<u>Typical Water Quality Parameters Explained</u>

BOD

Biological oxygen demand (BOD) is a measure of the amount of oxygen consumed by bacteria that decompose organic material. BOD also includes the amount oxygen required for the oxidation of various chemicals such as sulfides, ferrous iron, and ammonia in water. While a dissolved oxygen test indicates how much oxygen is available, a BOD test indicates how much oxygen is consumed [1].

BOD is determined by comparing the dissolved oxygen level in a freshly collected sample to the dissolved oxygen level in a sample that was collected at the same time, but incubated under specific conditions for a certain number of days. The difference in the two oxygen levels is recorded in units of mg/L. Unpolluted natural waters should have a BOD of 5 mg/L or less. Raw sewage may have BOD levels ranging from 150–300 mg/L (Source: Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods, 1991). The relationship of BOD level and and water quality is shown in Table 1.

Table 1. BOD level and water quality [2].

BOD, mg/L	Water Quality
1 - 2	**Very Good:** There will not be much organic matter present in the water supply.
3 - 5	**Fair:** Moderately clean.
6 - 9	**Poor:** Somewhat polluted, usually indicates that organic matter present and microorganisms are decomposing that waste.
10 or more	**Very Poor:** Very polluted, contains organic matter.

COD

Chemical oxygen demand (COD) is a measure of the oxygen equivalent of the organic matter present in a sample that is susceptible to oxidation by a strong chemical oxidant. COD can be related empirically to BOD, organic carbon, and organic matter for samples from a specific source. After a correlation has been established, COD can be very useful to monitor and control samples [1].

Conductivity

Conductivity is a measure of how well water can pass through an electrical current. Conductivity is not a pollutant itself, but serves as an indicator of the presence of pollutants. It is an indirect measure of the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, iron and aluminum. The presence of these substances increases the conductivity of a body of water. Organic substances like oil, alcohol, and sugar do not conduct electricity very well and thus, have a low conductivity in water [1].

Inorganic dissolved solids are essential ingredients for aquatic life. They regulate the flow of water in and out of organisms' cells and are the building blocks of the molecules necessary for life. A high concentration of dissolved solids can decrease dissolved oxygen levels and cause water balance problems for aquatic organisms (Source: Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods, 1991). As Figure 1 shown, conductivity values below 300 µs/cm protect aquatic life and values above 500 µS/cm should not be exceeded [3].

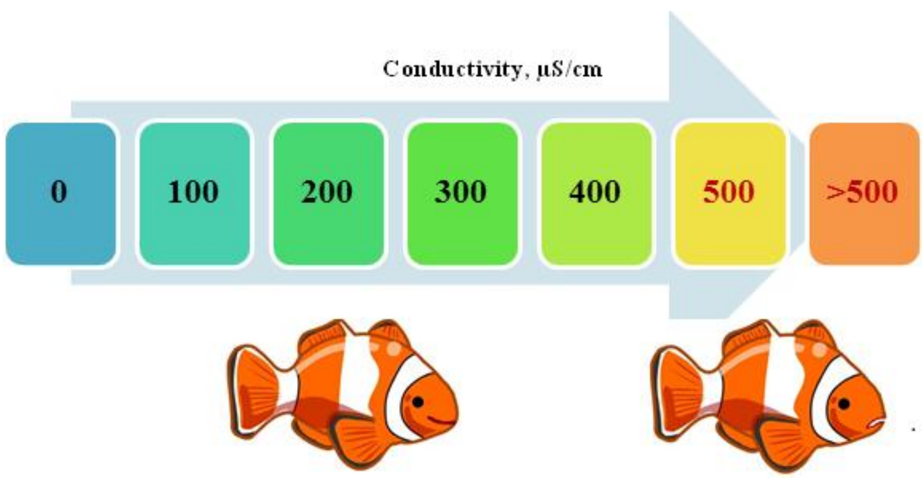

Figure 1. Conductivity values and the aquatic life [3].

Dissolved Oxygen

The concentration of dissolved oxygen (DO) in water is the mass of oxygen gas present per liter of water. DO can be expressed in milligrams per liter (mg/L) or parts per million (ppm). The underwater DO cycle is shown in Figure 2 [4].

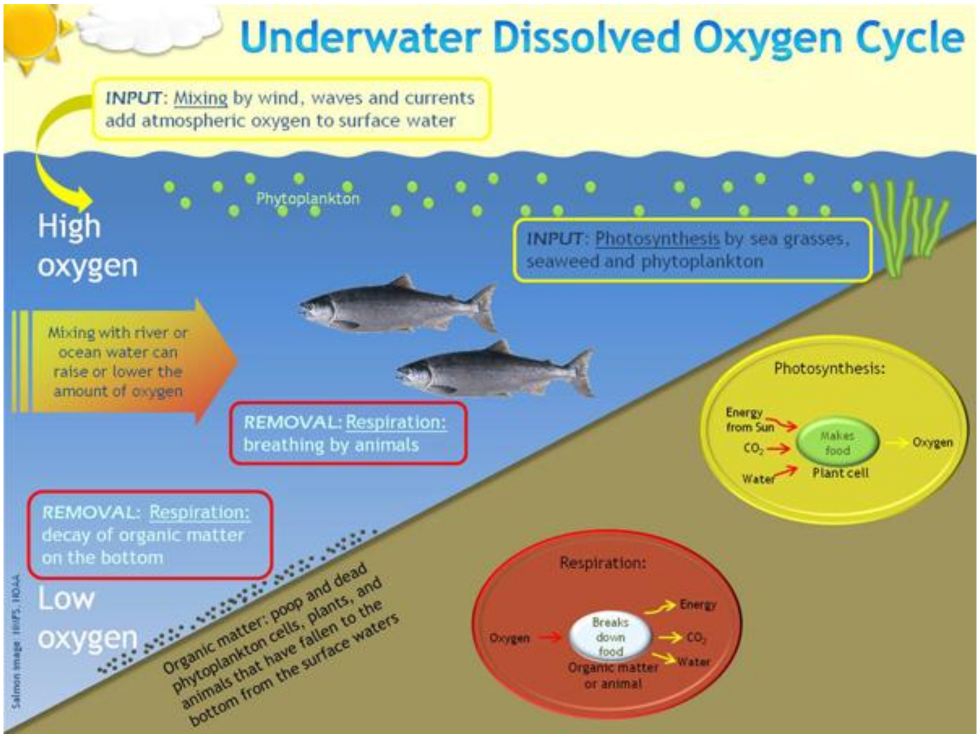

Figure 2. Underwater dissolved oxygen cycle [4].

(Source: The Northwest Association of Networked Ocean Observing Systems, NANOOS, http://www.nanoos.org/education/learning_tools/hypoxia/oxygen_underwater.php)

Factors Affecting DO:

1. Temperature – Oxygen is more easily dissolved in cold water.
2. Flow – Oxygen concentrations vary with the volume and velocity of water flow. Because more oxygen from the atmosphere enters faster flowing water, faster flowing water tends to be more oxygen rich than slower, stagnant water.
3. Aquatic Plants – Green plants release oxygen into the water during photosynthesis. Photosynthesis occurs during the day when the sun is out and ceases at night. In streams with significant populations of algae and other aquatic plants, the DO concentration may fluctuate daily, reaching its highest levels in the late afternoon. Because plants take in oxygen, dissolved oxygen levels may drop significantly by early morning.
4. Altitude – Oxygen in more easily dissolved in water at low altitudes than at high altitudes.

5. Dissolved or Suspended Solids – Oxygen is more easily dissolved in water with low levels of dissolved or suspended solids.

Human Activities Affecting DO [1]:

1. Removal of vegetation may lower oxygen concentrations due to increased water temperature that results from a lack of canopy shade. Lower oxygen concentrations can also be due to increased suspended solids that result from the erosion of bare soil.
2. Typical urban human activities may lower oxygen concentrations. Runoff from water-resistant surfaces with salts, sediments and other pollutants increases the amount of suspended and dissolved solids in stream water.
3. Organic wastes and other nutrient inputs from sewage, industrial discharges, septic tanks, and agricultural/urban runoff can result in decreased oxygen levels. Nutrient inputs often lead to excessive algal growth. When the algae die, the organic matter is decomposed by bacteria. Bacterial decomposition consumes a great deal of oxygen.
4. Dams may pose an oxygen supply problem when they release waters from the bottom of their reservoirs into streams and rivers. Although the water on the bottom is cooler than the water on top, it is often low in oxygen due to large accumulations of organic matter that has been decomposed by bacteria.

Streams with high DO concentrations are typically considered healthy streams because they are able to support a greater diversity of aquatic organisms. Healthy streams are characterized by cold, clear water with enough riffles to provide sufficient mixing of atmospheric oxygen into the water. Chart of the DO needs of various types of marine organisms is shown in Figure 3 [5].

In streams that have been impacted by any of the above factors, summer is usually the most crucial time for DO levels because stream flows tend to decrease and water temperatures tend to increase.

In general, DO levels less than 3 mg/L are stressful to most aquatic organisms. A majority of fish die at 1-2 mg/L. However, fish can swim away from low DO areas. Water with DO levels from

0.5-2 mg/L are considered hypoxic, and waters with less than 0.5 mg/L are anoxic (depleted of dissolved oxygen). The range of tolerance for DO in fish is shown in Figure 4 [6].

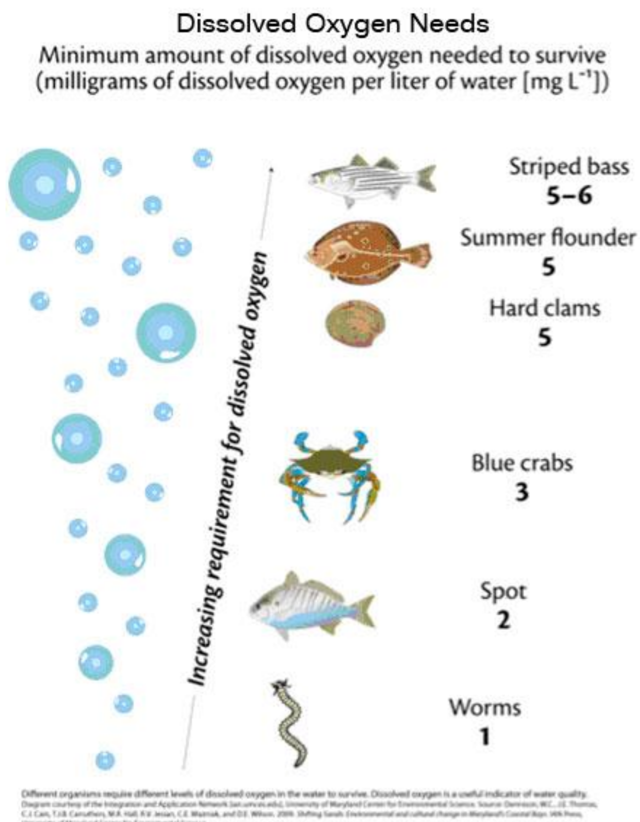

Figure 3. The DO needs of various types of marine organisms [5].
(Source: Watershed Counts, http://www.watershedcounts.org/marine_water_quality.html)

Because the temperature of a stream can vary daily, it is important to factor out the effect of temperature when analyzing the DO levels in a sample of water. This is achieved by considering the saturation value. Saturation is the maximum level of DO that would be present in the water at a specific temperature, in the absence of other influences. Once the temperature of the water is known, an oxygen saturation table can be used to determine the maximum DO concentration. The percent saturation can then be calculated by comparing the maximum saturation value with the actual measured DO value. Simply divide the measured DO value by the maximum saturation value (Source: Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods, 1991).

For example, if a stream has a temperature of 8°C, the maximum saturation value would be 11.83 mg/L. If the DO reading is 8.5 mg/L, the percent saturation would be 8.50/11.83 = 71.9%. Since a healthy stream is considered to be 90-100% saturated, other external factors must be negatively affecting the stream's oxygen levels [1].

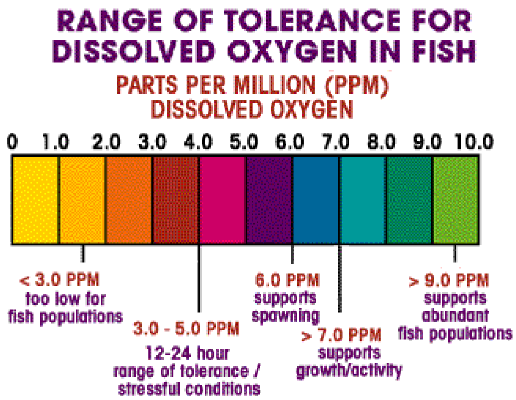

Figure 4. The range of tolerance for DO in fish [6]

(Source: Brian Oram, http://www.water-research.net/index.php/dissovled-oxygen-in-water)

Fecal Coliform

Human and animal wastes are sources of pathogenic (disease-causing) bacteria and viruses and thereby can contaminate stream systems. Disease causing organisms are often accompanied by other common types of nonpathogenic bacteria found in animal intestines such as fecal coliform bacteria, *Enterococci* bacteria, and *Escherichia coli* (*E. coli*) bacteria [1]. Therefore, fecal coliform serves as indicator of water quality. In general, increased levels of fecal coliforms indicate failure in water treatment, a break in the integrity of the distribution system, possible contamination with pathogens.

To measure fecal coliform, water samples are first collected in sterilized containers. The samples are then forced through a filter and incubated at a specific temperature for a certain amount of time. The colonies that form during incubation are counted and recorded as the number of colony forming units per 100 mL of water (Source: Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods, 1991). The photo of fecal coliform colonies is shown in Figure 5 [7].

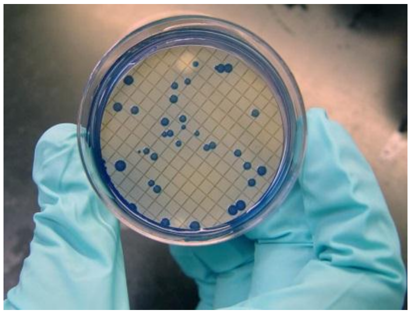

Figure 5. The photo of fecal coliform colonies [7].

(Source: http://hoopmanscience.pbworks.com/w/page/47828206/Water%20Monitoring%3A%20%20Coliform)

Hardness

Hardness is frequently used as an assessment of the quality of a water supply. Hardness is determined by the water's content of the following salts (Source: Limnology, Wetzel, 1983):

- Calcium and magnesium (temporary hardness)
- Bicarbonate, carbonate, sulfates, chlorides, and other anions of mineral acids (permanent hardness)

Figure 6 shows the formation of hard water [8].

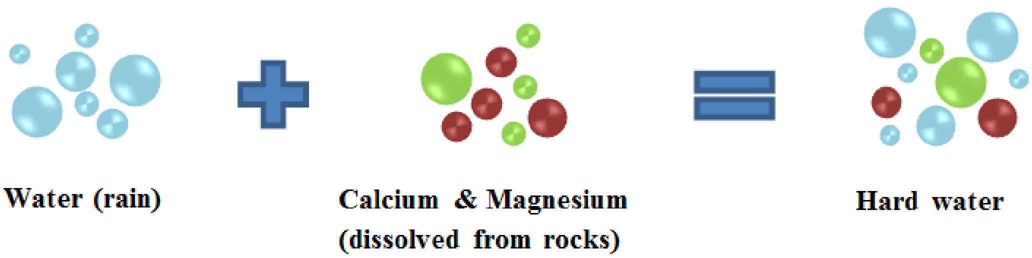

Figure 6. The formation of hard water [8].

How hardness is classified is based on the following scale in Table 2 (Source: American Society of Agricultural Engineers, S-339, and the Water Quality Association, WQA):

Table 2. Water hardness scale.

Degree of Hardness	Grains per Gallon, gpg	mg/L
Soft	<1.0	<17.0
Slightly Hard	1.0-3.5	17.1-60
Moderately Hard	3.5-7.0	60-120
Hard	7.0-10.5	120-180
Very Hard	>10.5	>180

Metals

The effects of metals in water and wastewater range from beneficial to troublesome to dangerously toxic. Some metals are essential, while others negatively affect water consumers, wastewater treatment systems, and receiving waters. Some metals may be either beneficial or toxic depending on concentration (Source: 19th Edition, Standard Methods, 1995).

The primary mechanism for toxicity to organisms that live in water is by absorption or uptake across the gills; this physiological process requires metal to be in a dissolved form. It is important to note that particulate metals appear to exhibit substantially less toxicity than dissolved metals (Source: U.S. EPA).

Metal Classification:

1. Dissolved – This classification includes metals of unacidified samples that pass through a 0.45 micrometer membrane filter and are thought to better represent the bioavailable fraction of metal in a water sample when compared to total recoverable metals (Source: U.S. EPA, The metal Translator: Guidance for Calculating a Total Recoverable Permit Limit from a Dissolved Criterion, June 1996).
2. Recoverable – This classification includes metals that are not tightly bound and thus, are biologically available to aquatic organisms.
3. Total – This classification includes all metals (inorganically and organically bound metals as well as dissolved and particulate metals). Total metals give an unrealistically high value of the metals that are biologically available to aquatic organisms.

In small concentrations, some metals are not acutely toxic. Heavy metals such as cadmium (Cd), mercury (Hg), arsenic (As) and lead (Pb) are the most toxic to aquatic organisms. Some water quality parameters that affect metal toxicity include temperature, pH, hardness, alkalinity, suspended solids, redox potential, and dissolved organic carbon. Metals can bind to many organic and inorganic compounds thereby, reducing the toxicity of the metals. The possible sources and sinks of heavy metals are shown in Figure 7 [9].

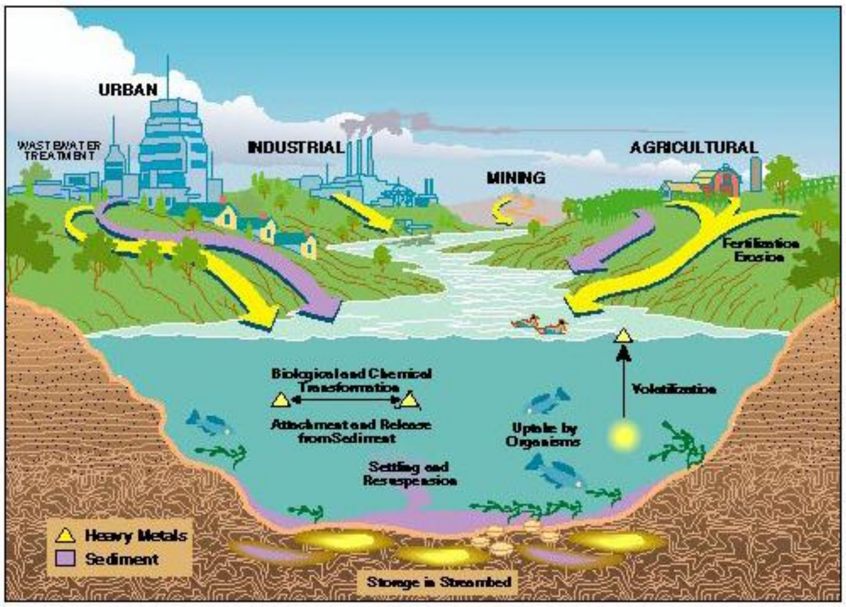

Figure 7. Sources and sinks of heavy metals in water [9].

(Source: John R. Garbarino HCH, David A. Roth, Ronald C. Antweiler, Terry I. Brinton, and Howard E. Taylor. Heavy Metals in the Mississippi River. US Geological Survey Circular, 1995)

Nitrogen

Nitrogen is essential to all forms of life. Nitrogen in the atmosphere and soil goes through many complex chemical and biological processes. For example, the nitrogen cycle is the process by which nitrogen is converted between its various chemical forms, as shown in Figure 8 [10].

Nitrogen occurs in natural waters in various forms including nitrate (NO_3), nitrite (NO_2), and ammonia (NH_3), as shown in Figure 9 [11]. Nitrate is the most common form measured. Ammonia, on the other hand, is the least stable form of nitrogen and thus, is difficult to measure accurately. Nitrite is less stable and usually present in much lower amounts than nitrate.

These three compounds are interrelated through the process of nitrification – the biological oxidation of ammonia to nitrate. In this process, nitrite is produced as an intermediate product. In relatively stable, oxygenated natural water systems the oxidation of nitrite to nitrate is rapid, but the conversion of NH_3 to NO_2^- is significantly slower (Source: Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods, 1991).

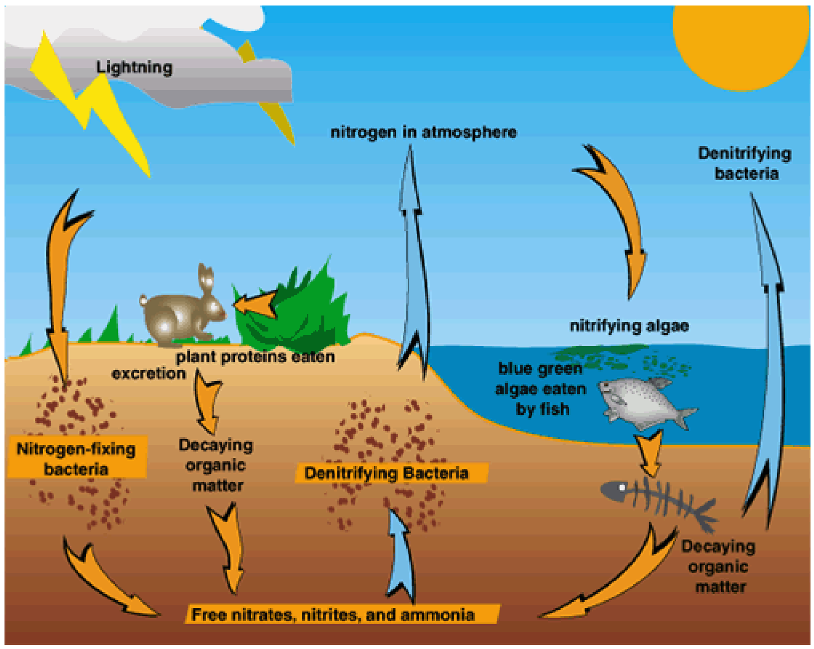

Figure 8. Nitrogen cycle in atmosphere, soil and water [10].

(Source: https://myweb.rollins.edu/jsiry/biogeochem.html.)

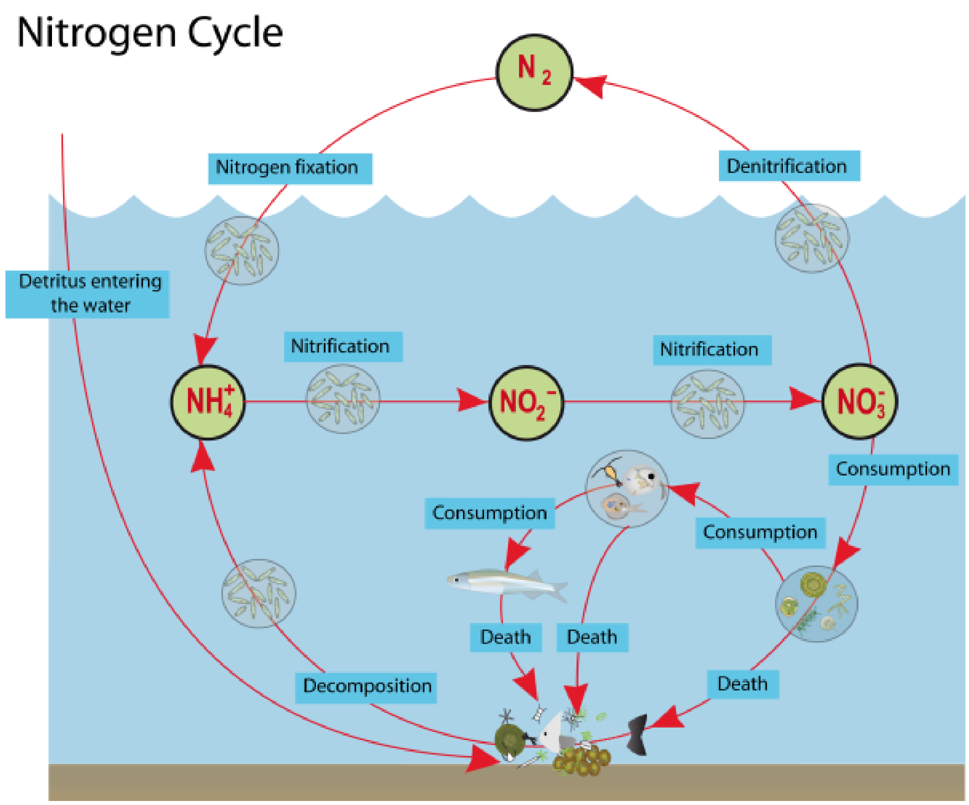

Figure 9. Nitrogen cycle in water [11].

(Source: Rhode Island Sea Grant, http://seagrant.gso.uri.edu/blog/2015/02/25/nitrogen-cycle-lie/.)

Order of decreasing oxidation state:

Nitrate (most stable) → Nitrite → Ammonia → Organic Nitrogen (least stable)

Forms of Nitrogen [1]:

1. Nitrogen as Ammonia – Ammonia (NH_3) is one of the most important pollutants in aquatic environments because of its relatively high toxic nature and its ubiquity in surface water systems. Ammonia is discharged in large quantities in industrial, municipal, and agricultural waste waters. In aqueous solutions, ammonia assumes two chemical forms: ammonium (NH_4^+) and ammonia (NH_3). Total NH_3 is therefore equal to the sum of the NH_3 and NH_4^+.
   a. Ammonium is ionized and less toxic/nontoxic.
   b. Ammonia is unionized and toxic.
2. Nitrogen as Nitrate – Nitrate (NO_3) usually appears in trace quantities in surface water. It is an essential nutrient for many photosynthetic autotrophs and has been identified as a growth limiting nutrient. Nitrate is only found in small amounts of fresh domestic

wastewater. However, in nitrogen treatment plants, nitrate can be found in concentrations up to 30 mg nitrogen/L (Source: 19th Edition, Standard Methods, 1995). Nitrate is a less serious environmental problem than other forms of nitrogen because it can be nontoxic even at relatively high concentrations. When nitrate concentrations become excessive and other essential nutrient factors are present, eutrophication (nutrient enrichment) and algal blooms can be become a problem (Source: Fundamentals of Aquatic Toxicology, 1985).

3. Nitrogen as Nitrite – Nitrite (NO_2) is extremely toxic to aquatic life. It is usually present only in trace amounts in most natural freshwater systems and is rapidly oxidized to nitrate. In sewage treatment plants that use the nitrification process to convert ammonia to nitrate, nitrite is sometimes discharged at elevated concentrations into receiving waters. If the pH of the water sample increases, either naturally or by the addition of a base, the concentration of unionized NH_3 increases. This impedes the conversion of nitrite to nitrate, causing nitrite to accumulate (Source: Fundamentals of Aquatic Toxicology, 1985).
4. Nitrogen as Total Kjeldahl – When organic nitrogen and ammonia are measured together they are referred to as “Kjeldahl nitrogen (TKN)” (Source: 19th Edition, Standard Methods, 1995).
5. Organic Nitrogen – Organic nitrogen is the byproduct of living organisms’ proteins, peptides, nucleic acids, urea, and other synthetic organic materials. Typical organic nitrogen concentrations vary from a few hundred mg/mL in some lakes to more than twenty mg/L in raw sewage (Source: 19th edition, Standard Methods, 1995).

pH

pH is an important chemical factor of aquatic life. Water that is too acidic or basic can disrupt biochemical reactions resulting in the harm or death of aquatic organisms. pH is expressed on a scale of 1 to 14. A solution with a pH less than 7 is considered acidic. A solution with a pH greater than 7 is considered basic. The pH scale is logarithmic, meaning that the values change in factors of ten. For example, a one-point pH change indicates that the strength of the acid or base has increased or decreased tenfold.

Streams generally have a pH ranging between 6 and 9. The presence of dissolved substances from bedrock, soil and other materials greatly affect the pH of streams. The pH scale with examples and environmental effects is shown in Figure 10 [12].

Changes in pH impact many aspects of water chemistry. For instance, as pH increases, smaller concentrations of ammonia are needed to reach a level that is toxic to fish. As pH decreases, metal concentrations may increase because higher acidity increases the metals' ability to be dissolved from sediments into water (Source: Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods, 1991).

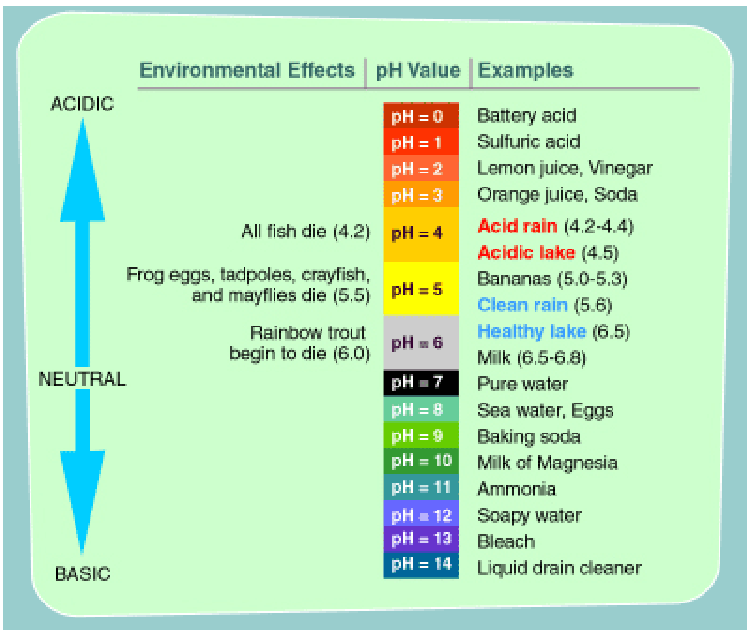

Figure 10. The environmental effects and examples for different pH values [12].

(Source: US EPA, http://www3.epa.gov/acidrain/education/site_students/phscale.html)

A. Acidity

The acidity of water is its quantitative capacity to react with a strong base until it reaches a designated pH. It is important to note that acidity can be interpreted in terms of specific substances only when the chemical composition of the sample is known (Source: 19th Edition, Standard Methods, 1995).

B. Alkalinity

The alkalinity, or the buffering capacity, of water refers to how well it can neutralize acidic pollution and resist changes in pH. Alkalinity measures the amount of alkaline compounds such as carbonates, bicarbonates and hydroxides, in a specific sample of water. These compounds are natural buffers that remove excess hydrogen (H^+) ions, resulting in a basic solution (Source: Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods, 1991).

Total Solids

Total solids is a measure of the suspended and dissolved solids in a body of water. It is related to both conductivity and turbidity. To measure total suspended and dissolved solids, a sample of water is placed in a drying oven to evaporate the water, leaving only the solids. To measure dissolved solids, the sample is filtered before it is dried and weighed. To calculate the suspended solids, the weight of the dissolved solids is subtracted from the total solids (Source: Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods, 1991).

The chart in Figure 11 shows the typical total dissolved solids (TDS) concentration in different kinds of water [13]. TDS is not a pollutant, but can indicate the presence of pollutants. Watersheds have naturally occurring dissolved solids, but mine runoff can carry toxic sediments and solids. Increases of TDS amounts in streams may indicate the addition of pollutants from a nearby mine. TDS is recorded in milligrams per liter (mg/L). TDS higher than 500 mg/L could be harmful to aquatic life [3].

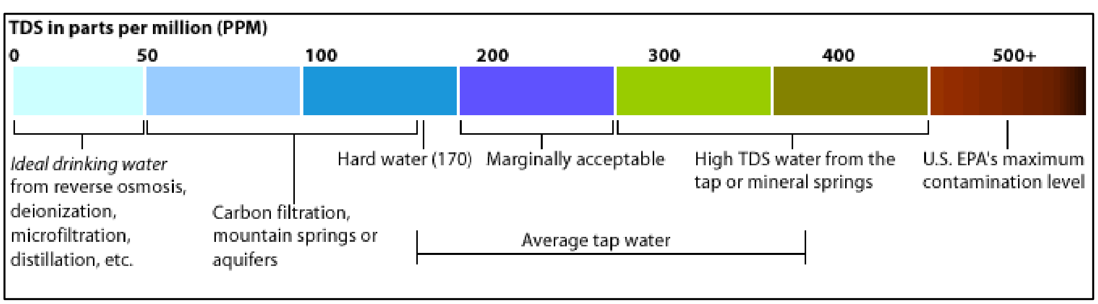

Figure 11. The chart of typical TDS concentration in water [13].

(Source: http://www.tdsmeter.com/what-is.)

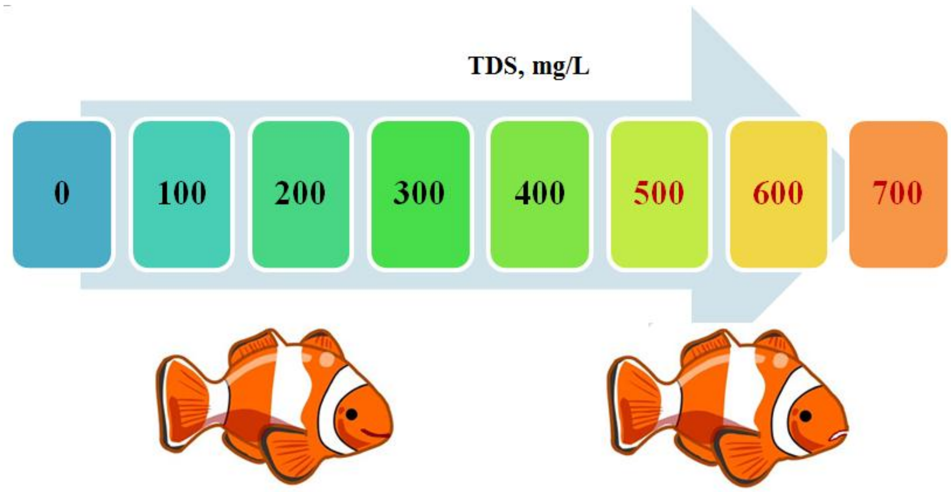

Figure 12. TDS values and the aquatic life [3].

Temperature

Water temperature is a limiting factor for aquatic life. For example, temperature controls the rate of metabolic and reproductive activities, thereby affecting life cycles. If water temperatures increase, decrease or fluctuate too widely, metabolic activities may speed up, slow down, malfunction, or stop altogether [1].

Usually the temperature variation in water is much less than that in terrestrial environments [14]. However, there are many factors that can influence water temperature [1]. Water temperatures can fluctuate seasonally, daily, and even hourly, especially in smaller sized bodies of water. Spring discharges and overhanging vegetation provide shade and helps buffer the effects of temperature changes. Temperature is also influenced by the quantity and velocity of water flow. It is important to note that the sun has a smaller effect on the temperature of faster flowing water than slower flowing water.

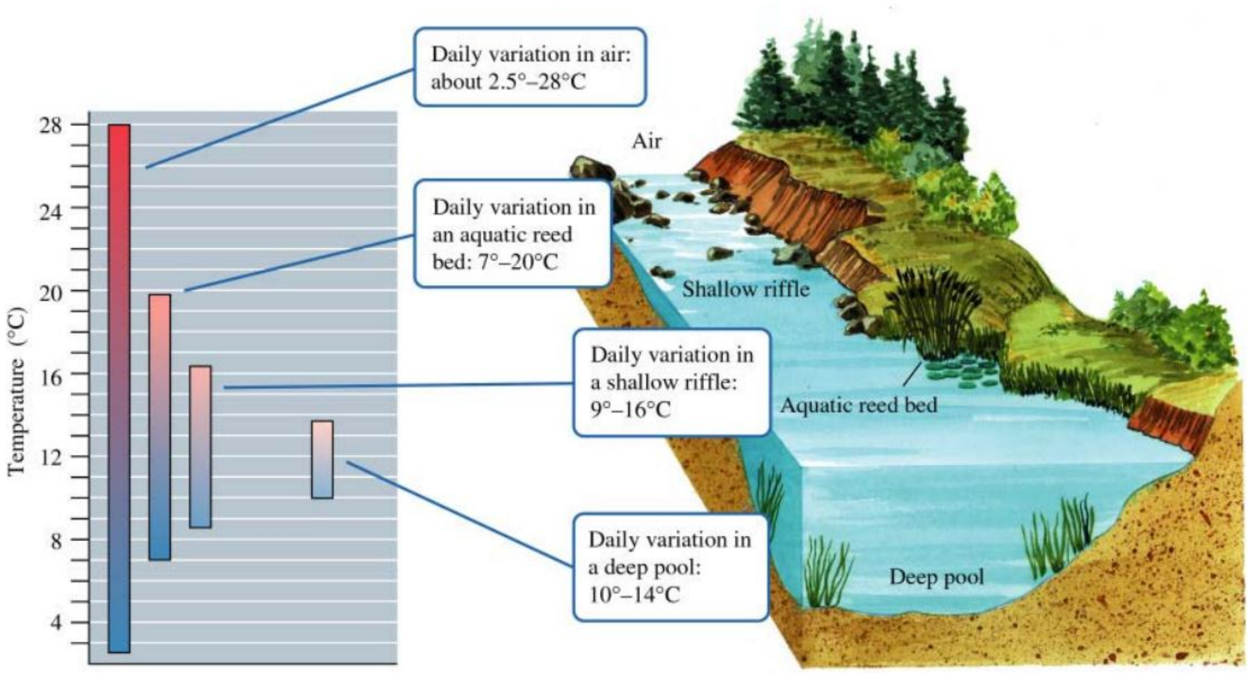

Figure 13. Temperature variation in water [14].

(Source: Figure 5.7, Molles & Cahill, Ecology, 2008)

Temperature affects the concentration of dissolved oxygen in a water body. Oxygen is more easily dissolved in cold water (Source: Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods, 1991).

Turbidity

Turbidity is a measure of the cloudiness of water. The measurement of turbidity is shown in Figure 14. Cloudiness is caused by suspended solids (mainly soil particles) and plankton (microscopic plants and animals) [1]. Moderately low levels of turbidity may indicate a healthy, well-functioning ecosystem. However, higher levels of turbidity pose several problems for water systems. Turbidity blocks out the light needed by submerged aquatic vegetation. Turbidity can also raise surface water temperatures since suspended particles facilitate the absorption of heat from sunlight.

Suspended soil particles may carry nutrients, pesticides, and other pollutants throughout a water system, and can bury eggs and benthic critters when they settle. Turbid waters may also be low in dissolved oxygen. High turbidity may result from runoff containing sediment or from nutrient inputs that cause plankton blooms (Source: Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods, 1991).

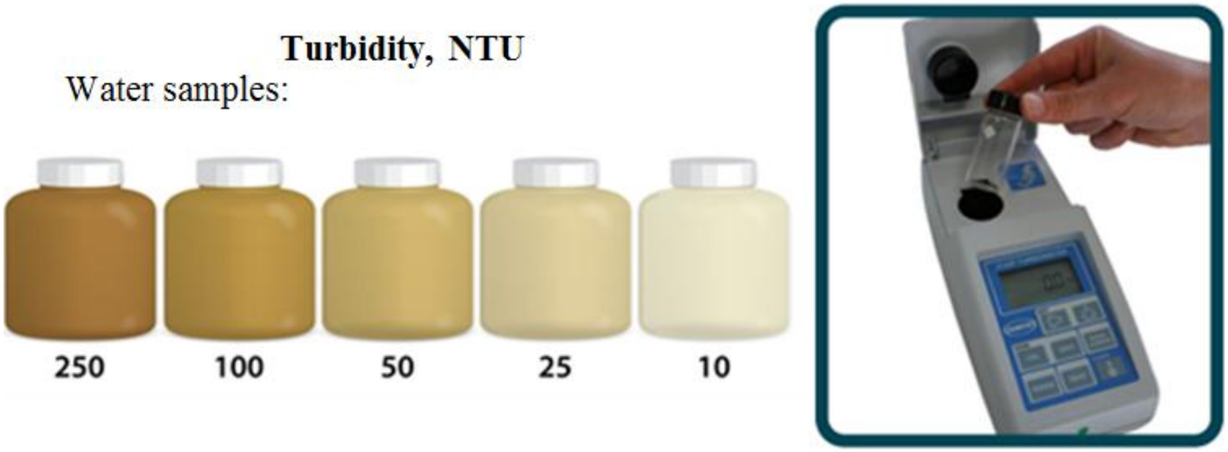

Figure 14. Turbidity measurement.

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