Aquatic Ecology Document

2010

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1. Learning Outcomes

Teachers! *These are the Manitoba Curriculum Connections:*	***Reference Code***	***Students!*** *These are the Envirothon Learning Outcomes. These are "testable"!* **Students should be able to:**
Gr. 8 Science 8-4-03	A1	Describe the chemical and physical properties of water and explain their implications for freshwater and saltwater ecosystems.
Gr. 8 Science 8-4-06	A2	Identify the processes and phases for each part of the water cycle
S2 -1-01	A3	Define and illustrate relevant cycles such as nitrogen, oxygen and phosphorous.
Gr. Science 8-4-06	A4	Explain the different types of aquifers and how each type relates to water quality and quantity.
8-4-07	A5	Know how to delineate the watershed boundary for a specific water body.
S4 – 2.1.4	A6	Identify common aquatic organisms and plants through the use of keys and the role they play in the ecosystem.
No correlation to outcomes	A7	Understand fish anatomy and structures.
S4 – 2.1.4	A8	Identify different species of fish.
S2 – 1-08	A9	Identify the general and specific habitats of species covered.
S2 – 1-07	A10	Identify species and areas that are either endangered or at risk, and the factors contributing to their status.
S2 – 1-07	A11	Identify, with examples, what effects the introduction of new species may have upon a habitat, community, or ecosystem (e.g. zebra mussels, rainbow smelt, etc.)
S2-1-03	A12	Describe the flow of energy within aquatic food chains and webs.
Gr. 8 – 4-01	A13	Briefly describe the benefits of wetlands, including both function and value.
Gr.8 – 4-01	A14	Describe the benefits of riparian areas, including both the function and value.
S4 – 3.5.1 Gr.8 – 4-17	A15	Analyze the management and interaction of competing uses, and the ways industry, hydropower, irrigation, transportation, navigation, waste, recreation/sport, wildlife, fisheries, stocking and other factors affect our water.
S4 – 3.5.1 Gr. 8 – 4-18	A16	Know methods used to assess and manage aquatic environments and be able to use water quality information to determine the general water quality of a specific body of water. This includes sampling, technique, and water quality parameters used to monitor and assess aquatic ecosystems as well as point and non-point source pollution.
S4 – 3.5.1	A17	Be familiar with major methods and laws used to protect water quality (e.g. both surface and ground water) and use this information to make management decisions to improve and protect the quality of water in a given situation. Discuss methods of conserving water.
S4 – 3.5.2	A18	Show an understanding of the importance of sustainable development and biodiversity.
no correlation to outcomes	A19	Understand how climate change affects aquatic ecosystems.

2. List of Attached Documents

Reference Code	**Attached Documents**
A2, A3	Nutrient Cycles (Water, Carbon, Nitrogen, Phosphorus)
A4	Groundwater
A5	How to Read a Topographic Map and Delineate a Watershed
A6	Invertebrate Keys and Pollution Tolerance Charts
A6	Identifying Aquatic Plants
A7	Fish Anatomy
A8	Fish Identification Key and Glossary
A8	Identifying Orders of Fish
A8, A9	Fish Species
A9, A10	Fish Species at Risk in Manitoba
A11	Aquatic Invasive Species in Manitoba
A9, A13	Wetlands
A9, A14	How Much Habitat is Enough?
A14	Shorelines, Riparian Areas, Buffer Zones
A15	Water Use
A16	Water Quality
A16	Chemical Monitoring
A16	Non Point Source Pollution
A17	Water Policy and Legislation
A17	Water Conservation
A18	Sustaining Aquatic Ecosystems in Boreal Regions
A19	Climate Change and Aquatic Ecosystems

3. Water as Environment

Introduction

Most people take water for granted. It is as close as a faucet in the home or a nearby creek or canal. The casual observer comprehends very little about this vital ingredient of life. However, without water, nothing could continue to live. The properties and features of this amazing liquid play a significant role in where fish are located and how they relate to their habitat.

Scientists report that water is totally recycled many times. None of it leaves the atmosphere and even the water humans drink was used many times before. Even so, that does not mean that water is evenly distributed across the earth, nor does it indicate that there won't be floods in one area and drought in another.

Knowledge of water density and how it leads to stratification of lakes is important, as well as knowledge of the need for sound water management and the effects of pollution on an area rich in aquatic life. Water quality affects fish populations and individuals within the system. The condition of the water helps to determine the fish present and the available food sources.

The Nature of Water - Water covers 70 percent of the earth's surface with no substance being more common. Only three percent of the water is fresh, and about three-quarters of that is locked in glaciers and icecaps. In fact, these frozen regions contain as much fresh water right now as all of the earth's rivers will carry for the next 1,000 years.

The demand for clean water continues to mushroom as the earth's population increases and as industrial processes require more and more water. In the home alone, each person uses about 264 litres of water daily for basic needs. This figure does not even include water required to produce food or used in industrial and manufacturing sectors of the economy.

Climate in many parts of the world is controlled by the slow heating and cooling of water areas. During the winter months, oceans bring moderating temperatures to land masses while cooling breezes are produced in the summer. Recreationally, water lures countless people for swimming, boating, exploring the aquatic habitat and fishing.

Physical and Chemical Features – Two hydrogen atoms and one oxygen atom combine as a molecule to form water. Within a relatively sort temperature range, water can be a liquid, a solid or a gas. No other substance can accomplish that within the span of 100 degrees C. The molecules in ice are farther apart and practically motionless in comparison to the liquid state, where the molecules are much closer together and move about freely.

Surface tension is defined as the ability of a substance to stick to itself and pull itself together. Water has a very high surface tension that forms a film. Small organisms often live on top of this film or just underneath it. The tension can be so strong that if organisms break through in either direction, they cannot get back and will dry up or drown.

The ability of the liquid to climb against the pull of gravity is called “capillary”. This is an important property that helps water filter upward through roots and other objects.

Water can also dissolve other substances. In the process of absorption, water levels remain constant. This process dissolves particles from rock, soil, nutrients, chemicals and other properties with which water comes into contact.

Thermal Properties – Heat capacity of a substance refers to the amount of heat required to produce a specific increase in temperature. With the exception of ammonia, water has a higher heat capacity than any other substance. During cooling, water gives up much more heat without a temperature drop than virtually any other substance. These thermal properties are extremely important and cause water to heat and cool more slowly than land or air.

Water freezes at 0 degrees C and boils at 100 degrees C. Water is constantly losing molecules from its surface with these molecules becoming a water vapour. This process is called evaporation, and an incredible amount of heat must be absorbed without a temperature change before this is possible. When half a kg of water is evaporated, it absorbs as much heat as it takes to raise the temperature of over 2.3 kg of water from the freezing to the boiling point. In turning to ice, water at 0 degrees C gives off 80 times as much heat as an equal quantity would in lowering its temperature one degree.

Density – Like other substances, the colder water gets, the denser it becomes. This process continues until water reaches the temperature of 4 degrees C where it is at its heaviest, weighing 10,004 kg per cubic meter. Then, a unique change takes place. Below that temperature, water begins to become less dense and lighter, expanding slightly in the process. Water colder than 4 degrees C floats upward toward the surface. As it freezes, it adds about nine percent of its volume, enabling ice to float.

If this phenomenon did not occur, ice would form on the bottom first and destroy aquatic life. There would not be enough heat in the summer to melt the ice and over a peiod of years, the whole water cycle would cease, as would life on earth.

Above 4 degrees C, water becomes less dense as its temperature increases. Cooler water is heavier and sinks to the bottom. Fluids transmit pressure equally in all directions. Any body completely submerged under water has equal pressure on all sides. In 30.5 m of water, for example, there is about 4 kg of pressure per square cm. Anything that lives at that depth must be able to withstand the pressure. Therefore, fish that move from bottom to surface and back must adjust to rapid pressure changes.

The fact that water becomes lighter and less dense just before it freezes plays an important role in deep northern lakes. As the warming rays of the spring sun melt the ice and begin to heat the surface water, a change takes place. When the surface water reaches 4 degrees C, it begins to sink to the bottom aided by wind and currents. The cold water on the bottom is displaced and pushed toward the surface where it receives more oxygen. When this occurs, the lake is said to turn over. During that period of almost uniform temperature, fish may be found at any depth.

As the sun continues to warm the water, three distinct layers form in the lake. The warm surface layer is called the "epilimnion", while the colder bottom water is known as the "hypolimnion". Depending on its depth and the work of decomposers in the water and on the bottom, the hypolimnion may become depleted of oxygen and not support fish life. However, deep oligotrophic lakes rarely have a hypolimnion without oxygen. Between these two layers, there is a narrow belt called the "thermocline". By definition, the thermocline exhibits rapid temperature changes of at least 1.8 degrees C for each metre of depth.

In the fall, surface water begins to cool first and becomes dense, sinking to the bottom. That forces the bottom layer toward the surface until the temperatures become uniform. Then, the lake turns over a second time. This is a very important mixing process, helping to restore oxygen to areas that had a minimal supply. Thermoclines also exist in saltwater estuaries and in the ocean and often determine where fish will be. Usually pelagic species remain above it. One can locate a thermocline by taking temperature reading at various depths until a rapid change is noted.

Viscosity – Because water is viscous, it offers resistance to animals living in water that must be overcome through the expenditure of energy. A tradeoff occurs since a body placed in water seems to grow lighter. A force equal to the weight of the displaced water buoys up the body. This also allows a fish or aquatic animal to maintain buoyancy and counters the tendency to sink. Salt water is more buoyant than fresh water.

To the human eye, all water looks the same – a thin liquid that appears very viscous regardless of temperature. Actually, water does have changing viscosity and is twice as viscous at 0 degrees C than it is at 30 degrees C. This can be demonstrated very simply by pouring a glass of ice water into a sink and then pouring some boiling water from a kettle into the sink. The boiling water will splash much more than the cold water will, showing that the cold water is much more viscous.

Universal Solvent – Water does not dissolve everything, but it dissolves so many different compounds that it is often thought of as the closest thing to a universal solvent. It dissolves almost anything, at least to some degree, and holds an incredible number of substances in solution. Every time water runs over the surface or trickles through the ground, it dissolves some of the substances there. These are carried to oceans or inland lakes. Equally important, water does not change these substances which are vital to all forms of aquatic life, making them available to all types of organisms.

Transparency and Absorption of Colour – Water clarity controls the quality of light that penetrates this liquid medium and the depth to which it penetrates. Even under extremely clear conditions, almost all light is filtered out within the first 9 metres. It is important to recognize that light is the essential ingredient in photosynthesis, explaining why plant growth is limited to relatively shallow water. Plankton and silt particles in many bodies of water cause turbidity, which limits light penetration. Under ideal conditions, one percent of the light can penetrate into the depths. One researcher estimates that in an exceptionally clear body of water, light can be detected as deep as 195 metres. A muddy river however, may be totally dark only a few metres below the surface.

Darkness and loss of colour increase with depth. The long wavelengths are absorbed more quickly and the red end of the spectrum disappears in less than 9 metres when the water is perfectly clear. That distance decreases with turbidity. Blues and greens have shorter wavelengths and are the slowest to be absorbed. Due to absorption of the long wavelengths of light, pigments (colours) appear differently at greater depths. The blues and greens are visible at much greater depths, when red objects appear black. Colours turn to a shade of grey and objects are seen in black and white, much as with the human eye during periods of very low visibility. Fluorescent colours retain their shades even deeper than standard colouration. Orange, which is close to red in the spectrum, seems to retain its colour much deeper, but certainly not as deep as the blues, greens, and even yellow.

Many species of fish require at least a minimal amount of light and tend to be disoriented in total darkness. No one really knows how much light is minimal, but experiments in large aquariums where total darkness was introduced by researchers demonstrated that some fish could not or would not tolerate the absence of light.

Geophysical Properties

Geophysical properties of freshwater ecosystems include such factors as temperature, colour, transparency, speed, depth and the nature of the bottom. All these factors interact with one another. They also interact with chemical factors and with biological factors. For example, a slow stream tends to be warmer than a fast stream. The slow stream also has smaller particles on its bottom. Further, the slow stream usually has less oxygen in it (a chemical factor) than a fast stream does. As a result of all these factors, the slow stream usually has different organisms in it (a biological factor) than the fast stream does.

Geophysical Properties of Standing Water - Several geophysical properties affect the ecology of lakes and ponds. This section discusses five of them: temperature, nature of the bottom, colour, turbidity and transparency.

Temperature – As you know, each species of organism has its own optimum or preferred temperature. For example, the optimum temperatures for three common species of fish are: 32^oC for Cyprinusm carpio (carp), 24^oC for Perca flavenscens (perch), and 15^oC for Salmo trutta (trout). These and other aquatic organisms can stand some variation from the optimum temperature. However, if the temperature shifts too far from the optimum, the organism either dies or moves to a new location. With most species of fish, an increase of $5\,^oC$ above the optimum can be quite harmful. This is particularly true if the increase in temperature is unexpected for that time of year. For example, if a stream has an average May temperature of $18\,^oC$ and hot outflow from an industry raises the temperature to $25\,^oC$, a large number of fish will probably die. If on the other hand, the temperature gradually rises to $25\,^oC$ as a result of normal summer warming, a fish kill will probably not occur. The fish have time to migrate to cooler regions.

Why does an increase in temperature kill fish and other aquatic life? As the water temperature increases, the body temperature of any poikilothermic (“cold-blooded”) animal in the water increases. This, in turn, results in an increase in the rate of metabolism in the animal. Of course, this increases the animal’s need for oxygen. Yet, as the temperature of the water goes up, its ability to hold oxygen goes down. Eventually a temperature is reached at which the oxygen demand of the animal exceeds the available oxygen and the organism dies. This temperature is called the lethal temperature.

Nature of the Bottom – The bottom of a pond or lake normally consists of decaying plant and animal matter. This detritus is home to countless bacteria and fungi. They feed on the detritus. As they do so, they respire and use up oxygen. As a result, many other species cannot live near the bottom. If light reaches the bottom, submerged plants may live there. They help provide oxygen. They also provide food and habitat for a wide variety of organisms.

Colour **–** The colour of water gives us an idea of the amount of suspended and dissolved matter in the water. If, for example, the water is green, we can assume that the water contains phytoplankton (algae). A light yellow or brown colour can be caused by a suspension of dead algae or by a suspension of clay that storm runoff may have carried into the water.

Turbidity – Water may be turbid or cloudy due to the presence of suspended solids. Some of these solids may be living organic matter such as phytoplankton and zooplankton. Also, they may be non-living organic matter such as small pieces of dead organisms and sewage. These solids may also be inorganic matter such as silt and clay.

Ecologists use an instrument called a turbidimeter to measure turbidity. Turbidity can also be measured roughly, using a Secchi disc, or by finding the total suspended solids (T.S.S.)

Transparency – The transparency of water is a measure of how well light passes through the water. It is an indication of the amount of suspended solids in the water. Transparency is usually measured with a Secchi disc. This metal disc is 20 cm in diameter. It is divided into four quarters, two of which are white and two black. To obtain a Secchi disc reading, the disc is lowered into the water until it disappears. This depth is recorded. The disc is then lowered past this point and slowly raised until it can be seen again. This depth is recorded and averaged with the first reading. This entire procedure is repeated two more times. The final average of all three readings is the Secchi disc reading.

If the Secchi disc reading is low (for example, 1 m), the water contains much suspended matter. If however, it is high (for example, 8 m), the water is quite clear and free of suspended solids. Lakes polluted with acid precipitation have high Secchi disc readings. That is because suspended matter such as phytoplankton and zooplankton have been killed and settled.

To get a reliable Secchi disc reading, ecologists take the reading from the shady side of the boat or through a glass-bottomed bucket to reduce surface glare. The reading will, of course, depend on the location, time of day and type of day (sunny or dull). The Secchi disc reading corresponds roughly to what ecologists call the compensation depth. This is the depth at which oxygen production by phytoplankton in the upper water equals oxygen use by bottom organisms such as bacteria.

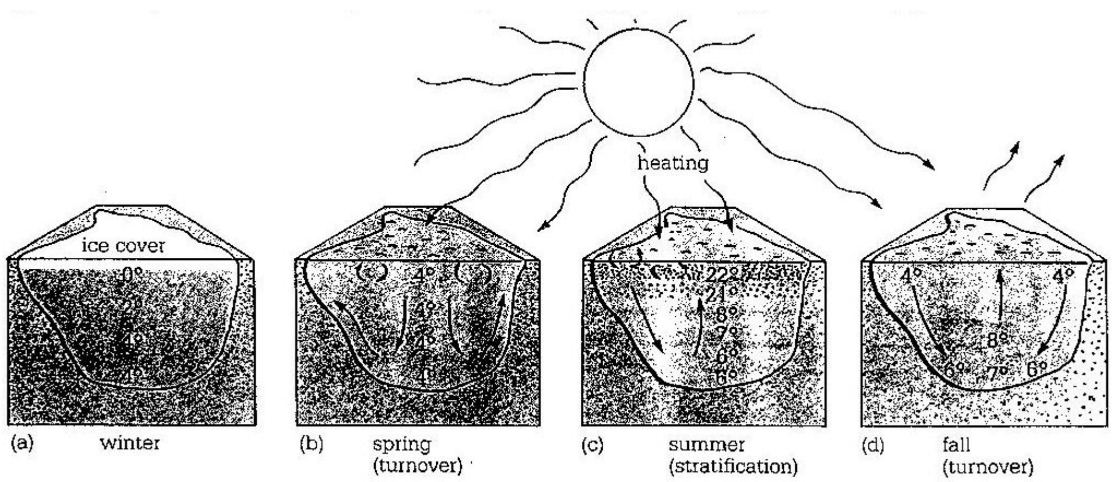
Layering and Overturn in Lakes – Light can reach the bottom at all places in a pond. As a result, submerged vegetation grows over the entire bottom of the pond. In contrast, light cannot reach the bottom at all places in a lake. As a result, submerged vegetation plays a lesser role in a lake ecosystem than in a pond ecosystem. In fact, phytoplankton form the base of most food chains in a lake. The phytoplankton live mainly in the upper few metres of a lake. They require light for photosynthesis. However, consumers are found at all depths in most lakes. Those that are herbivores spend their time at various depths. Some live at a depth of several hundred metres in certain lakes. Of course, these consumers need oxygen. Most of the decomposers that live in the bottom ooze also need oxygen. Yet photosynthesis does not occur at such depths. How then does oxygen get to the bottom of a deep lake? It does so by an interesting process called overturn. Let us see how it happens.

Spring Overturn ^{o}C – As the ice on a lake melts in the spring, the cold water that forms sinks to the bottom. (You learned that water is most dense at 4 ^{o}C). Therefore, the lake gradually fills from the bottom with cold water. At some time in the spring, the lake is the same temperature throughout. As a result, it also has the same density throughout. Such water mixes easily when the spring winds blow over it. This mixing of the water carries oxygen to the bottom. It also brings nutrients from the bottom to the top, where they support the growth of phytoplankton. This process is called spring overturn.

Summer Stagnation – As summer approaches, the sun warms the upper layer of water faster than the winds can mix it. By mid-summer, the lake usually has three layers in it. The upper layer, or epilimnion, contains warmer water that circulates freely. The lower layer, or hypolimnion, contains colder water that does not circulate. In between is a layer of transition from warm to colder water. It is call the metalimnion, or thermocline. Usually the temperature drops about 1.0 ^{o}C for every depth increase of 1.0 m. Because of density differences, the hypolimnion is cut off from circulation. It receives no further oxygen from the epilimnion. Limnologists say that the lake is now in summer stagnation. If the lake is eutrophic (nutrient-rich), much of the remaining oxygen is quickly used up. Then the hypolimnion becomes unsuitable for life that requires a large supply of oxygen.

Fall Overturn – As fall approaches, the epilimnion cools and gradually gets deeper. Finally the entire lake is a uniform temperature again. The fall winds are now able to cause another mixing of the water. This mixing is called the fall overturn.

Winter Stagnation – With the coming of winter, the upper water cools still further. This cooling increases the density of the water. The resulting cool water sinks to the bottom. This process continues as long as the temperature of the water is above 4 ^{o}C. Water with a temperature below 4 ^{o}C is less dense. Therefore it stays on top and eventually freezes. Once again three layers form. The epilimnion is now ice and water near 0 ^{o}C. The hypolimnion is water at or above 4 ^{o}C. The thermocline is reversed. It goes from cold water at the top to warmer water below. Again, because of density differences, the hypolimnion is cut off from the epilimnion. No additional oxygen will reach the hypolimnion until the next spring overturn. The lake is said to be in winter stagnation.



Oxygen-Carbon Dioxide Balance in a Lake

Photosynthesis – Most of the oxygen in a lake comes from Photosynthesis of producers (plants and algae). These organisms use up carbon dioxide and water during photosynthesis. They also produce oxygen and organic compounds such as glucose. Photosynthesis occurs only when light and chlorophyll are present. The oxygen which is produced dissolves in the water.

$$\text{Carbon Dioxide + Water + Light Energy} \xrightarrow{\text{Chlorophyll}} \text{Glucose + Oxygen}$$

PHOTOSYNTHESIS PRODUCES OXYGEN AND USES UP CARBON DIOXIDE

Respiration – During respiration the producers and consumers (animals) use oxygen to "burn up" foods like glucose. Most decomposers (bacteria and fungi) do the same thing. Respiration gives the organisms the energy they need for life processes. Respiration produces two by-products, carbon dioxide and water.

$$\text{Glucose + Oxygen} \longrightarrow \text{Carbon Dioxide + Water + Heat Energy}$$

RESPIRATION PRODUCES CARBON DIOXIDE AND USES UP OXYGEN

The Balance Between Photosynthesis and Respiration – Organisms occur throughout a lake – from top to bottom. As a result, respiration takes place throughout the lake. Therefore, oxygen is used up and carbon dioxide is produced at all depths. Often though, respiration is greatest near the bottom. This is because dead organisms sink to the bottom where numerous decomposers feed on them. Thus the lower part of the hypolimnion often has high carbon dioxide and low oxygen values. This part of the lake is called the tropholytic zone. ('troph' means feeding, and 'lytic' means decomposition). The organisms in this zone feed by decomposing organic matter.

If a lake is oligotrophic ('lacking food' or clean), the oxygen concentration decreases only slightly with depth. If a lake is eutrophic ('adequate food' or 'nutrient rich'), the oxygen concentration decreases a great deal in the bottom of the hypolimnion, that is, in the tropholytic zone.

In some lakes, no oxygen occurs in the tropholytic zone. In such lakes, the bacteria in the bottom ooze respire anaerobically (without oxygen). This forms methane and hydrogen sulphide (‘rotten egg’) gasses. Methane is the natural gas many people burn in their homes for cooking and heating. You can smell hydrogen sulphide if you push a stick into the black muck around a pond, lake or marsh.

Although respiration occurs at all depths, photosynthesis does not. Photosynthesis requires light. Light can penetrate only so far into the water before it becomes too weak to cause much photosynthesis. Thus oxygen is not given off at all depths. Most of it is produced in an upper layer called the trophogenic zone (‘troph’ – means feeding, and ‘genic’ means producing). The organisms in this zone produce food by photosynthesis.

How Standing and Flowing Waters Differ

Since standing waters don’t move and flowing waters do, three important differences occur between these types of water.

Source of Oxygen – In standing waters, photosynthesis by producers (plants and algae)is the main source of oxygen. However, it is not the main source in most flowing waters. In fact, most plants and algae are swept away by the current. Fast water gets most of its oxygen by aeration. The water of low-order streams in particular, usually rushes over rocks. Therefore, air circulates through the water (aeration).

A few producers do live in flowing waters. Clinging to the rocks are blue-green algae, green algae, diatoms and mosses. These organisms photosynthesize. As a result, they add oxygen to the water. The amount of oxygen added is usually small compared to that which enters by aeration.

Source of Food – The producers of ponds and lakes support most of the food chains. Such food chains are called autotrophic food chains (self-feeding food chains). Producers may also support some food chains in streams. For example, herbivores such as snails may graze on algae and mosses on the rocks. The snails in turn, may be eaten by carnivores such as fish. However, only a small part of the total food supply of a fast stream comes from the producers. Most of it enters the water from the surrounding land. This can happen in two ways. First, leaves, twigs, grass and other organic matter fall into the water or are washed in by rain. Scavengers feed on this organic matter. They in turn, are eaten by carnivores. Food chains which begin with non-living organic matter such as this are called detritus food chains. Second, insects and other small terrestrial animals also often fall into the water. These are eaten by fish and other predators. Such food chains, like detritus food chains, have their first steps outside the stream. As a result, they are called heterotrophic food chains (other-feeding food chains).

High-order streams are generally wider, slower, warmer and more nutrient-rich than low-order streams. Therefore, plants and algae are often more abundant in them. Also, decaying organic matter builds up on the bottom of slower streams. In fact, a wide, slow stream has many properties of a pond or small lake.

Adaptations of Organisms – The organisms of both standing and flowing waters have special adaptations which suit them to their habitats. For example, stonefly nymphs that live under the rocks in fast streams are streamlined in shape. They have muscular legs and hooks on their feet. In contrast, sludge worms are adapted to the bottom ooze of ponds, lakes and slow streams. They have no adaptations for holding on in fast water. Instead, they are adapted to the muddy bottom. They build a tube in the muddy bottom material and feed head-down in this tube. To capture oxygen in this low-oxygen environment, they rotate their ‘tails’ through the water.

Chemical Properties: Five Key Factors

Oxygen

Oxygen is a clear, colourless, odourless and tasteless gas. Air is about 21% oxygen by volume. Most living things need oxygen. Although oxygen doesn't dissolve very well in water, enough does dissolve to support a wide variety of living things.

How Much Oxygen is Needed? – Most aquatic organisms depend on dissolved oxygen for survival. Also, most species have rather definite oxygen requirements. As a result, the test for oxygen is one of the most important tests to do when you are studying water quality.

In general, water should contain at least 5 μg/g of oxygen (five micrograms of oxygen in one gram of water). Water with this concentration will support a fairly diverse community of organisms. Variations in oxygen requirements are wide of course. The amount of oxygen required varies with the organism, its degree of activity, the water temperature, the pollutants present, and many other factors.

Temperature, Metabolic Rate and Oxygen – The amount of oxygen an animal needs depends on many factors – one factor is activity. An animal normally needs more oxygen when it is active than when it is resting. That's because its metabolic rate goes up when it is active. (Metabolism is the sum of all the processes occurring in an organism. That includes respiration which, as you know, requires oxygen).

Solubility of Oxygen in Water – Fish such as trout, which need high oxygen conditions, seek out cold water. In contrast, fish such as carp, which can tolerate low oxygen conditions, seek out warm water. This is because oxygen, like all gasses, is more soluble in cold water. That is, cold water contains more oxygen than warm water.

Sources of Oxygen – In fast streams and rivers, most of the oxygen comes from the air. As the water splashes over rocks, it picks up oxygen from the air. For example, a fast stream at 15^0 cannot have over 10.1 μg/g of oxygen in the water.

In lakes like Lake Erie, oxygen is a limiting factor. The bottom of Lake Erie may have the right temperature and food supply for trout. Yet the low oxygen level prevents trout from living there as they did before we began to dump sewage in the lake.

Carbon Dioxide

Carbon dioxide is a clear, colourless, odourless and tasteless gas. It is the ‘fizz’ in soda pop. Let us see how it gets into water and what it does to organisms.

Carbon Dioxide from the Air – Carbon dioxide, like oxygen, continually enters rivers and lakes from the air. However, air is only about 0.034% carbon dioxide by volume. Therefore, when air is the only source of carbon dioxide, very little ends up in the water. For example, at 0^oC, the solubility of carbon dioxide in water is only 1 μg/g, when air is the only source. Thus a fast, clean stream will not likely have over 1 μg/g of carbon dioxide in it.

Carbon Dioxide from Respiration – In most natural bodies of water, the air is just a minor source of carbon dioxide. Respiration by living organisms is the major source. This is particularly true of lakes and slow or polluted rivers.

As a result of respiration, water near the surface of most bodies of water has up to 10 μg/g of carbon dioxide in it. Water near the bottom ooze has even more. Decomposers feed on organic matter in the bottom ooze. As they respire, they add carbon dioxide to the water at the bottom. Water that contains over 25 μg/g of carbon dioxide is harmful to most gill-breathers. It interferes with breathing. Concentrations of 50-60 μg/g will kill many species.

Carbon Dioxide in Rain and Groundwater – As raindrops fall, they dissolve carbon dioxide from the air. Usually the quantity does not exceed 0.6 μg/g, but if this rain falls on land and moves through soil, it picks up more carbon dioxide. The spaces between the soil particles have a fairly high level of carbon dioxide in them. This is due to respiration by the soil organisms, particularly the decomposers. If the groundwater runs to a lake, it will increase the carbon dioxide concentration of the lake.

Factors That Remove Carbon Dioxide – *Atmospheric Exchange* – Fast-moving rivers lose most of their carbon dioxide through atmospheric exchange. That is, they give up the carbon dioxide to the atmosphere. Suppose for example, that a marsh drains into a river. The marsh water could have as much as 30 μg/g of carbon dioxide in it at 20°C. But a fast river which is not producing carbon dioxide can only hold about 0.5 μg/g at 20°C. Thus the excess carbon dioxide (29.5 μg/g) will get 'knocked out' of the river in the turbulent regions.
Photosynthesis – Lakes and other standing waters lose most of their carbon dioxide through photosynthesis. Respiration will build up the carbon dioxide level at night, but photosynthesis will reduce it during the day.

pH

The pH Scale – The pH of water is a measure of its acidity. Values for pH run from 0 – 13. On this scale, a pH of 7.0 is neutral. A pH less than 7 is acidic and a pH greater than 7 is basic (alkaline). In other words, the lower the pH of water, the more acidic it is. Water becomes less acidic and more basic as its pH increases.

The pH scale is logarithmic. This means that going from one number to the next is not a change of one, but a change of ten. For example, water with a pH of 6 is 10 times more acidic than water with a pH of 7. As well, water with a pH of 5 is 100 times more acidic than water with a pH of 7.

pH and Life – A pH between 6.7 and supports a well-balanced fish population. As long as the pH is within this range, it seems to have little effect on the life processes of most fish species. In fact, most species can tolerate pH values beyond this range for a limited time. Only a very few species can tolerate pH values lower than 5.0 or greater than 9.0. Further, few gill-breathers of any kind are found outside the range from 4.0 to 9.5. An improper pH interferes with gas exchange across the gill membranes. In other words, breathing becomes difficult.

Most plants and algae are also affected when the pH becomes very low or very high. An improper pH slows down nutrient uptake by the plants and algae. As a result, their growth becomes stunted and eventually they die.

pH and Eutrophication – Eutrophication is the process of aging or increasing productivity of a lake. Eutrophic means 'adequate food' or nutrient-rich. As a lake ages, it accumulates nutrients from runoff. It may also get nutrients from pollution such as sewage. These nutrients increase the amount of life in the lake, or its productivity.

A young, clean lake in the early state of Eutrophication is oligotrophic, or 'lacking food'. This kind of lake will likely be basic if it is in an area with basic bedrock such as limestone or dolomite. The pH of such a lake normally drops as the lake ages. That is, the water becomes more acidic with time. This is because the decay of organic matter releases acids into the water. Among these acids is carbonic acid. This acid forms when the carbon dioxide from respiration reacts with water. The lake at this more acidic stage is called mesotrophic ('middle amount of food').

In time, a mesotrophic lake ages further and becomes an eutrophic lake. As this process occurs, the pH usually rises again and the lake becomes more basic (less acidic).

YOUNG LAKE	→	MIDDLE AGED LAKE	→	OLD LAKE
Basic		More Acidic		More Basic
OLIGOTROPHIC		MESOTROPHIC		EUTROPHIC

A young, clean lake in an area with acidic bedrock such as quartz or granite, will likely be slightly acidic. But like the lake just discussed, it will probably turn more acidic and later, more basic as it ages.

Factors Affecting pH – Life in a lake and the bedrock can affect the pH of water. Many other factors can also affect pH. Acid spills by industries lower the pH. Also, smelters and coal-burning power plants put sulphur dioxide into the air. The sulphur dioxide reacts with water vapour in the air to form sulphuric acid. When it rains or snows, this acid gets into lakes and rivers. Such snow or rain is called acid precipitation or, sometimes acid rain. The pH of acid precipitation is usually below 4.0. Sewage usually raises the pH of water. Household sewage has many bases in it. Also, the decay of sewage by bacteria produces bases.

Alkalinity

What is Alkalinity? – Alkalinity is the ability of water to neutralize acids. Therefore, the alkalinity of water can also be described as the sum of all the bases in water. (Bases neutralize acids.) In natural waters, the alkalinity is due mainly to carbonates and bicarbonates. But hydroxides may also contribute to the alkalinity if domestic or industrial pollution are present. These three substances – carbonates, bicarbonates, and hydroxides – are used in many antacid pills that people take to neutralize excess stomach acid.

Source of Alkalinity

Respiration in the Water – When organisms in the water (including decomposers) respire, they release carbon dioxide into the water. This carbon dioxide dissolves in the water to form carbonic acid. Almost as fast as it forms, some of this carbonic acid breaks up into carbon dioxide and water. You have likely seen this happen. Carbonic acid is present in the soda water used to make most soft drinks. The fizz that occurs when you take the top off a bottle of 'pop' is due to the escape of some of the carbon dioxide.

Some of the carbonic acid that is left breaks down to form bicarbonates and carbonates:

$$\text{Carbon Dioxide + Water} \longleftrightarrow \text{Carbonic Acid} \longleftrightarrow \underset{\text{ALKALINITY}}{\text{Bicarbonate + Carbonate}}$$

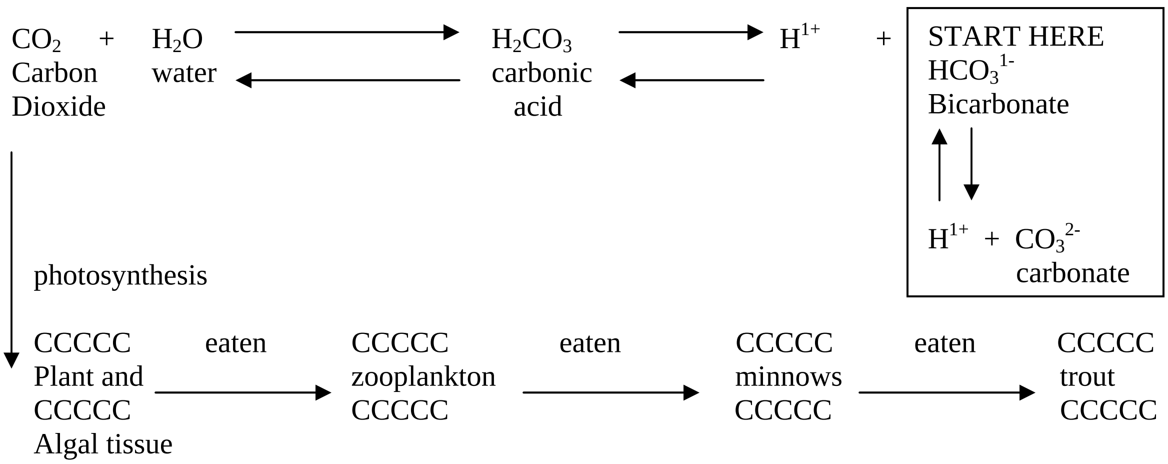
The arrows indicate that all reactions are reversible. In other words, the carbonates and bicarbonates can change back into carbonic acid. And, the carbonic acid can change back into carbon dioxide and water.

Rain and Groundwater – Rain dissolves carbon dioxide as it falls. More importantly, it dissolves still more carbon dioxide as it runs through the soil. Thus groundwater will usually contain carbonates and bicarbonates. Further, if the bedrock is a carbonate such as limestone, the now acidic groundwater reacts with that bedrock to form still more bicarbonate and carbonate.

Domestic and Industrial Sources – Many household drain cleaners contain lye, which is a hydroxide. Baking soda is a bicarbonate. Both of these can raise the alkalinity of water if you put them down the drain. Water softeners also put carbonates into the water.

Domestic sewage also raises the alkalinity of water. Decomposers produce carbon dioxide as they feed on the sewage. The carbon dioxide produces carbonates and bicarbonates. Many industries also discharge substances into rivers and lakes which raise the alkalinity. What might some of these substances be?

Importance of Alkalinity – The alkalinity is a fairly reliable measure of the productivity (ability to support life) of a lake. To show you why, we are going to write the chemical equations for the word equations you saw earlier. But they will help you see why alkalinity is a good measure of productivity.



A productive lake has a great deal of life in it. Thus a great deal of carbon dioxide forms. Carbon dioxide in turn, forms high concentrations of bicarbonate and carbonate. In other words, a productive lake has a high alkalinity. This high alkalinity helps keep the lake productive. During sunny days the free carbon dioxide (CO_2) is quickly used up. If the lake has no reservoir of carbonate and bicarbonate, photosynthesis would stop. But the carbonates and bicarbonates form carbon dioxide (by the reverse reactions) and keep photosynthesis going.

Hardness

Causes – Hardness in water is caused mainly by calcium and magnesium ions. The hardness is usually high in regions of sedimentary rock such as limestone (calcium carbonate) and dolomite (magnesium calcium carbonate). Calcium and magnesium ions are picked up by the water as it runs over these minerals. Runoff from cities is also often hard. Acidic rain dissolves calcium and magnesium from buildings and streets.

Importance

***Supports Life** – **s**ome hardness is necessary for all living things. All living things need calcium and magnesium in order for their cells to function. Vertebrates like fish need calcium to build bones. Every chlorophyll molecule has a magnesium atom in it. If all other changes are favourable, then the productivity of a lake will likely be higher.

Human Health – Water with a total hardness around 250 μg/g is best for drinking. People who drink soft water for long periods of time are most likely to get cardiovascular diseases (diseases of the heart and circulatory system).

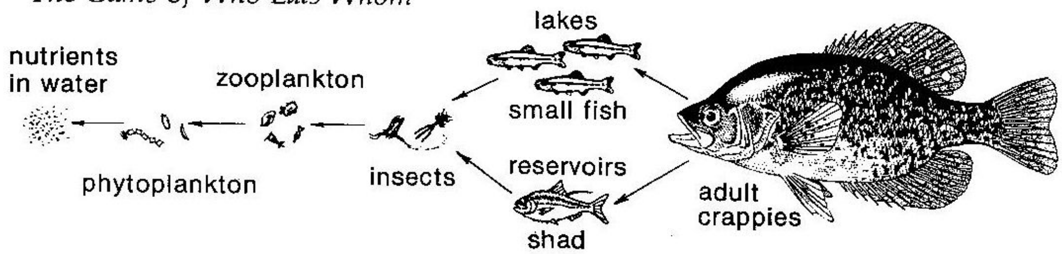
Water with a total hardness above 500 μg/g can make you very ill if you are not accustomed to it. It often causes diarrhea. In your large intestine are billions of coliform bacteria. They help the lining of the intestine remove water from the waste food material. This water is then put back into the bloodstream. (This is an excellent example of mutualism). However, a sudden change in the hardness of drinking water causes the coliform bacteria to stop functioning. Thus the water stays in the waste food material, and you get diarrhea.

Economics – Very hard water is undesirable for many economic reasons. First, the calcium and magnesium ions react with soap to form curds. These make it difficult to wash properly. Synthetic detergents have been developed that do not form curds. Nonetheless, if you want to use soap and the water is hard, you must soften the water. This process is expensive.

The calcium and magnesium ions also precipitate out in household plumbing. If the water is very hard, the pipes can become clogged unless the water is softened. These ions also cause the familiar tea kettle scale and the costly boiler scale that torments industry.

Typical Aquatic Food Chain

"The Game of Who Eats Whom"



What Crappies Eat

Shad	Zooplankton
Aquatic Insects	Minnows
Sunfish	Carp
Catfish	Black Bass
Striped Bass	Drum
Bluegills	Crappies
Crustaceans	

Size is of the essence, and small is best. Normally, adult crappies eat young-of-the-year fish, if available. However, their diet can vary from one body of water to another, and even seasonally on the same body of water.

Aquatic Food Chains and Food Webs

Food Chains – Organisms may be linked together in feeding relationships. These feeding relationships are called food chains, and often begin with producers that are eaten by herbivores that in turn, are eaten by carnivores. However, some food chains begin with dead plants or animals. An example is a crayfish feeding on a dead fish in a lake. In a sense, even this food chain began with a producer. The fish, when it was alive was in a food chain that began with a producer. The fish may have eaten smaller animals that in turn had eaten algae or plants.

Though many food chains have just three steps (producer, herbivore, carnivore), others can be quite long. That's because they have several "orders" of carnivores. In other words, they have more predator-prey relationships. Even a long food chain usually has the three main trophic levels – producer, consumer and decomposer. The decomposers feed at all levels along the food chain. The consumer level can have four sub-levels – herbivore, first-order carnivore, second-order carnivore, and top carnivore.

Food Webs – Most organisms are in more than one food chain. A certain species of plant could be eaten by several species of animal. Also, a certain species of animal could eat more than one type of food. For example, one species of mayfly could be part of the following food chains:

Algae → Mayflies → Fish
Algae → Microscopic animals → Mayflies → Fish
Plants → Microscopic animals → Mayflies → Fish
Algae → Mayflies → Stoneflies → Small Fish → Larger Fish

Since organisms are often in more than one food chain, the food chains in an ecosystem are connected. The connected food chains are called a **food web**.

Ecological Pyramids

Pyramid of Numbers – Food chains usually proceed from very small organisms to larger and larger ones. Therefore the number of organisms at each trophic level tends to decrease as you move along the food chain. In other words, many small producers feed fewer larger herbivores that in turn, feed still fewer and larger carnivores. Such relationships are often represented by a pyramid of numbers.

Not all pyramids of numbers have a regular shape. In fact, some aren't pyramids at all! Think about the hundreds of mould organisms that feed on a dead fish. What will this "pyramid" of numbers look like?

Although the pyramid of numbers is simple, it is not used much by ecologists. That is because it treats all organisms only in terms of numbers. It ignores differences in size. Yet to a hungry fish, size is important. One stonefly with a mass of 1.2 g makes a better meal than one mayfly with a mass of 0.4 g.

Pyramid of Biomass – To avoid the fault in the pyramid of numbers, ecologists often use a pyramid of biomass. Each trophic level in this pyramid shows the biomass (total mass of the organisms) at that level. It makes much more sense to talk about masses of organisms at each trophic level than about number of organisms. After all, the important thing for a trout is the total mass not the number of stoneflies it eats. (In like manner, you probably don't care how many potatoes you eat for dinner. Rather, you care about the total amount, or mass, of potato. One big potato may feed you better than three small ones.)