Water Quality Protocols Background

Basic Water Chemistry

Many environmental groups perform nine tests to determine a stream's water quality. The chemical/biological/physical tests that should be performed on a stream's water are: dissolved oxygen (DO), fecal coliform (FC), pH, biochemical oxygen demand (BOD), temperature (T), total phosphates (PO_4), total nitrates (NO_3), turbidity, and total dissolved solids. The LaMotte Limnology Kit will cover the nitrates, phosphates, pH, and dissolved oxygen as well as carbon dioxide, silica, total hardness, calcium hardness, and magnesium hardness. It is possible to perform hundreds of other tests. The nine tests were selected because of their significant impact on aquatic organisms and because they are relatively inexpensive to perform. Further, by performing these nine tests and overall water quality index can be determined.

It is important to realize several things. Proper safety procedures (including the use of protective eyewear, gloves, and clothing) should be practiced at all times. Sample collection techniques are extremely important in order to get accurate and reliable results. Chemical testing can only be considered accurate for time, place, and sample that is collected.

Dissolved Oxygen Background

Dissolved oxygen is the term for microscopic bubbles of oxygen that are mixed in the water. The presence of oxygen in water is good. Dissolved oxygen is necessary for healthy lakes and rivers. Most aquatic plants and animals need oxygen to survive. Fish will drown in water when the dissolved oxygen levels get too low. The absence of dissolved oxygen in water is a sign of severe pollution.

Most dissolved oxygen gets into the water from the air. Waves on lakes and slow-moving rivers, water tumbling over riffles or waterfalls on fast-moving rivers mixes oxygen into the water. Plants and algae also add oxygen to the water as they do photosynthesis. Because plants need light to do photosynthesis, dissolved oxygen levels tend to be highest in the late afternoon and lowest at dawn.

Temperature has a very big affect on oxygen levels. It may seem strange, but cold water holds more dissolved oxygen than warm water. Think about it this way: if two cans of soda were opened with one in the refrigerator and one left one at room temperature, which would lose its fizz first? In the winter, dissolved oxygen levels are usually higher than in summer. That is why fish kills usually occur in late summer just before dawn.

Climate can affect oxygen levels in other ways. During dry seasons water levels decrease and the flow rate or discharge of a river is lower. As the water moves slower, it mixes less with the air; and the dissolved oxygen level goes down. During rainy seasons oxygen levels tend to be higher.

The main man-made factor causing dissolved oxygen levels to change in a negative ways involves the build-up of organic wastes. Organic wastes are the remains of any living or once-living thing. Leaves, grass clippings, dead plants or animals, and sewage are examples of organic wastes. Organic wastes are decomposed by bacteria which take oxygen out of the water. When people dump organic wastes into lakes and streams it causes dissolved oxygen levels to decrease which can harm the aquatic life.

When dissolved oxygen levels get lower, they can cause major changes in the types and amounts of aquatic organisms found living in the water. Species that need high levels of dissolved oxygen such as mayfly nymphs, stonefly nymphs, caddisfly larvae, pike, trout, and bass will move out or die. They will be replaced by organisms such as sludge worms, blackfly larvae, and leeches which can tolerate lower dissolved oxygen levels.

A dissolved oxygen (DO) test determines how many milligrams of oxygen are dissolved in a liter of water (mg/L). It does not tell you how much DO the water is capable of holding at the testing temperature. The amount of oxygen found in a sample of water compared to the amount of oxygen that the sample could hold is called the percent saturation.

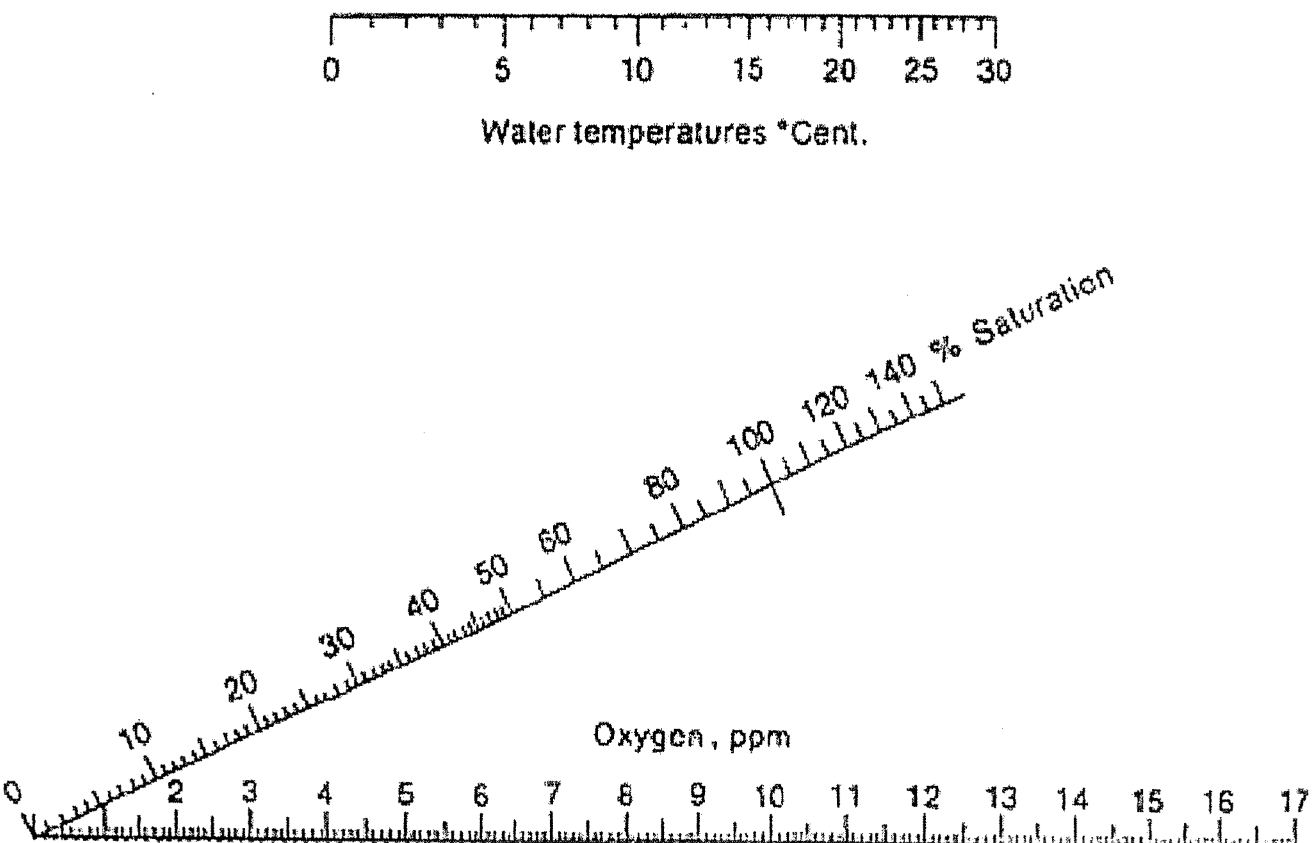
Water temperature affects how much oxygen the water can hold. The warmer the water temperature is, the lower the DO. It is no accident that fish requiring a lot of oxygen are found in cold water. If DO levels are too low, fish and other aquatic animals will move away or die.

When water holds all the dissolved oxygen it can hold at a given temperature, it is said to be 100% saturated. If water holds half as much oxygen as it can hold at a given temperature, it is 50% saturated.

Sometimes water can be supersaturated; that is, water can hold more oxygen than it is supposed to be able to hold at a given temperature. Supersaturation may result when water is tumbled over rapids and falls. Conditions of supersaturation usually don't last long. Because tiny air bubbles rise to the surface of the water and pop, the percent of saturation soon drops to 100% or less. Supersaturation is a common problem along rivers controlled by dams. Supersaturation, even for short periods of time, can be very harmful to fish. Capillaries in the gills of fish can rupture or tear from too much oxygen. Fish with this condition usually die. It is referred to as gas bubble disease.

Rivers that have a dissolved oxygen saturation percent value of 80% - 120% are considered to be excellent. If the DO saturation percent is 60% - 79%, it is okay, but not great. If the DO percent saturation value is over 125% or below 60%, the water quality is poor.

One can determine the percent saturation using a Celsius thermometer, DO test kit, and a percent saturation chart.



How to use a Percent Saturation Chart:

1. Use a thermometer to determine the water sample's temperature in degrees Celsius. Use your pencil to put a dot on the top line of the scale that corresponds to the water's temperature.
2. Use a test kit to determine the amount of dissolved oxygen (DO) in the sample. The DO amount should be measured in ppm. Use your pencil to put a dot on the bottom line of the scale that corresponds to the amount of DO in the water sample.
3. Read your water sample's percent saturation off the middle diagonal line labeled percent saturation.

Fecal Coliform Background

Bacteria are single-celled organisms that can only be seen with the aid of a very powerful microscope. Bacteria can be found everywhere: in air, water, soil, even on our own bodies. They can benefit us by recycling wastes, helping plants to grow, and by making certain types of food. They may harm us by causing diseases and food spoilage.

Biochemical Oxygen Demand (Five Day Test) Background

The biochemical oxygen demand (BOD) test gives a rough idea about how much biodegradable wastes are in the water. Biodegradable wastes are wastes that can be broken down and recycled by nature. Biodegradable wastes are usually composed of organic wastes. Organic wastes are produced by plants and animals. Leaves, grass clippings, and manure are examples of organic wastes. Most organic wastes found in water come from natural sources.

If water contains a lot of biodegradable organic wastes, it probably also contains a lot of bacteria. Organic matter is decomposed or broken down when it is fed upon by aerobic bacteria. Aerobic bacteria need oxygen in order to digest or decompose organic wastes. In this process, organic material is broke down and oxidized (combined with oxygen). This test measures how much oxygen is being used by these microscopic organisms. The more oxygen used by microscopic organisms, the less available for fish and other aquatic life forms.

Humans can have a bad effect on streams by increasing the amount of organic wastes. This can happen when humans allow runoff from certain industries (such as pulp and paper mills, meat-packing plants, food processing industries, or sewage treatment plants) to enter a stream. It can happen when streams are disturbed by construction which stirs up organic wastes trapped in the streambed. It can also happen when agricultural runoff, such as fertilizers or manure, enters a stream.

Fertilizers contain phosphates and nitrates. When it rains, fertilizers that have been applied to lawns and fields may run off into a stream causing algae and other aquatic plants to grow rapidly. Plants that grow fast die fast. Dead plants increase the amount of organic wastes in the water. Bacteria take oxygen out of the water in order to decompose organic wastes. This lowers the oxygen content of the water which may cause fish and other aquatic animals to die. This condition is called cultural eutrophication. Whenever a pond or lake is covered with a layer of slimy, green algae, it is beginning cultural eutrophication. The last stage of cultural eutrophication has been reached when there is a strong "rotten egg" odor.

Although specialized equipment is used by water technologists to measure BOD, a close approximation of BOD values can be obtained by using a dissolved oxygen kit and waiting five days.

Temperature Background

Water temperature is not only important to swimmers and fisherman, but also to industries and even fish and algae. A lot of water is used for cooling purposes in power plants that generate electricity. They need cool water to start with, and they generally release warmer water back to the environment. The temperature of the released water can affect downstream habitats. Temperature also can affect the ability of water to hold oxygen as well as the ability of organisms to resist certain pollutants.

Phosphates Background

Phosphates are chemical compounds made from the elements phosphorous and oxygen. Phosphorous is necessary for plant and animal growth. Phosphorous is usually present in natural waters as phosphate (PO_4).

Phosphates exist in several forms. Orthophosphates are produced by natural processes and are found in wastewater. Polyphosphates are used for treating water boilers and for making laundry detergents. Organic phosphates are produced by living things and are the breakdown of organic pesticides. The sum of these three forms of phosphates is referred to as total phosphates.

Phosphorous is an essential element for life. Animals use phosphorus to conduct metabolic reactions (chemical reactions that occur inside the body that allow the body to stay alive) and to produce bone. Plants use phosphorus in order to grow. Nearly all fertilizers contain phosphates.

Phosphates are usually present in the environment in low concentration which limits plant growth. Phosphates enter the environment from human or animal wastes, fertilizers, soaps, industrial wastes, and the disturbance of land and its vegetation. When too much phosphorus becomes available, plants grow rapidly. Phosphates that enter a stream may cause algae to multiply and grow quickly. This may result in an algae bloom. Algae blooms are thick layers of green slime that cover the surface of ponds or slow moving streams.

Algae blooms are harmful to most aquatic organisms. They cause a decrease in the dissolved oxygen levels of the water. They prevent waves and the surface of the water from coming into contact with the air which provides the main source of oxygen for the water. Their dark color absorbs more heat energy from sunlight causing the water temperature to rise. Warm water hold less oxygen than cold and it cause the metabolic rate of aquatic organisms to increase. In addition, the algae which grow rapidly near the surface block sunlight to plants that live on the bottom causing them to die. Plants which grow fast die fast and then sink to the bottom. Dead plant material is decomposed by bacteria increasing the biochemical oxygen demand (BOD). All of these factors combine to cause oxygen levels in the water to decrease rapidly. This can result in a fish kill and the death of many organisms.

Algae blooms are indicators of cultural eutrophication. Eutrophication refers to the aging of a lake or other body of water. Cultural eutrophication occurs when nutrients are added from agricultural runoff, sewage, detergents, or other sources such as golf courses or lawns. Advanced stages of cultural eutrophication can be detected by an unmistakable "rotten egg" smell.

Nitrates Background

Nitrates (NO_3) are a chemical compounds made from the elements nitrogen and oxygen. Nitrogen is needed by all plants and animals in order to make proteins (the building blocks of cells), to grow, and to reproduce.

Nitrogen is very common and found in many forms in the environment. Nitrogen is most abundant in its molecular form (N_2) which makes up 79% of the air we breathe. In this form, nitrogen is useless to most plants and animals. Blue-green bacteria, the most common algae found in algae blooms, can convert nitrogen (N_2) into other compounds such as ammonia (NH_3) and nitrates (NO_3) which can be used by plants in order to grow. Nitrogen is a common ingredient found in most fertilizers.

Animals get the nitrogen they need by eating plants or by eating animals that have eaten plants. Animal digestive systems break down plant proteins to form nitrogen compounds which can be used to form the proteins they need. Much nitrogen is released in the wastes produced by animals. Ducks and geese contribute a heavy load of nitrogen (from excrement) in areas where they are plentiful. When plants and animals die, proteins are broken down by bacteria forming ammonia (NH_3). Ammonia is broken down by other bacteria to form nitrite (NO_2). Ammonia and nitrite are both poisonous to animals. Nitrite is then consumed by a third type of bacteria which forms nitrates (NO_3). Nitrates can then be used by plants in order to grow. This recycling of nitrogen through the environment is called the nitrogen cycle.

Nitrate is a major ingredient in most fertilizers. When it rains, varying amounts of nitrates wash from farmlands and lawns into nearby streams. Nitrates can also enter streams from animal wastes, leaking septic systems, and sewage. Too much nitrate may contribute to cultural eutrophication.

Nitrate (NO_3) can be harmful to humans. It is broken down in our intestines becoming nitrite (NO_2). Nitrite affects the ability of red blood cells to carry oxygen. If infants consume water high in nitrite/nitrates, they may suffer from a serious condition called methemoglobinemia or "baby blue" disease. Wells contaminated by sewage or agricultural runoff are a major concern in some areas. Nitrites can also cause serious illnesses in fish.

Turbidity Background

Turbidity is the amount of particulate matter that is suspended in water. Turbidity measures the scattering effect that suspended solids have on light: the higher the intensity of scattered light, the higher the turbidity. Material that causes water to be turbid include: clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, plankton, and microscopic organisms.

Turbidity makes the water cloudy or opaque. Turbidity is measured by shining a light through the water and is reported in nephelometric turbidity units (NTU). During periods of low flow (base flow), many rivers are a clear green color, and turbidities are low, usually less than 10 NTU. During a rainstorm, particles from the surrounding land are washed into the river making the water a muddy brown color, indicating water that has higher turbidity values. Also, during high flows, water velocities are faster and water volumes are higher, which can more easily stir up and suspend material from the stream bed, causing higher turbidities.

Total Dissolved Solids Background

Total Dissolved Solids (TDS) are solids in water that can pass through a filter (usually with a pore size of 0.45 micrometers). TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. A certain level of these ions in water is necessary for aquatic life. Changes in TDS concentrations can be harmful because the density of the water determines the flow of water into and out of an organism's cells. However, if TDS concentrations are too high or too low, the growth of aquatic life can be limited, and death may occur. TDS may also reduce water clarity, contribute to a decrease in photosynthesis, combine with toxic compounds and heavy metals, and lead to an increase in water temperature.

TDS is used to estimate the quality of drinking water, because it represents the amount of ions in the water. Water with high TDS often has a bad taste and/or high water hardness, and could result in a laxative effect.

To measure TDS, the water sample is filtered, and then the filtrate (the water that passes through the filter) is evaporated in a pre-weighed dish and dried in an oven at 180° C, until the weight of the dish no longer changes. The increase in weight of the dish represents the total dissolved solids, and is reported in milligrams per liter (mg/L).

One factor that affects TDS is the geology and soil of the watershed. Some rock and soil release ions very easily when water flows over them; for example, if acidic water flows over rocks containing calcite ($CaCO_3$), such as calcareous shales, calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions will dissolve into the water. Therefore, TDS will increase. However, some rocks, such as quartz-rich granite, are very resistant to dissolution, and don't dissolve easily when water flows over them. TDS of waters draining areas where the geology only consists of granite or other resistant rocks will be low (unless other factors are involved).

During storm events, pollutants such as salts from streets, fertilizers from lawns, and other material can be washed into streams and rivers. Because of the large amount of pavement in urban areas, natural settling areas have been removed, and dissolved solids are carried through storm drains to creeks and rivers.

Fertilizer can dissolve in storm water and be carried to surface water during storms, and contribute to TDS. The effluent from Wastewater Treatment Plants (WWTPs) adds dissolved solids to a stream. The wastewater from our houses contains both suspended and dissolved solids that we put down our drain. Most of the suspended solids are removed from the water at the WWTP before being discharged to the stream, but WWTPs only remove some of the TDS. Important components of the TDS load from WWTPs include phosphorus, nitrogen, and organic matter.

Soil erosion is caused by disturbance of a land surface. Soil erosion can be caused by Building and Road Construction, Forest Fires, Logging, and Mining. The eroded soil particles may contain soluble components that can dissolve and be carried by storm water to surface water. This will increase the TDS of the water body. As plants and animals decay, dissolved organic particles are released and can contribute to the TDS concentration.

The U.S. Environmental Protection Agency (U.S. EPA) sets a secondary standard of 500 mg/L TDS in drinking water (http://www.epa.gov/safewater/mcl.html). Secondary standards are unenforceable, but recommended, guidelines for contaminants that may cause cosmetic or aesthetic effects in drinking water. High TDS concentrations can produce laxative effects and can give an unpleasant mineral taste to water. High TDS concentrations in water are also unsuitable for many industrial applications.

Carbon Dioxide Background

Small quantities of carbonic acids are formed quite readily by carbon dioxide dissolving in water. The availability and amount of carbon dioxide present to be absorbed by plants depends on the complex system of aqueous carbonic acid and carbonates. Carbon dioxide is about 40 times more soluble in water than oxygen, but leaves water 10,000 times less easily from water than air. Approximately 0.2% of dissolved carbon dioxide is converted to carbonic acid. An increase in carbon dioxide causes and increase of carbonic acid, and a drop in pH level; if carbon dioxide decreases the pH level increases.

There is a close relationship with the carbonate system/hardness and pH values. Generally speaking the higher the hardness, the higher the pH value, but the pH seems to be easier to stabilize in hard water.

Silica Background

Most dissolved silica observed in natural waters results originally from the chemical breakdown of silicate minerals in irreversible processes of weathering, and most streams in the Northeastern United States have dissolved silica concentrations less than 10 mg/L. Aquatic organisms (primarily diatoms) extract and use silica in their shells and skeletons in freshwater and in seawater.

Hardness Background

Hardness is measure of polyvalent cations (ions with a charge greater than +1) in water. Hardness generally represents the concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, because these are the most common polyvalent cations. Other ions, such as iron (Fe^{2+}) and manganese (Mn^{2+}), may also contribute to the hardness of water, but are generally present in much lower concentrations. Waters with high hardness values are referred to as "hard," while those with low hardness values are "soft".

Hardness affects the amount of soap that is needed to produce foam or lather. Hard water requires more soap, because the calcium and magnesium ions form complexes with soap, preventing the soap from foaming. Hard water can also leave a film on hair, fabrics, and glassware. Hardness of the water is very important in industrial uses, because it forms scale in heat exchange equipment, boilers, and pipe lines. Some hardness is needed in plumbing systems to prevent corrosion of pipes.

Hardness mitigates metals toxicity, because Ca^{2+} and Mg^{2+} help keep fish from absorbing metals such as lead, arsenic, and cadmium into their bloodstream through their gills. The greater the hardness, the harder it is for toxic metals to be absorbed through the gills.

Soft waters are mainly derived from the drainage of igneous rocks, because these rocks don't weather very easily and so don't release many cations. Hard water is often derived from the drainage of calcareous (calcite-rich) sediments, because calcite ($CaCO_3$) dissolves, releasing the calcium. Calcium, magnesium, and other polyvalent cations such as iron and manganese may be added to a natural water system as it passes through soil and rock containing large amounts of these elements in mineral deposits. Drainage from operating and abandoned mine sites can contribute calcium, magnesium, iron, manganese, and other ions if minerals containing these constituents are present and are exposed to air and water. This can increase the hardness of a stream. Some industrial processes may also produce significant amounts of calcium and manganese that are later discharged into streams.

The effluent from Wastewater Treatment Plants (WWTPs) can add hardness to a stream. The wastewater from our houses contains calcium, magnesium, and other cations from the cleaning agents, food residue, and human waste that we put down our drains. Most of these cations are removed from the water at the WWTP before being discharged to the stream, but treatment can't eliminate everything.