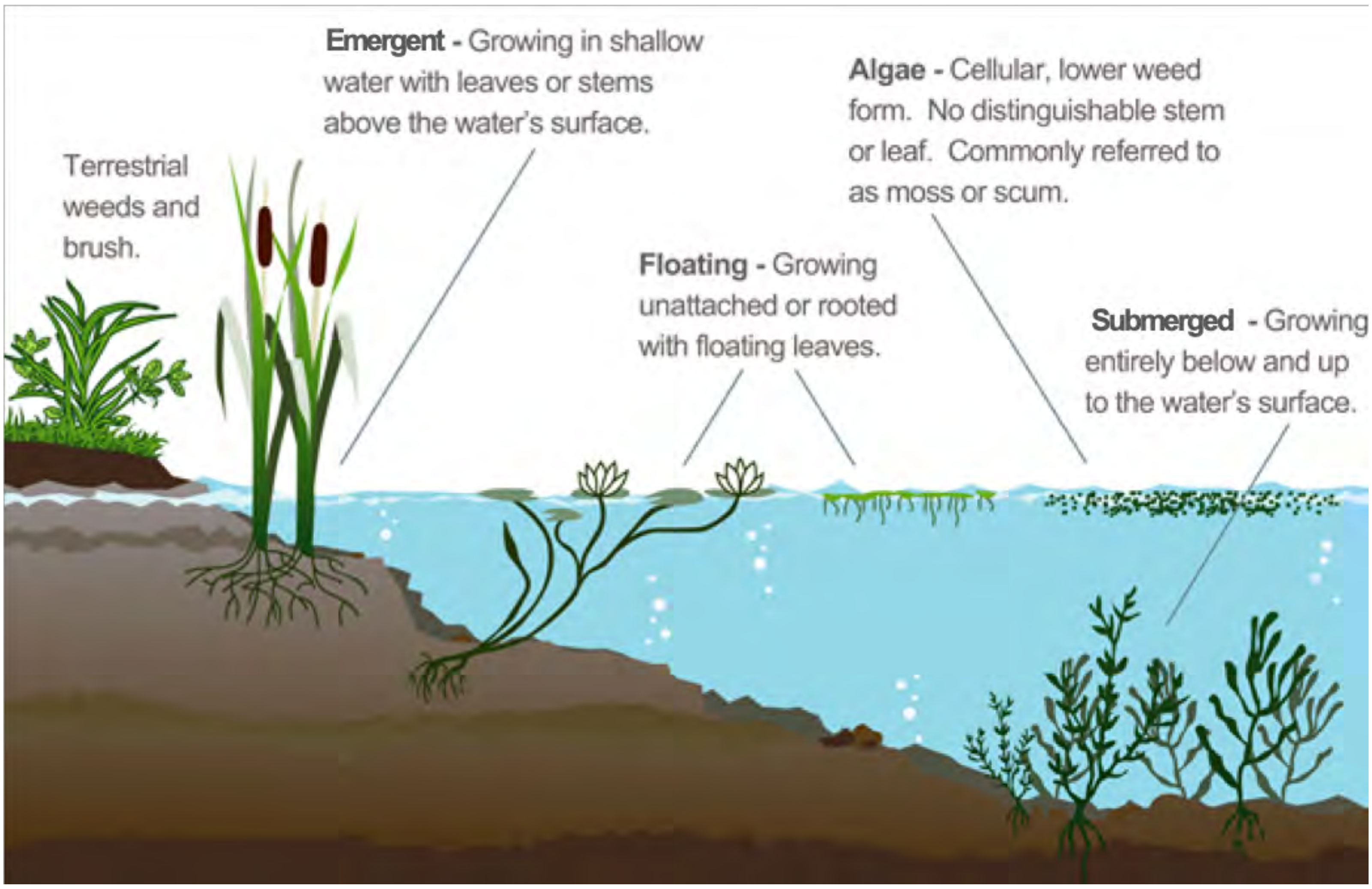
AQUATIC PLANTS

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 in the province.

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.



Types of aquatic plants

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.

ALGAE

Algae are primitive plants which bear no true leaves, stems or root systems. Most algae are microscopic, though some types are gregarious, clumping together to become visible to the naked eye. Other forms may be individually large enough to be seen easily. Reproduction in algae is by means of spores, cell division or fragmentation

Three groups of algae will be highlighted in this section:

1. Filamentous algae
2. Planktonic algae
3. Macrophytic algae

Filamentous algae

Filamentous algae are characterized by long threads or filaments of narrow cells attached to one another, end to end. These filaments are sometimes branched, forming a tuft attached to stones (they have no structure comparable to a root). In early spring they grow on the pond bottom rising to the surface during hot, sunny weather to form a bubble-filled scum. Common genera of filamentous algae include *Cladophra* and *Spirogyra*.

Planktonic algae

Planktonic algae are single- or multi-cellular microscopic organisms, and commonly form simple chains or clumps due to their gregarious nature. They appear green, blue-green or brown in colour and float freely within the water column. "Algal blooms" collect at the surface of the water during periods of calm and are concentrated in-shore by wind. As these blooms die off and decay, the resulting oxygen depletion of the water may kill fish populations. Some species of planktonic algae release toxins as they decay, occasionally rendering the water poisonous to livestock and wildlife (e.g., *Microcystis*). Other species may impart tastes and odors to water, making it undesirable for consumption. Types of planktonic algae which may form "algae blooms" in ponds and lakes include *Aphanizomenon*, and *Anabaena*.

Macrophytic algae

Macrophytic algae can grow sufficiently large so that individual plants may be seen readily without the aid of a microscope. *Chara* will be found in hard water or alkaline lakes and in slow moving steams in which calcium is abundant. Thick mats of *Chara* may be encountered covering the bottom in shallow or very deep water. *Chara* provides a habitat for a wide variety of aquatic animals which act as food for fish and is often mistaken for a plant because it has stem and leaf-like structures.

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.

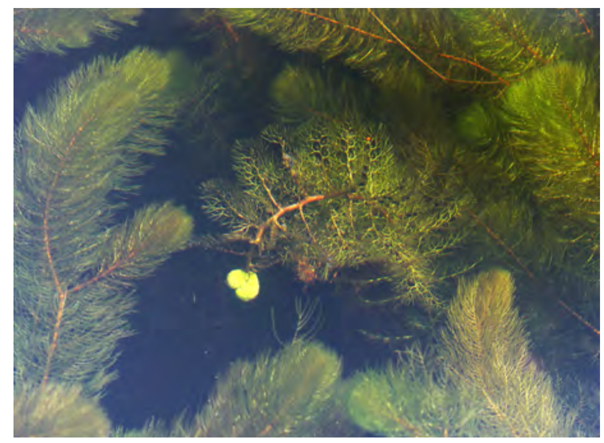
Common bladderwort (*Utricularia vulgaris L.*)
Has numerous leaves and yellow flowers. Is food for waterfowl, provides cover for fish, and consumes small aquatic animals using its bladders. Is found in lakes, sloughs, and ditches, floating near the surface in quiet water.

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.

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.

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.

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.

Coontail

Canada waterweed
© 2018 Michael Millane

Common cattail

Giant Bulrush
© Illinois Wildflowers

AQUATIC INVASIVE SPECIES

© Environmental Defence Canada

WHAT ARE INVASIVE SPECIES?

An invasive species is an exotic (originating from another region of the world) species whose introduction causes or is likely to cause economic harm, environmental harm, and/or harm to native species (including human) health. Species include plants, seeds, eggs, spores, other propagules, and animals (e.g., mammals, reptiles, amphibians, fish, insects and other invertebrates). Often human actions have permitted the species to cross a natural or artificial barrier to dispersal (e.g., mountains, oceans, highways, urban development, etc.). **Although all invasive species are non-native, not all non- native species are invasive**. Non-native species are only considered invasive if they have harmful ecological, environmental, or economic affects. All ecosystems are at risk from the harmful effects of invasive species. The adverse effects of invasive species vary widely, from the extirpation or extinction of native species to long-term effects on ecosystem function.

Invasive species can threaten an area's biodiversity by overwhelming native species, damaging habitat, disrupting food sources, and introducing parasites and disease. Most invasive species have little to no population control mechanisms in place and often increase in numbers rapidly. Once invasive species are established they can be difficult, or impossible, to control and remove. **Invasive species are often also referred to as aliens, exotics, non-native, or nonindigenous species**.

Invasive species characteristics

Extensive research has demonstrated that invasive species often have characteristics that allow them to outcompete native species. In nature, success is measured by how well you survive and reproduce. Many new non-native species will fail and die, others may have inconspicuous effects, while others will have large negative consequences and therefore become invasive. Invasive species share characteristics that make them successful in their new regions:

- *Few natural enemies* - invasive species do not have any natural enemies (e.g., predators, competitors, parasites, and pathogens) in the area they invade.
- *High reproductive rates* - Invasive species have rapid growth, very short life cycles, prolific young production, and seed/egg dormancy (in plants and invertebrates).
- *High survival* - Invasive species can tolerate a wide range of environmental conditions.
- *Good dispersal* - invasive species can effectively distribute themselves into new environments.
- *Aggressive competitors* - Most invasive species are superior competitors to native species.

A combination of these characteristics allows invasive species to outcompete native species in a region and become established.

ECONOMIC, SOCIAL, AND ENVIRONMENTAL IMPACTS OF INVASIVE SPECIES

Invasive species tend to crowd out and replace native species. They can severely damage ecosystem health and harm human activities, such as agriculture, forestry, fisheries, and recreation.

Economic

Invasive species can have large impacts on the economy, both positive and negative. Government and private landowners may incur significant cost to repair damage done by invasive species. Funds are also spent on monitoring and educational programs.

Social

Invasive species can have negative effects on societies. Invasive species can bring novel pathogens with them, leading to the introduction of disease, they have the potential to increase human health impacts including allergies and irritations, and may reduce recreational and tourism opportunities.

Environmental

Invasive species are a major threat to our environment because they can:

- Threaten biodiversity
- Introduce pathogens
- Increase predation and competition
- Hybridization
- Change community structure
- Change habitats, fire regimes, and alter ecosystem function and services

Biodiversity and community structure

Invasive species are the second most important threat to global biodiversity, next to climate change. It has been estimated that almost half of the species in North America that are at risk of extinction are endangered because of the effects of invasive species. Invasive species can spread pathogens (causing disease), act as new predators, parasites, or competitors, alter habitat, and/or hybridize with local species.

Pathogens and Parasites

Invasive species often bring novel parasites with them (i.e., additional invasive species) when they move into a region. The introduction of new parasite species to a region can have many of the same effects as free-living invasive species. Their presence may enhance, inhibit, or have no effect on the invasion of a free-living species.

Predation and Competition

Invasive species that are predators can severely reduce the population sizes of native species, sometimes even to **extirpation** (extinction from an area) or **extinction** (no individuals left). Native prey species have not evolved defenses against these new predators. Zebra mussels (*Dreissena polymorpha*) were accidentally brought to North America from Russia in the ballast of ships. Zebra mussels change aquatic habitats by filtering large amounts of water and reducing densities of planktonic organisms.

Hybridization

Hybridization occurs when two different species mate with each other and produce viable offspring. If the invasive species is more abundant than the native species, this hybridization may lead to a slow disappearance of the native species genes, and eventually lead to the extinction of the native species.

Alter habitat and ecosystem functions

Invasive species, particularly plant invaders, can alter the fire regime, nutrient cycling, hydrology, and energy in native ecosystems. They can greatly diminish the abundance or survival of native species and even block navigation or enhance flooding.

Purple loosestrife (*Lythrum salicaria*)

Purple loosestrife is native to Eurasia. It was likely introduced to North America in the early 1800's for ornamental purposes (a common path of introduction for invasive plants). It is a perennial found mostly in wet areas such as riparian zones, wetlands, and diches. Purple loosestrife impacts can be severe, reducing the quality of wetland habitat, reducing biodiversity of wetlands, and clogging irrigation systems. The plant forms dense stands with thick mats of roots that can spread over large areas, degrading habitat for many native birds, insects and other species.

Purple loosestrife
© 2012 Ontario's Invading Species Awareness Program

Phragmites australis

Phragmites grasses are native to Eurasia. The invasive form, *P. australis* was accidentally introduced to North America in the 1700s. Grass stems quickly form thick stands and out-compete native plants, which alters wildlife habitat, alters nutrient cycling, and impacts hydrology. It releases toxins from its roots into the soil to hinder the growth of and kill surrounding plants. Finally, it increases fire hazards as stands are composed of a high percentage of dead stalks. The invasive grass can be differentiated from native *Phragmites* in fall by looking at seed heads.

Phragmites
© Plants and animals of northeast Colorado

Curly-leaf Pondweed (*Potamogeton crispus*)

Curly-leaf pondweed, a perennial freshwater plant, is native to Eurasia and was introduced to North America in the mid-1800s. Dense beds of curly-leaf pondweed can out-compete native aquatic plants and depletes water oxygen levels, impacting the entire community. Curly-leaf pondweed is a popular plant in the aquarium industry.

Curly-leaf pondweed

Spiny waterflea (*Bythotrephes longimanus*)

Spiny waterfleas are very small invertebrates (zooplankton) with long, barbed spines. They reproduce rapidly and have few predators (fish have trouble swallowing their long spine). They can deteriorate aquatic ecosystems by aggressively consuming other zooplankton (e.g., *Daphnia*) the main food source for many small fish. *Bythotrephes* produce resting eggs that are resistant to drying and freezing, meaning that they can lay dormant for long periods of time and survive periods of non-optimal conditions. *Bythotrephes* are also a nuisance to humans because they get caught on fishing nets, fishing lines, ropes, downrigger cables and even clothing.

Spiny Waterflea
© Andrea Miehls/Government of Manitoba

Rusty crayfish (*Orconectes rusticus*)

Rusty crayfish are large, aggressive crayfish native to the Ohio River Basin in the USA. They are commonly found in lakes, rivers, ponds and streams. They eat large amounts of aquatic vegetation and their aggressive nature helps protect them from being eaten by native fish. Females can carry up to 200 fertilized eggs, enabling a single female introduced to a new area to start a new population. Once rusty crayfish are established, there is currently no practical way to permanently remove them. The rusty crayfish's large size, aggressive eating habits and rapid spread have had serious impacts on native species. They compete with native crayfish for food and resources, often causing the decline or disappearance of native crayfish. They are also better able to avoid being eaten by fish than native crayfish. Finally, by eating large quantities of aquatic vegetation, they reduce spawning and nursery habitat for native fish.

Rusty Crayfish
© Doug Watkinson/Ontario's Invading Species Awareness Program

Zebra mussels (*Dreissena polymorpha*)

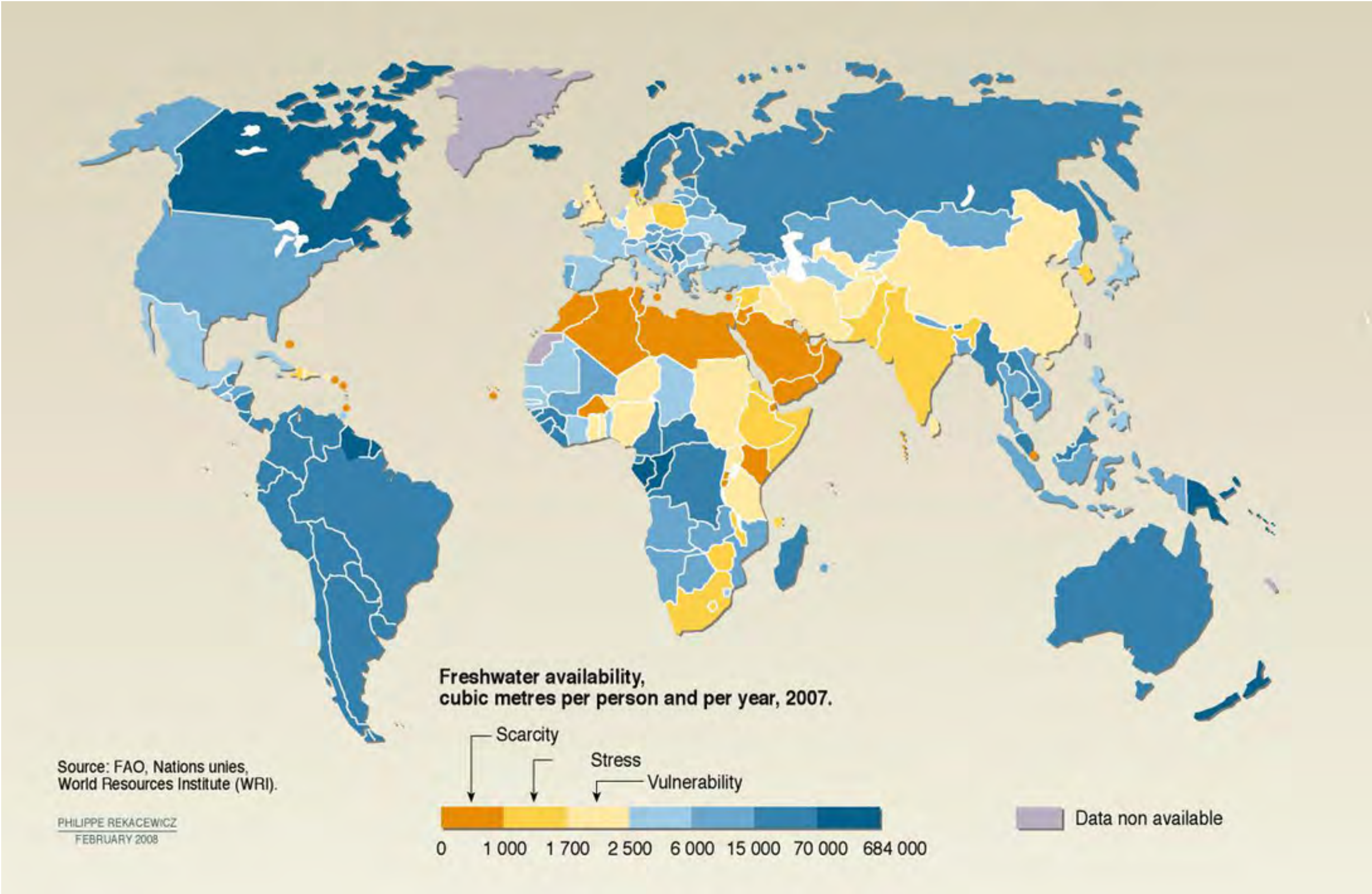
Zebra mussels are freshwater bivalves native to the Black Sea region of Eurasia, believed to have been introduced to North America in the late 1980's in ballast water from transoceanic ships. Zebra mussels heavily colonize hard and soft surfaces, including, docks, boats, break walls and beaches, altering the physical structure of the water body indefinitely. Zebra mussels filter water to the point where food sources such as plankton are removed, and the cascading effects of this filtration greatly alters the water body and its food web. Clearer water resulting from filtration allows sunlight to penetrate deeper and increases growth of aquatic vegetation and algae, which in turn impacts fish and wildlife. The physical structure of zebra mussel beds limits availability of habitat (e.g., for spawning, feeding, shelter) for many other aquatic species. Zebra mussels were first discovered in Manitoba in 2013 in Lake Winnipeg and the Red River. Preventing further spread of zebra mussels in the province is essential for the future health of our aquatic ecosystems.

Zebra mussels

© Dave Britton/Ontario's Invading Species Awareness Program

WATER POLICY AND LEGISLATION

Water, especially freshwater, must be properly managed to ensure long-term health of aquatic ecosystems. Canada has about 7% of the world's renewable freshwater supply, compared with 18% in Brazil, 9% in China, and 8% in the United States.



Freshwater availability worldwide

HISTORICAL WATER POLICY AND LEGISLATION

In the 1800s Manitoba's water was governed by Federal Legislation. The Drainage Act passed in 1880 provided an organized approach to drainage management. In 1894, the Northwest Irrigation Act established the Crown's right to allocate water through a licensing process and was subsequently amended and re-titled The Land Drainage Act in 1895.

Water resource control was transferred to Manitoba in 1930, at which time the province enacted The Water Rights Act, giving the province the authority to license irrigation and other water uses. The drought in the early 1930s brought about the Prairie Farm Rehabilitation Act, providing funding to farmers, and later served to provide water management assistance under Federal jurisdiction. During this time, the province established the Land Drainage Arrangement Act (1935) to provide for drainage districts and later drainage management districts. Costs of drain maintenance fell to the Municipalities.

The next major change in water management occurred in 1959. The Water Rights Act was amended, making groundwater as well as surface water subject to the Act. The Watershed Conservation District Act was also enacted that year, allowing municipalities to request the establishment of conservation districts wherein they could assume control of various aspects of water management. In the 1960s, The Water Resources Administration Act abolished drainage districts, created provincial waterways, and provided a clearer distinction between municipal and provincial responsibilities. The Province assumed responsibility for part of the drainage systems and undertook reconstruction of existing works to ensure better crop protection. The most current water related legislation was drafted in 1987. At that time, The Water Rights Act was amended to provide provisions for licensing requirements and enforcement.

MANITOBA WATER POLICY

In the past, Manitobans (and government) took their water resources for granted. Water was viewed simply as an unlimited commodity, and the values of the fish and wildlife habitat were not considered. Water management was primarily reactionary to deal with short-term issues. Until recently, questions of water quality were almost completely ignored. During the 1980s there was a recognition of the importance of the environment and so government shifted thinking towards longer term thinking in order to understand future benefits and impacts of water resources.

The Manitoba government is now attempting to work towards a more holistic and integrated water strategy. They believe that they need to become true stewards of this resources and consider the important components within a watershed. The goal of Manitoba's current water strategy is to develop watershed-based planning throughout the province. They hope a sustainable approach will ensure that all needs are met while maintaining ecosystem protection. The government of Manitoba has three elements to this framework: new legislation, improved financial foundations, and management on a watershed basis.

Objectives of Manitoba's water policy

1. *Water quality* - Protect and enhance aquatic ecosystems to ensure both groundwater and surface water are available for all uses and ecosystem needs.

2. *Conservation* - Conserve and manage wetlands, rivers, and lakes in Manitoba. Protect the ability of the environment to sustain life and provide economic, environmental, and aesthetic benefits.

3. *Use and allocation* - Ensure long-term sustainability of surface- and groundwater.

4. *Water supply* - Develop and manage water resources to ensure water is available for priority needs and to support sustainable economic development and environmental quality

5. *Flooding* - Minimize economic costs and human suffering caused by flooding.

6. *Drainage* - Enhance economic viability of the agricultural community through provision of well-planned drainage infrastructure.

7. *Education* - Increase awareness and knowledge of Manitoba's water resources, and how to protect them.

WETLAND PROTECTION IN MANITOBA

Many wetlands in southern Manitoba have been drained or filled in to accommodate agricultural activities. Our remaining wetlands need to be protected through conservation programs. Wetland conservation encompasses the protection, enhancement, and use of wetland resources according to principles that will ensure long-term social, economic, and ecological benefits. It is recognized that some wetlands should be protected and managed in their natural state, some actively managed to allow sustained, appropriate use of wetland renewable resources, and some developed for their non-renewable resource values.

A significant program aimed at protecting our remaining wetlands is the North American Waterfowl Management Plan (NAWMP). In 1986, the governments of Canada and the United States signed the plan in reaction to the sharp decline in waterfowl populations associated with the destruction of their habitat. They were joined by Mexico in 1993. The plan itself outlines the scope of the work to be done on a continental basis and provides broad guidelines for habitat protection and management actions. Many partners (from federal and provincial or state governments to nongovernmental organizations and landowners) representing various interests work in partnership to achieve the NAWMP's goal to restore, protect, and enhance wetland habitat for the benefit of waterfowl, biodiversity, and humans.

MANITOBA'S TRANSBOUNDARY WATER PROJECTS

Transboundary waters are sources of water that are shared between various users (e.g., provinces, countries, municipalities). Many users have competing, and/or different needs associated with this water. For example, the Hudson Bay drainage basin (watershed) covers large parts of Manitoba, Alberta, Saskatchewan, and parts of the northern United States. All water from this basin ends up in Manitoba, so the treatment and use of water outside our borders is of importance to all Manitobans (Government of Manitoba, n.d.-b).

There are several types of negative impacts that water flowing into Manitoba from other provinces/states may be subject to, including:

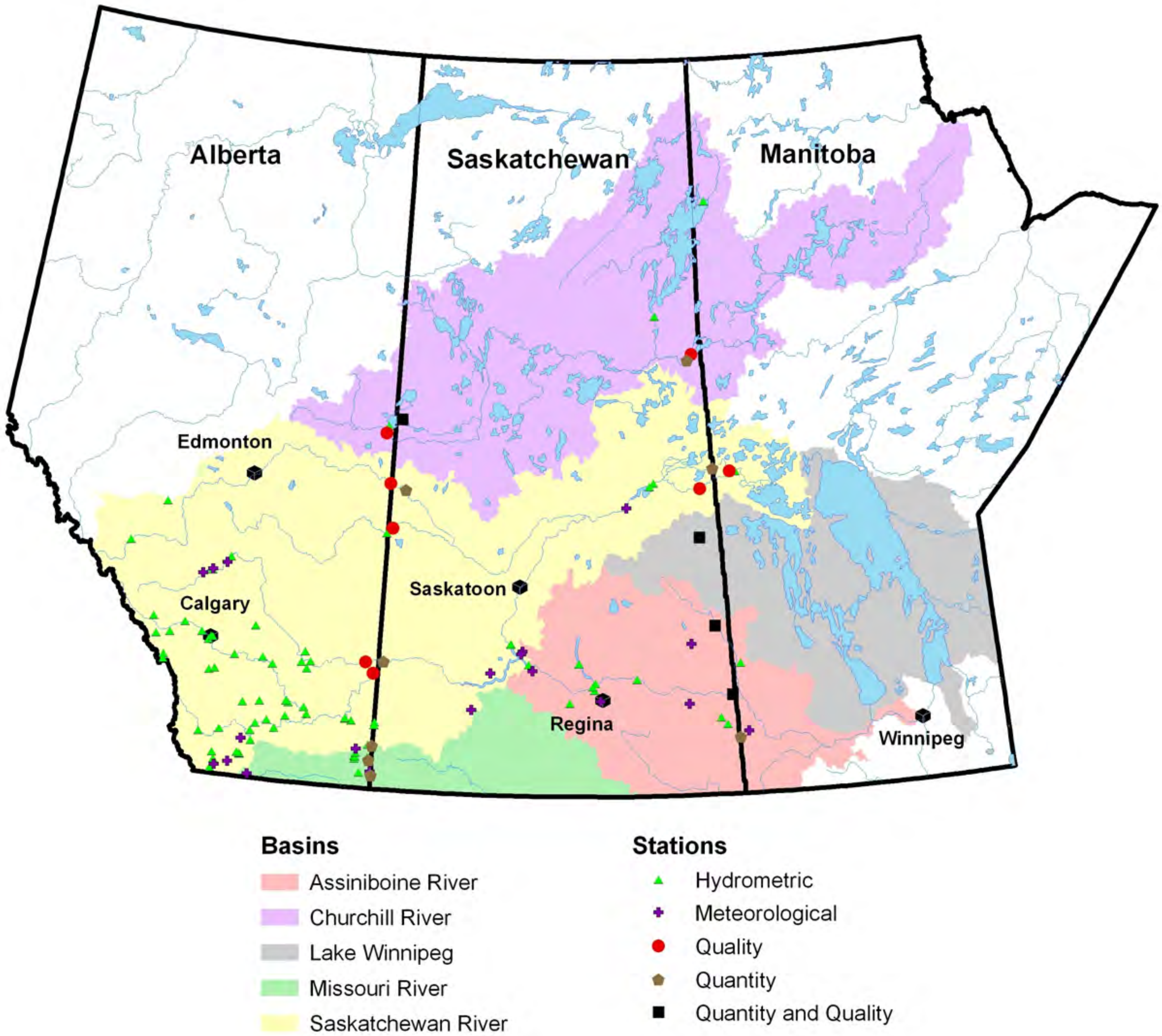
1. **Transfer of biota, including invasive species**. Biota transfer has become a major concern throughout North America, in part due to the major economic and environmental impacts associated with invasive species. In Canada, many jurisdictions (including Manitoba) have developed policies or legislation that oppose inter-basin water transfers because of potential for severe environmental damage.

2. **Degradation of water quality**. Increases in dissolved salts, suspended sediments, nutrients, trace elements, and pesticides is of concern.

3. **Water use and allocation**. Manitoba will be impacted if neighbouring provinces/states overuse/underuse water. Removal of too little water from neighbouring jurisdictions can lead to flooding increases, whereas the removal of too much water can lead to drought periods.

Prairie Provinces Water Board

In 1948 the provinces of Alberta, Saskatchewan, Manitoba, and the government of Canada created the Prairie Province Water Board to ensure water resources are shared fairly. The four governments signed a Master Agreement on Apportionment (MAA) in 1969, establishing an intergovernmental framework on how to manage transboundary waters. The purpose of the MAA is to apportion or share water equitably between the Prairie Provinces and to protect transboundary surface water quality and groundwater aquifers.



Prairie Provinces Water Board Management Map
© 2019 PPWB

INTERNATIONAL SHARED WATERS

Canada and the United States share many waterways, from the Great Lakes, which are among the world's largest bodies of freshwater, to oceans, to rivers that mark or cross the border between the two countries. Most of the Canadian population lives in these transboundary basins, with much of the economy directly dependent on the industrial, agricultural, transportation, and recreational benefits of these water resources. Decisions about these water basins made by one country strongly impact the other country. As such, Canada is the signatory to several treaties and agreements with the United States dealing with waters that flow along or across this boundary. These include the Boundary Waters Treaty (1909), Lake of the Woods Convention and Protocol (1925), St. Lawrence Seaway Project (1952), and the Great Lakes Water Quality Agreement (1972, amended 1978, 1987, 2012).

International Joint Commission

Boundary Waters Treaty (1909) set the basic principles guiding boundary water relations between Canada and the United States, to be overseen by the International Joint Commission (IJC). This independent commission works to anticipate, prevent, and resolve disputes between the two countries in an impartial manner. The IJC provides a mechanism for coordination and cooperation in managing shared waterways and investigating environmental issues of mutual interest. The recommendations and decisions by the IJC try to consider the needs of a wide range of water uses. The commission has three main responsibilities:

- **Regulating shared water uses** – make decisions on project applications, such as dams and diversions, that can impact the natural level and flow of water across the boundary.
- **Improving water quality** - investigating, monitoring, and recommending actions regarding the quality of water in lakes and rivers along the border.
- **Improving air quality** – investigating air pollution problems in boundary regions.

The IJC carries out its responsibilities by:

- Issuing 'Orders of Approval' in response to applications for use, obstruction, or diversion of boundary waters
- Establishing boards for managing levels and flows of boundary and transboundary waters or for monitoring and assessing water quality in these waters
- Carrying out investigations at the request of Canada and the United States to better understand an issue and to make recommendations to governments

While IJC reference recommendations are not binding, they are usually accepted by both the Canadian and United States governments.

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.

RESTORING THE HEALTH OF AN AQUATIC ECOSYSTEM

Can we restore the health of an aquatic ecosystem? Perhaps, but it takes time and is dependent on the nature of the disturbance. The effects of dredging, for example, may last from one to several years, but many of the displaced organisms such as fish can re-establish themselves. In other cases, more severe disturbances (e.g., dam construction) may cause local extinction of already endangered species. These ecosystems are unlikely to recover naturally.

AQUATIC SAMPLING TECHNIQUES

Water sampling in the Antarctica

© Gordon Picken/Cool Antarctica

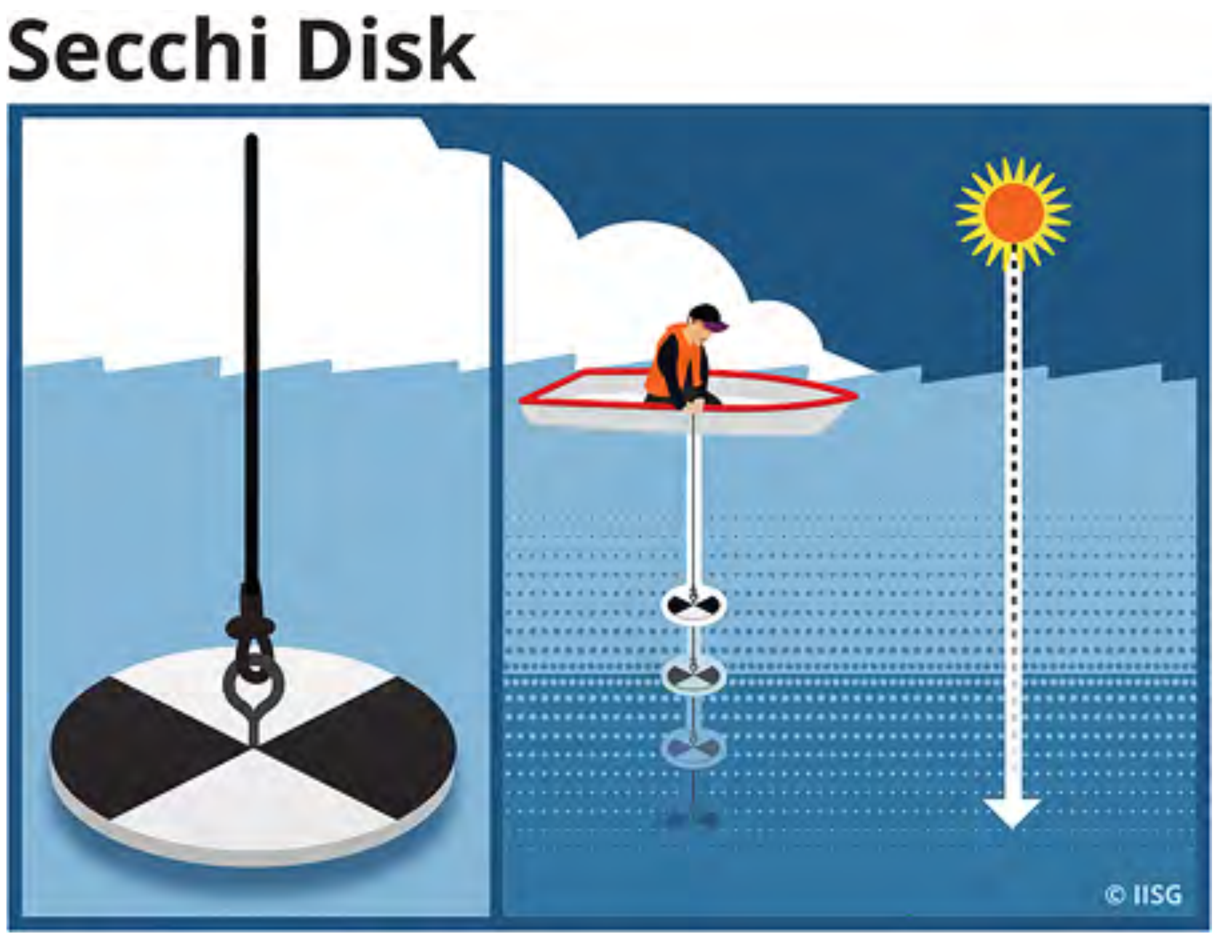
In order to better understand aquatic ecosystems, scientists have developed specialized techniques and equipment to assist in sampling the different ecosystem components. You may be asked to use some of these pieces of equipment on an Envirothon test! Demonstrations of many of these sampling techniques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



Secchi Disk
© Limno Loan, IISG

energize photosynthesis in algae and other aquatic plants. By measuring depth of PAR, a 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.

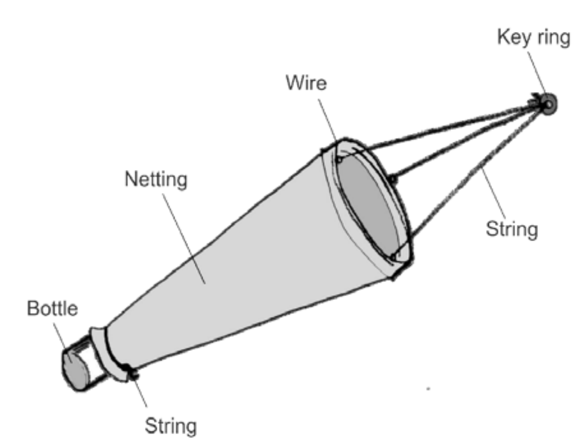
The **filtrate in the flask** will contain dissolved substances, including forms of carbon, nitrogen, and phosphorus that can promote algal growth. It may be coloured but should not contain visible particles. The filtrate may also contain pharmaceuticals and other manufactured chemicals as contaminants, 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, capturing a cube of water from that depth. After



Zooplankton Tow Net

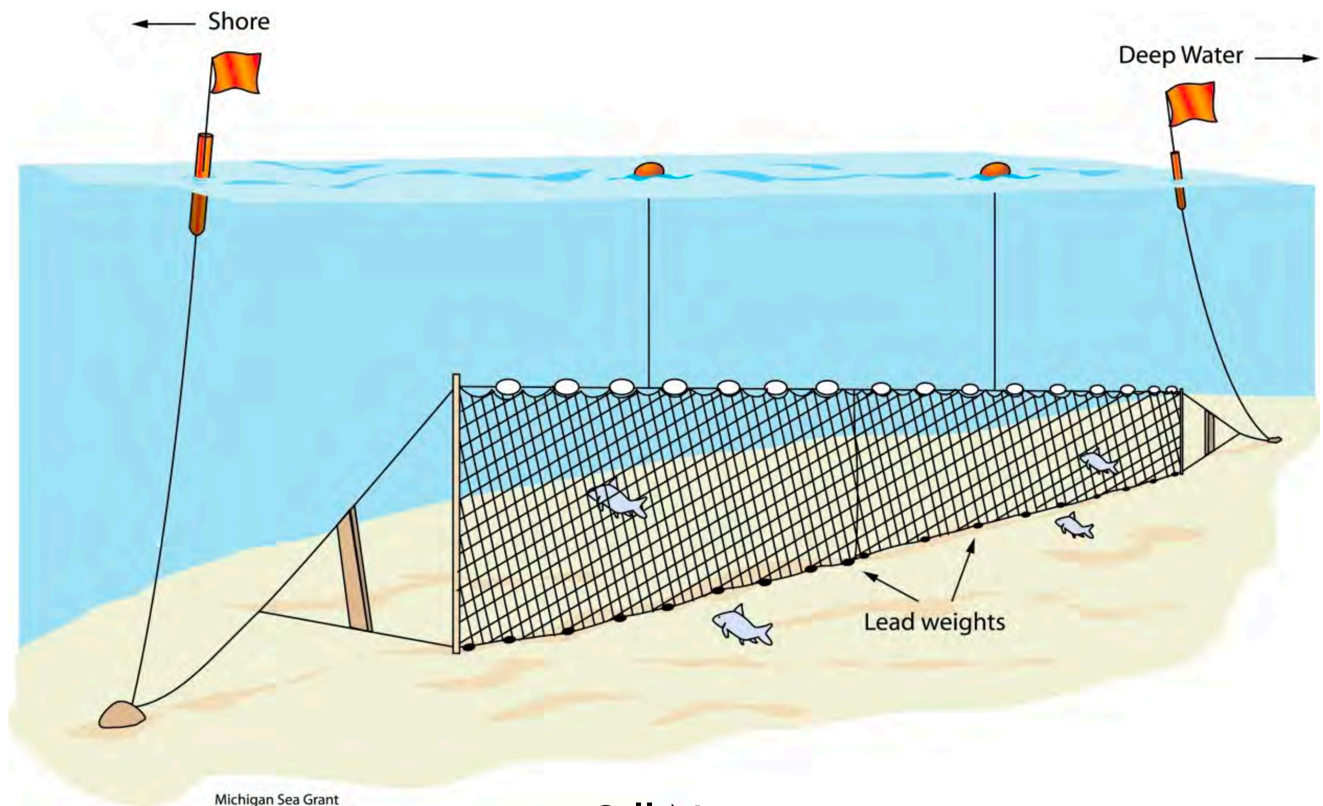
being pulled to the surface, the contents of the sampler is filtered through a mesh funnel before being placed in a bottle and preserved.

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.

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.

Schindler-Patalas trap

Ekman dredge

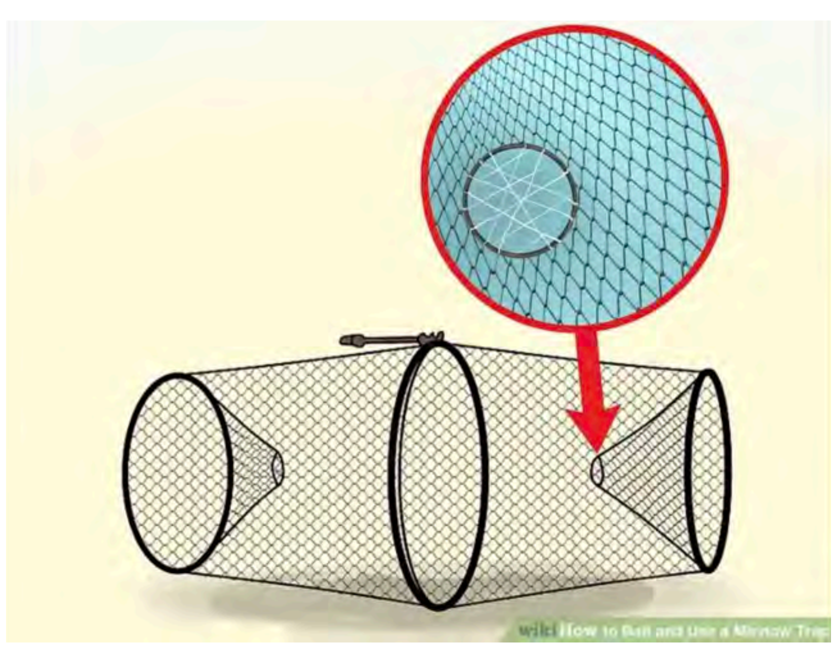


Gill Net

© Michigan Sea Grant

Seine Net

© IISD Experimental Lakes Area

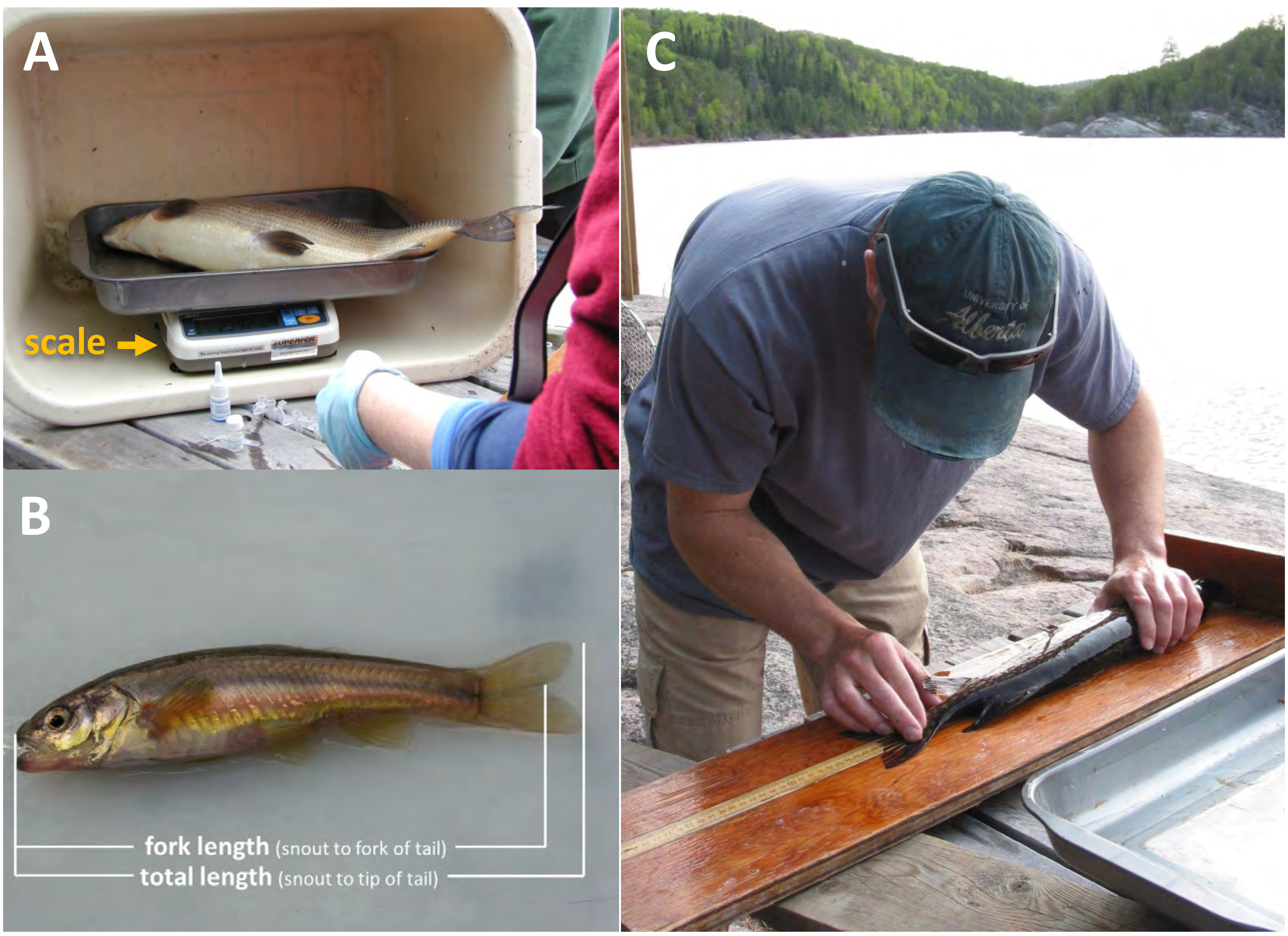


Minnow Trap

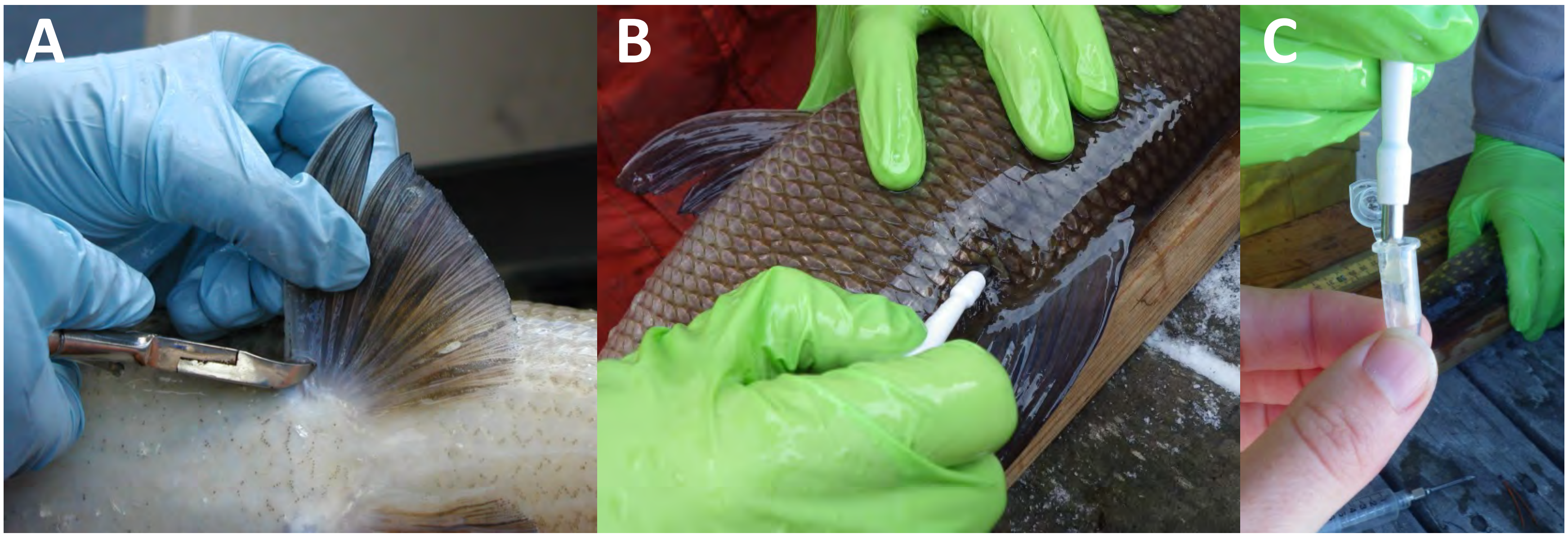
© WikiHow

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.
C: The muscle biopsy sample is preserved in a vial.

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

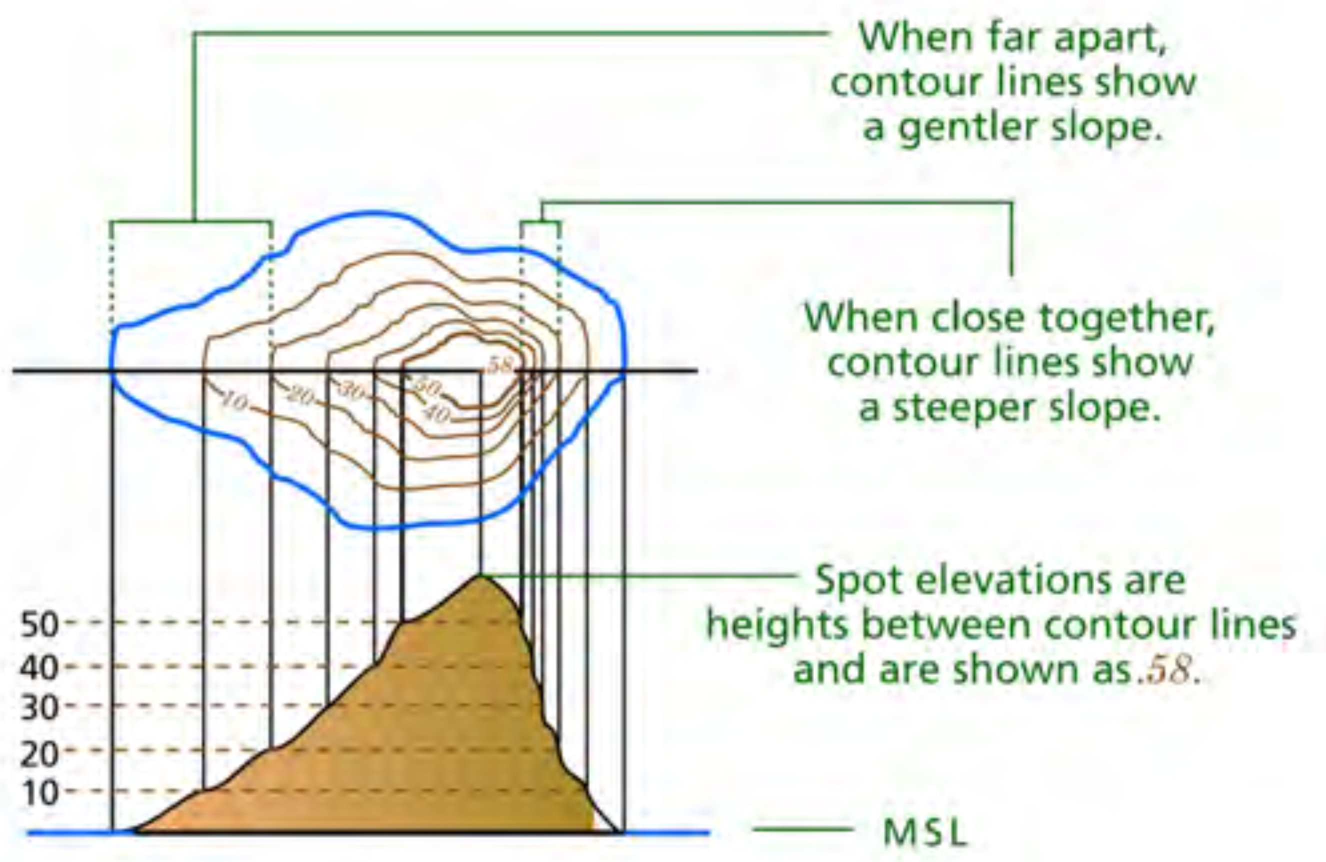
TOPOGRAPHIC AND BATHYMETRIC MAPS

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

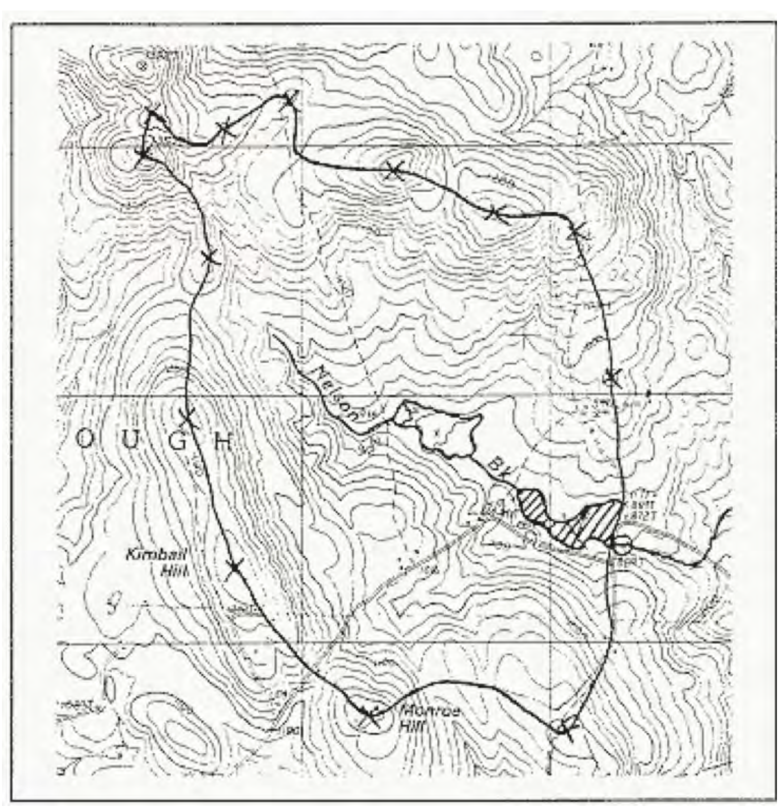
HOW ARE TOPOGRAPHIC AND BATHYMETRIC MAPS GENERATED?

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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