Objectives:
- Comprehend what is meant by the term “water quality”
- Understand how water quality is assessed
- Identify water pollution sources

**Water Quality**

**Water quality** can be described as the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular use. Scientists measure and analyze certain characteristics of the water to determine water quality (e.g., temperature, pH, dissolved oxygen, turbidity, specific conductance, ammonia, chloride, sulfate). These characteristics are then compared to standards and guidelines established by the United States Environmental Protection Agency (USEPA) and the States. The standards and guidelines are established to protect water for designated uses such as drinking, recreation, agricultural irrigation, or protection and maintenance of aquatic life.

A change in water quality can occur naturally as a result of the water flowing over the land and picking up characteristics from soils, topography, and vegetation or water quality may be affected by man’s actions. Now more than ever we hear in the news about situations in which the water is “polluted.” What this means is that the integrity of the water has been altered. For example, runoff into streams and lakes of pesticides applied to land such as farms or urban areas may compromise water quality.

Water pollutants are categorized as either point source or non-point sources.

- **A point source** refers to an identifiable source from which pollutants are discharged such as a petrochemical facility, a feedlot, or the effluent pipe from a wastewater treatment plant. Point source pollutants (PSPs) encountered in municipal wastewater treatment plants include ammonia, chlorine, chloride, nutrients like phosphorus and nitrogen, sulfate, bacteria, and dissolved solids. Other PSPs include toxic substances associated with industrial facilities such as oil and brine water related to oil drilling operations.

- **Non-point source** refers to pollutants that do not have a specific point of origin or are disperse, such as runoff from crops and urban areas. Such sources of pollutants may include nutrients, dissolved solids, suspended solids, pesticides, ammonia, sulfate, chloride, bacteria, trash, and oil and grease.
  - Erosion of soil and sediment is also a powerful non-point source of pollution as these soils can transport considerable amounts of nutrients, organic nitrogen and phosphorous, and some pesticides like DDT.
  - Non-point sources (NPSs) do not have to be directly transported in water. Air pollution in the form of nutrients, sulfur and nitrogen dioxide (usually from coal-burning facilities), and pesticides, can be transported far from their area of origin to impact water sources at a distance and constitutes a major portion of NPSs.

Regardless of the source of pollutants, numerous pathways exist to transmit these pollutants over large distances (Fig. 1). Seepage through empty spaces in the soil can allow pollutants to gain...
access to underground water sources, overland runoff can take pollutants directly into surface water bodies such as streams, and circulating lake or ocean water can resuspend particles that have settled to the bottom of these water bodies for years afterward. Wind currents can transmit pollutants over vast distances – as California residents have experienced from all the discharges from factories in China!

How Do We Measure Water Quality?

Many measurements can be taken of water quality both out in nature and in a laboratory setting. The next few pages detail the most common measurements used to assess water quality.

Water Temperature

Some industries withdraw water from a water body and use it to cool down the facility and then return the water back to the water body, essentially adding heat to the water. This is called thermal pollution. An increase in the temperature of the water has several biological, chemical and physical effects. This increase in temperature affects the ability of water to hold oxygen. As temperature increases, dissolved oxygen decreases. This can have severe repercussions on the reproductive cycles and respiration rates of fish. As fish are cold-blooded, the temperature of the water is also directly related to their metabolic rate. Chemical reactions such as the decomposition of wastes also occur much faster in warmer water, which in turn, consumes more oxygen. Warm water also makes some substances, such as cyanides, phenol, xylene, and zinc more toxic for aquatic animals.

Other variables that may naturally affect the temperature of a water body include:

- Color of the water - dark-colored water, or those with dark muddy bottoms absorb heat best.
- Depth of the water - deeper waters are cooler than shallow waters simply because they require more time to warm up.
- Shade - trees overhanging the shoreline or bank of a water body shade the water from sunlight.
- Latitude – water bodies in cooler climates are naturally cooler than those in warm climates. Temperatures vary from -2°C near the poles to 31°C along the equator.
- Time of year - the temperature of a water body varies with the seasons.
- Temperature of the water source - some water bodies are fed by cold mountain streams or underground springs. Others are supplied by rain and/or surface run-off. The temperature of the water flowing into the water body helps determine its temperature.
- Volume of water - the more water there is, the longer it takes to heat up or cool down.

| Q10 Rule | Changes in the growth rates of cold-blooded aquatic organisms and many biochemical reaction rates can often be approximated by this rule which predicts that growth rate will double if temperature increases by 10°C (18°F) within their "preferred" range. |

**Dissolved Oxygen**

Dissolved oxygen (DO) is a measure of the amount of gaseous oxygen (O₂) dissolved in water. Even though the water molecule (H₂O) contains an oxygen atom, fish and aquatic organisms cannot split water for oxygen; only organisms that perform photosynthesis can perform this process. So, the oxygen required for aquatic organisms to survive must be dissolved in the water body as a product of photosynthesis from the aquatic plants and algae, by aeration (rapid movements by wind, rain, and water currents) of the water, or by diffusion from the surrounding air. DO concentrations are usually expressed as mg/L or as percent saturation.

DO levels fluctuate over a 24-hour day. As the sun rises, photosynthesis begins (producing oxygen and consuming carbon dioxide) and continues to increase throughout the day. Once the sun sets, photosynthesis stops, therefore the oxygen content decreases due to respiration (i.e., breakdown of sugars in the body with oxygen to produce energy and CO₂) and consumption by fish and other aquatic organisms. Just before dawn, DO levels are usually at their lowest. DO levels are also lower in the summer since warmer water holds less oxygen than cooler water.

Sometimes organic materials or wastes, such as sewage, enter a water body and are naturally decomposed by bacteria (decomposers). Since the decomposition process performed by these bacteria requires oxygen, this reduces the amount of DO available for fish and other aquatic organisms. The amount of oxygen required to decompose such organic materials is called biochemical oxygen demand (BOD). Even excess nutrients (e.g., phosphorus, nitrogen) from surface runoff can increase BOD though they promote growth of photosynthetic aquatic plants and algae. Once these organisms die off they are a source of food for bacteria, which requires oxygen! This process of introducing biological nutrients with a net deleterious effect is called eutrophication. Taken to the extreme, BOD can increase to the point where water becomes anoxic or devoid of dissolved oxygen.

Studies suggest that 4-5 mg/L of DO is the minimum amount that will support a large, diverse fish population. Some sensitive species may require higher levels. The DO level in good fishing
waters generally averages about 9.0 mg/L. As DO levels drop below about 3.0 mg/L even the more hardy fish die.

Dissolved oxygen can also be considered as a percentage of how much oxygen is dissolved in water compared to how much oxygen could be dissolved in water. A concentration of 90% or more dissolved oxygen is considered healthy, although this is contingent on other factors. For example, I could theoretically have water with a temperature of 35°C and have all the dissolved oxygen it could hold (i.e., 100% or fully saturated), but if this water existed near the North Pole, the fish would die from thermal shock!

Other variables that may naturally affect the DO of a water body include:

- Wind – as air holds much more oxygen than water, the interface between air and water promotes diffusion of oxygen into water. Stirring the water increases surface area and diffusion.
- Temperature – warmer water holds less DO than colder water.
- Depth – as decomposition occurs generally at the bottom of a water body, DO decreases with depth. Shallow lakes tend to be more evenly mixed with more uniform DO.
- Seasonal changes – in addition to temperature, loss of leaves in fall can add decomposing material to a water body, decreasing DO.
- Changes in water level, ice cover, and volume of inflowing and outflowing streams.

**pH**

The term “pH” means “the power of hydrogen.” When measuring pH, we are therefore determining the relative concentration (expressed in exponential form) of hydrogen ions. pH is reported in logarithmic units, so each whole number on the pH scale represents an increase or decrease by a factor of 10. Therefore, a substance with a pH of 4 is 10 times more acidic as one with a pH of 5 and a substance with a pH of 9 is ten times more basic/alkaline than a substance with a pH of 8. pH ranges from 0-14, with 7 being neutral. **Acids** have excess hydrogen ions (H\(^+\)) and have a pH less than 7. **Bases** have excess hydroxide/hydroxyl ions (OH\(^-\)) and have a pH greater than 7. The concentration of hydrogen ions is in equilibrium with the concentration of hydroxide ions in pure water yielding a pH of exactly 7. Therefore, we can also define pH as a measure of how acidic or basic something is. The farther a material’s pH is from 7, the more acidic or basic it is (Fig. 2).

The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). For example, in addition to affecting how much and what form of phosphorus is most abundant in the water, pH may also determine whether aquatic life can use it. In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble.

Changing pH in a water body can be an indicator of increasing pollution or some other environmental factor. Most lakes are basic when they are newly formed and become more acidic with time due to the build-up of organic materials. As organic substances decay, carbon dioxide (CO\(_2\)) forms and combines with water to produce a weak acid, called “carbonic” acid. Large amounts of carbonic acid lower a water’s pH. Water vapor formed via evaporation is then
slightly acidic, making all rain slightly acidic. This “acidic” ground and rain water is responsible for creating underground caverns in limestone which are easily soluble in acids. Could we say then that Natural Bridge Caverns near San Antonio resulted from death and decay? Excess decomposition or, as is usually the case, release of chemicals into the air, can create acid rain which is harmful to then sensitive tissue of plants and fish! It can also more quickly dissolve limestone and marble buildings and tombstones which are commonly made out of marble!

Most fish can tolerate pH values of about 5.0 to 9.0. Some effects that pH has aquatic life are shown in Table 1.

<table>
<thead>
<tr>
<th>Limiting pH values</th>
<th>Effects Based on Some Scientific Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>3.8</td>
<td>10.0</td>
</tr>
<tr>
<td>4.0</td>
<td>10.1</td>
</tr>
<tr>
<td>4.1</td>
<td>9.5</td>
</tr>
<tr>
<td>4.3</td>
<td>--</td>
</tr>
<tr>
<td>4.5</td>
<td>9.0</td>
</tr>
<tr>
<td>4.6</td>
<td>9.5</td>
</tr>
<tr>
<td>5.0</td>
<td>--</td>
</tr>
<tr>
<td>5.0</td>
<td>9.0</td>
</tr>
<tr>
<td>--</td>
<td>8.7</td>
</tr>
<tr>
<td>5.4</td>
<td>11.4</td>
</tr>
<tr>
<td>6.0</td>
<td>7.2</td>
</tr>
<tr>
<td>1.0</td>
<td>--</td>
</tr>
<tr>
<td>3.3</td>
<td>4.7</td>
</tr>
<tr>
<td>7.5</td>
<td>8.4</td>
</tr>
</tbody>
</table>

**Turbidity**

**Turbidity** is a measure of the clarity or clearness of water (Fig. 3). Turbidity is measured by passing a beam of light at 90° through a sample of water and seeing how much light is reflected off suspended materials in the water; the greater the concentration of materials, the cloudier the water, and the greater the reflection. Material such as clay, silt, residue from leaves that are suspended in the water and photosynthetic algae (i.e., phytoplankton) reduce the ability of light to be transmitted and make the water cloudy. The largest source of these suspended materials is sediment pollution that results from erosion of farmland, logging operations, construction sites, and mining operations. Turbidity is measured in nephelometric turbidity units (NTU). The device which measures reflection is a nephelometer.

If suspended materials reduce the amount of light that enters a water body then photosynthesis will also be reduced and the production of oxygen for fish and other aquatic organisms will be reduced. Increased amounts of suspended materials may clog or damage the gills of fish and aquatic organisms, resulting in death. These suspended materials also provide a surface area for harmful bacteria to attach and breed. Increased turbidity also means reduced visibility for aquatic organisms which may reduce their ability to find food (Fig. 4).
Specific Conductance

Specific conductance, also called electrical conductivity, is a measure of how well water can conduct an electrical current. It is dependent on the amount of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions with a negative charge) or sodium, magnesium, calcium, iron, copper, and aluminum cations (ions with a positive charge). Pure water, such as distilled water, will have a very low specific conductance while seawater will have a high specific conductance (as large numbers of ions are present in the form of dissolved salts). Organic chemicals such as amino acids, sugars, pesticides, solvents, industrial chemicals, and plastics do not conduct an electrical current even though they may influence turbidity. The basic unit of measurement for specific conductance is the siemens. Because specific conductance in natural water is usually less than 1 siemen/cm, specific conductance is usually reported in microsiemens (1/1,000,000 siemen) per centimeter, or µS/cm.

Ammonia

Sewage is a major source of ammonia (NH₃) in water since it is a decomposition product from urea and protein. Other sources of ammonia include fertilizers, the production of nitric acid, nitrogen compounds, and household ammonia. Ammonia may be toxic to fish and aquatic organisms, even in very low concentrations. When levels reach 0.06 mg/L, fish can suffer gill damage. Ammonia levels greater than approximately 0.1 mg/L usually indicate polluted waters, and when levels reach 0.2 mg/L, even ammonia-tolerant fish like carp begin to die. Toxicity of ammonia is greatly influenced by and increases directly with the pH and temperature.

Nitrates and Nitrites

Nitrates and nitrites are produced in the nitrogen cycle, when bacteria break down ammonia (NH₃) or ammonium (NH₄ – formed when ammonia reacts with water) first into nitrite (NO₂), and then into nitrate (NO₃). Nitrate is a major ingredient of fertilizer. When nitrate from agricultural and lawn runoff washes into nearby water bodies, the growth of algae and aquatic plants is stimulated. This results in a lowered DO level and fish may die as discussed above. Nitrates also may get into water bodies from livestock feedlots and discharges from car exhausts.

Phosphates

Phosphates are used in fertilizers, pesticides, industrial processes, and cleaning compounds. Natural sources of phosphate include rocks and soil. When phosphates enter into nearby water bodies the growth of algae and aquatic plants is stimulated. This results in a lowered DO level and fish may die. Phosphates also enter water bodies from human and animal wastes.

Sulfates

Sulfates are the name given to salts possessing the sulfate ion SO₄²⁻. Sulfates commonly are formed during combustion of fossil fuels and are introduced to the air as small particles called aerosols. They can also be introduced to water bodies through the current extensive application of copper sulfate. Copper sulfate is a naturally-occurring inorganic salt commonly employed a fungicide used to control bacterial and fungal diseases of fruit, vegetable, nut and field crops. It is also used as an algaecide, an herbicide in irrigation and municipal water treatment systems, and as a molluscicide, a material used to repel and kill slugs and snails. Copper sulfate is very toxic to fish. Its toxicity to fish varies with the species and the physical and chemical characteristics of the water; however, even at recommended rates of application, it may be
poisonous to trout and other fish, especially in soft or acid waters. Its toxicity to fish generally decreases as pH increases. Fish eggs are more resistant than young fish fry to the toxic effects of copper sulfate. As copper sulfate works wonders as a fungi- and algaecide, its application to water kills vegetation which increases decomposition and BOD.

**Chlorine**

*Chlorine* is an excellent disinfectant and is commonly added to most drinking water supplies in the U.S. It is used as a disinfectant in wastewater treatment plants and swimming pools, as a bleaching agent in paper mills and textile production, and is a major ingredient in laundry bleach. Chlorine becomes more toxic as the pH level of the water drops. The effects of chlorine on fish and aquatic organisms are included in Table 2. It is measured in mg/L.

<table>
<thead>
<tr>
<th>Total chlorine (in mg/L)</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.006</td>
<td>Kills trout fry in two days.</td>
</tr>
<tr>
<td>0.01</td>
<td>Recommended maximum for all fish and aquatic life.</td>
</tr>
<tr>
<td>0.01</td>
<td>Kills Chinook Salmon and Coho Salmon.</td>
</tr>
<tr>
<td>0.01-0.05</td>
<td>Oysters have difficulty pumping water through their bodies.</td>
</tr>
<tr>
<td>0.02</td>
<td>Maximum Brook and Brown Trout can withstand.</td>
</tr>
<tr>
<td>0.05</td>
<td>Maximum amount that can be tolerated by young Pacific Salmon in the ocean.</td>
</tr>
<tr>
<td>0.1</td>
<td>Kills most marine plankton.</td>
</tr>
<tr>
<td>0.25</td>
<td>Only the hardiest fish can survive.</td>
</tr>
<tr>
<td>0.37</td>
<td>Maximum fish can tolerate.</td>
</tr>
<tr>
<td>1.0</td>
<td>Kills oysters.</td>
</tr>
</tbody>
</table>


**Copper**

*Copper* is a reddish metal that occurs naturally in rock, soil, water, sediment, and air. Its unique chemical and physical properties have made it one of the most commercially important metals. Since copper is easily shaped or molded, it is commonly used to make pennies, electrical wiring, and water pipes. Copper compounds are also used as an agricultural pesticide, and to control algae in lakes and reservoirs. Copper also occurs naturally in plants and animals. It is an essential element for all known living organisms, including humans. However, very large single or long-term intakes of copper may harm your health.

It is no surprise then, that copper and its compounds are common in the environment. You may be exposed to copper by breathing air, eating food, or drinking water containing copper. You may also be exposed by skin contact with soil, water, or other copper-containing substances. Copper forms different compounds when it joins with one or more other chemicals. These may be naturally-occurring or man-made. Most copper compounds found in air, soil, and water are
strongly attached to dust or embedded in minerals, and cannot easily enter the body. These forms are not likely to affect your health. Other forms become dissolved in water and are not attached to other particles. In this form, copper is more likely to affect your health.

Levels of copper found naturally in ground water and surface water are generally very low; about 4 micrograms of copper in one liter of water (4 ug/1) or less. This is equivalent to 0.004 parts per million (ppm) or 0.004 milligrams per liter of water (mg/L). However, drinking water may contain higher levels of a dissolved form of copper. In your home, high levels of copper occur if corrosive water comes in contact with copper plumbing and copper-containing fixtures in the water distribution system. If corrosive water remains motionless in the plumbing system for six hours or more, copper levels may exceed 1 mg/L (1000 ug/L).

Copper in our diet is necessary for good health. You eat and drink about 1 mg of copper per day. Drinking water normally contributes approximately 0.15 mg/day. Immediate effects from drinking water which contains elevated levels of copper include vomiting, diarrhea, stomach cramps, and nausea. The seriousness of these effects can be expected to increase with increased copper levels or length of exposure. On the average, drinking water accounts for less than 5% of our daily copper intake. The U.S. Environmental Protection Agency (U.S. EPA) has determined that copper levels in drinking water should not exceed 1.3 mg/L.

So how does it affect fish? Federal mandates usually limit copper in open water (e.g., streams, rivers, lakes) to be under 0.1 mg/L. Copper is essential for normal growth and development of aquatic organisms but excess copper can cause toxicity leading to inhibition of growth or death. It is persistent, meaning it doesn’t break down biologically or chemically, and in plants, it inhibits photosynthesis, leading to death, decomposition, and increased BOD. Copper is measured in mg/L.

Links to Reference Websites:

- **Water On The Web** by Dr. Bruce Munson [http://waterontheweb.org/under/waterquality/index.html]
- **Cornell, Extension Toxicology Network** [http://pme.cce.cornell.edu/profiles/extoxnet/carbaryl-dicrotophos/copper-sulfate-ext.html]