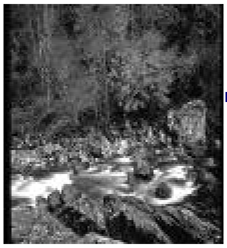


APPENDIX B

DESCRIPTION OF COMMONLY CONSIDERED WATER QUALITY CONSTITUENTS

Dissolved Oxygen

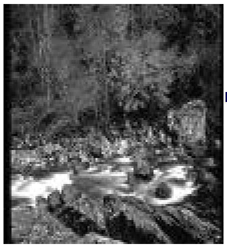
Fish and other aquatic animals depend on dissolved oxygen (the oxygen present in water) to live. The amount of dissolved oxygen in streams is dependent on the water temperature, the quantity of sediment in the stream, the amount of oxygen taken out of the system by respiring and decaying organisms, and the amount of oxygen put back into the system by photosynthesizing plants, stream flow, and aeration. Dissolved oxygen is measured in milligrams per liter (mg/l) or parts per million (ppm). The temperature of stream water influences the amount of dissolved oxygen present; less oxygen dissolves in warm water than cold water. For this reason, there is cause for concern for streams with warm water. Trout need DO levels in excess of 8 mg/liter, striped bass prefer DO levels above 5 mg/l, and most warm water fish need DO in excess of 2 mg/l.

Biochemical Oxygen Demand (BOD)/Chemical Oxygen Demand (COD)

Natural organic detritus and organic waste from waste water treatment plants, failing septic systems, and agricultural and urban runoff, acts as a food source for water-borne bacteria. Bacteria decompose these organic materials using dissolved oxygen, thus reducing the DO present for fish. Biochemical oxygen demand (BOD) is a measure of the amount of oxygen that bacteria will consume while decomposing organic matter under aerobic conditions. Biochemical oxygen demand is determined by incubating a sealed sample of water for five days and measuring the loss of oxygen from the beginning to the end of the test. Samples often must be diluted prior to incubation or the bacteria will deplete all of the oxygen in the bottle before the test is complete.

The main focus of wastewater treatment plants is to reduce the BOD in the effluent discharged to natural waters. Wastewater treatment plants are designed to function as bacteria farms, where bacteria are fed oxygen and organic waste. The excess bacteria grown in the system are removed as sludge, and this "solid" waste is then disposed of on land.

Chemical oxygen demand (COD) does not differentiate between biologically available and inert organic matter, and it is a measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. COD values are always greater than BOD values, but COD measurements can be made in a few hours while BOD measurements take five days.



If effluent with high BOD levels is discharged into a stream or river, it will accelerate bacterial growth in the river and consume the oxygen levels in the river. The oxygen may diminish to levels that are lethal for most fish and many aquatic insects. As the river re-aerates due to atmospheric mixing and as algal photosynthesis adds oxygen to the water, the oxygen levels will slowly increase downstream. The drop and rise in DO levels downstream from a source of BOD is called the *DO sag curve.*

pH/Acidity/Alkalinity

pH is a measure of the amount of free hydrogen ions in water. Specifically, pH is the negative logarithm of the molar concentration of hydrogen ions.
$pH = -\log[H^+]$

for example,	at pH 2,	$[H^+] = 10^{-2}$ or .01
	at pH 10	$[H^+] = 10^{-10}$ or .0000000001
	at pH 4	$[H^+] = 10^{-4}$ or .0001

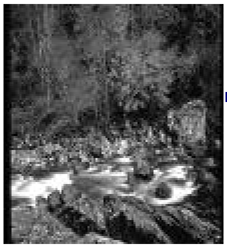
Because pH is measured on a logarithmic scale, an increase of one unit indicates an increase of ten times the amount of hydrogen ions. A pH of 7 is considered to be neutral. Acidity increases as pH values decrease, and alkalinity increases as pH values increase. Most natural waters are buffered by a carbon-dioxide-bicarbonate system, since the carbon dioxide in the atmosphere serves as a source of carbonic acid.

$$H_2CO_2 \dashrightarrow HCO_3 + H^+ \qquad pK \sim 7.5$$

This reaction tends to keep pH of most waters around 7 - 7.5, unless large amounts of acid or base are added to the water. Most streams draining coniferous woodlands tend to be slightly acidic (6.8 to 6.5) due to organic acids produced by the decaying of organic matter. Natural waters in the Piedmont of Georgia also receive acidity from the soils. In waters with high algal concentrations, pH varies diurnally, reaching values as high as 10 during the day when algae are using carbon dioxide in photosynthesis. pH drops during the night when the algae respire and produce carbon dioxide.

The pH of water affects the solubility of many toxic and nutritive chemicals; therefore, the availability of these substances to aquatic organisms is affected. As acidity increases, most metals become more water soluble and more toxic. Toxicity of cyanides and sulfides also increases with a decrease in pH (increase in acidity). Ammonia, however, becomes more toxic with only a slight increase in pH.

Alkalinity is the capacity to neutralize acids, and the alkalinity of natural water is derived principally from the salts of weak acids. Hydroxide, carbonates, and bicarbonates are the dominant source of natural alkalinity. Reactions of carbon dioxide with calcium or



magnesium carbonate in the soil creates considerable amounts of bicarbonates in the soil. Organic acids such as humic acid also form salts that increase alkalinity. Alkalinity itself has little public health significance, although highly alkaline waters are unpalatable and can cause gastrointestinal discomfort.

Nutrients

Nutrients such as phosphorous and nitrogen are essential for the growth of algae and other plants. Aquatic life is dependent upon these photosynthesizers, which usually occur in low levels in surface water. Excessive concentrations of nutrients, however, can overstimulate aquatic plant and algae growth. Bacterial respiration and organic decomposition can use up dissolved oxygen, depriving fish and invertebrates of available oxygen in the water (*eutrophication*).

Fertilizers, failing septic systems, waste water treatment plant discharges, and wastes from pets and farm animals are typical sources of excess nutrients in surface waters. In aquatic ecosystems, because phosphorous is available in the lowest amount, it is usually the limiting nutrient for plant growth. This means that excessive amounts of phosphorous in a system can lead to an abundant supply of vegetation and cause low DO. The forms of nitrogen found in surface water are nitrate, nitrite, and ammonia. Ammonia is usually rapidly converted to nitrate in aerobic waters, as is true in soils (nitrate is a stable form of nitrogen, while ammonia is unstable). Ammonia is associated with municipal treatment discharges, and the stressing effects of ammonia on aquatic organisms, increase at low dissolved oxygen levels and at increased pH. Increased nitrogen levels adversely affect cold-water fish more than they do warm water fish. Nitrogen concentrations of 0.5 mg/liter are toxic to rainbow trout. Nitrogen is also a concern in drinking water because an increased level of nitrate has been linked with blue-baby syndrome in infants. In 1986, EPA established a 10 mg/liter concentration of nitrate as a standard for drinking water.

Limnologists and stream ecologists have broadly categorized the productivity of lakes and streams into three classes: *oligatrophic, mesotrophic, and eutrophic*. An *oligatrophic* water has very low inputs of nutrients and carbon, and so primary biological productivity (plant growth) is low. Water tends to be very clear. Most mountain streams and lakes in pristine areas tend to be oligatrophic. A *mesotrophic* water has moderate amounts of nutrients and carbon. Aquatic life tends to be very diverse in mesotrophic waters. A *eutrophic* water is highly productive because of high amounts of nutrients and carbon. Eutrophic waters tend to be unstable in their chemistry and biology, and as a result, species richness and diversity tends to be low even though biomass is quite high. Eutrophication is usually a man-induced process where elevated nutrient levels over-stimulate biological production.

Conductance or Electrical Conductivity (EC) and Dissolved Solids

Conductivity is the ability of a substance to conduct electricity. The conductivity of water is a more-or-less linear function of the concentration of dissolved ions. Conductivity itself is not a human or aquatic health concern, but because it is easily measured, it can serve as an indicator of other water quality problems. If the conductivity of a stream suddenly increases, it indicates that there is a source of dissolved ions in the vicinity. Therefore, conductivity measurements can be used as a quick way to locate potential water quality problems. Conductivity is measured in terms of conductivity per unit length, and meters typically use the units microsiemens/cm.

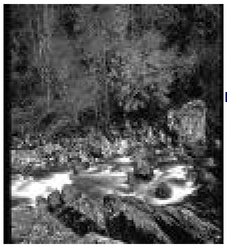
All natural waters contain some dissolved solids due to the dissolution and weathering of rock and soil. Dissolved solids are determined by evaporating a known volume of water and weighing the residue. Some but not the entire dissolved solids act as conductors and contribute to conductance. Waters with high total dissolved solids (TDS) are unpalatable and potentially unhealthy. Water treatment plants use flocculants to aggregate suspended and dissolved solids into particles large enough to settle out of the water column in settling tanks. A flocculent is a chemical that uses double-layer kinetics to attract charged particles.

Metals, Pesticides and Herbicides, Organics

Metals, petroleum products, and organic contaminants, including solvents, electrical insulators, lubricants, herbicides, fungicides, and pesticides, can accumulate in aquatic environments and cause toxic effects on aquatic life and increase health risks of drinking water. These chemicals are at very low concentrations in the natural environment, and they are typically introduced to surface waters as waste from human activities. Some of the metals of concern for human and aquatic health are cadmium, lead, copper, mercury, selenium, and chromium. Cadmium is widely used in industry and is often found in solution in industrial waste discharges. Cadmium replaces zinc in the body, and long-term consumption of cadmium may lead to bodily disorders. Cadmium is toxic to both humans and fish and seems to be a cumulative toxicant. Small salmon fry have been killed from concentrations of 0.03 mg/liter

Lead sources are batteries, gasoline, paints, caulking, rubber, and plastics. Lead can cause a variety of neurological disorders. In children, it inhibits brain cell development. Lead also prevents the uptake of iron, so people ingesting lead often exhibit symptoms of anemia including pale skin, fatigue, irritability, and mile headaches.

Metal plating, electrical equipment, pesticides, paint additives, and wood preservatives are sources of copper. Copper is also toxic to juvenile fish. Other toxicants that are associated with industrial effluent are mercury and silver. Mercury and silver affect fish



in ways similar to cadmium, copper, lead and zinc. When fish are exposed to either of these at certain concentrations, gill tissues are damaged and death by asphyxiation can occur.

Pesticides and herbicides are found in streams and rivers draining agricultural and residential areas, usually during periods of extended wet weather or intense precipitation when overland flow is most likely. These substances are toxic to many aquatic organisms and they may act as mutagens for human beings. Since water treatment plants are not designed to remove these substances, it is important to prevent their introduction to drinking water supplies.

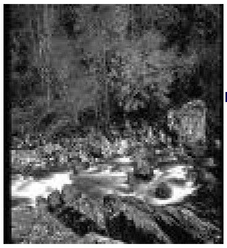
There are a wide variety of organic chemicals, including chlorinated hydrocarbons that are used as solvents, cleaners, lubricants, insulators, and fuels in many industries. Many of these chemicals are believed to be cancer-causing agents. Since these are organic chemicals, most of them are biologically active to some degree. This means that bacteria in the environment often degrade these substances into byproducts. Unfortunately, some of these byproducts are more toxic than the original substance.

The EPA regulates concentrations of literally hundreds of these chemicals in drinking water and groundwater. These chemicals are often found in association with each other, and the inter-actions of these chemicals as mutagens are poorly understood. Because they are suspected cancer-causing agents, regulatory levels for many of these chemicals are in the parts per billion range, which means that analytical techniques for these chemicals are rigorous, time-consuming, and expensive. False positive measurements for these chemicals are quite common.

Sediment and Substrate

Sediment enters streams via upland soil erosion, bank erosion, and land sliding. Sediment is a natural component of streams, but excessive sediment can be carried into streams and rivers from erosion of unstable streambanks, construction sites, agricultural activities, and urban runoff. Sediment moves downstream in a river in two forms: *suspended load* and *bed load*. *Suspended load* includes the particles in suspension in the water column. The red-brown color of Georgia Piedmont streams is due to clay and colloid particles in suspension. *Bed load* refers to the sediment pushed along the bottom of the channel. Coarser substrate such as sand and gravel tends to move as bed load, not suspended load.

Sediment is usually measured as a concentration of total suspended solids (TSS), which is the dry weight after filtering a water sample, expressed in mg per liter. To determine a suspended sediment load (mass/time), the TSS concentration must be multiplied by the flow rate (volume/time). *Turbidity* is another indicator of the amount of material



suspended in water; it measures the amount of light that is scattered or absorbed. Suspended silt and clay, organic matter, and plankton can contribute to turbidity. Photoelectric turbidimeters measure turbidity in nephelometric turbidity units (NTUs). Turbidity units are supposed to correspond to TSS concentrations, but this correlation is only approximate.

Turbidity in a stream will fluctuate before, during and after stormflow. Georgia Rules and Regulations for Water Quality Control, Chapter 391-3-6 (February 2000…need to check latest), give general criteria for all waters, which include narrative standards for turbidity:

> "All waters shall be free from material related to municipal, industrial or other discharges which produce turbidity, color, odor or other objectionable conditions which interfere with legitimate water uses," (Paragraph 391-3-6-.03(5)(c).

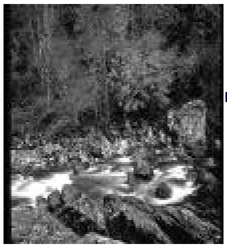
> "All waters shall be free from turbidity which results in a substantial visual contrast in a water body due to a man-make activity. The upstream appearance of a body of water shall be as observed at a point immediately upstream of a turbidity-causing man-made activity. That upstream appearance shall be compared to a point that is located sufficiently downstream from the activity to provide an appropriate mixing zone. For land disturbing activities, proper design, installation, and maintenance of best management practices and compliance with issued permits shall constitute compliance with [this] Paragraph 391-3-6-.03(5)(d)."

Furthermore, the new general NPDES stormwater permit for constructions sites requires that the difference in turbidity not exceed 25 NTU downstream from a construction site compared to upstream. If this criterion is exceeded AND if Best Management Practices (BMPs) are not properly designed, installed or maintained, then the permittee is subject to fines and third party lawsuits (Appendix K).

Turbidities of 10 NTU or less represent very clear waters; 50 NTU is cloudy; and 100-500 or greater is very cloudy to muddy. Some fish species may become stressed at prolonged exposures of 25 NTUs or greater. Furthermore, Barnes (1998) recommended that to maintain native fish populations in Georgia Piedmont Rivers and streams, that random monthly values should never exceed 100 NTU; that no more than 5 percent of the samples should exceed 50 NTU; and no more than 20% should exceed 25 NTU.

Similarly, average TSS concentrations in the range of 25-80 mg/L represent moderate water quality. An average concentration of 25 mg/L has been suggested as an indicator of unimpaired stream water quality (Holbeck-Pelham and Rasmussen, 1997). Some states use 50 mg/L as a screening level for potential impairment to waterbodies.

Fine sediment deposited on the streambed can fill gravel spaces, eliminating spawning habitat for some fish species and also eliminating habitat for many invertebrate species. Turbidity and or TSS can reduce light penetration, decreasing algal growth, and low algal productivity can reduce the productivity of aquatic invertebrates, a food source of many



fish. High turbidity levels affect fish feeding and growth; the ability of salmonids to find and capture food is impaired at turbidities from 25 to 70 NTU. Gill function in some fish may also be impaired after 5 to 10 days of exposure to a turbidity level of 25 NTU. Turbidities of less than 10 describe very clear waters. Waters with turbidity in excess of 50 are quite cloudy, and waters with turbidities exceeding 500 are downright muddy.

Large bed loads can also reduce or eliminate pool habitat essential to low-flow and summer survival of fish. Essentially, channels with high bed loads tend to feature shallower water and a larger wetted perimeter. Channel bed topography as well as the size distribution of sediments on the bottom of the channel (referred to as substrate) are vital factors for the productivity of many fish species. Pools provide resting areas for fish, protection from terrestrial and avian predators, and sometimes provide cooler water, which lowers metabolic needs. Areas of cool water in streams and lakes are called thermal refugia.

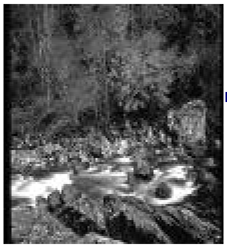
Temperature

Metabolic rate and the reproductive activities of aquatic life are controlled by water temperature. Metabolic activity increases with a rise in temperature, thus increasing a fish’s demand for oxygen; however; an increase in stream temperature also causes a decrease in DO, limiting the amount of oxygen available to these aquatic organisms. With a limited amount of DO available, the fish in this system will become stressed. A rise in temperature can also provide conditions for the growth of disease-causing organisms.

Water temperature varies with season, elevation, geographic location, and climatic conditions and is influenced by stream flow, streamside vegetation, groundwater inputs, and water effluent from industrial activities. Water temperatures rise when streamside vegetation is removed. When entire forest canopies were removed, temperatures in Pacific Northwest streams increased up to 8^{o} C above the previous highest temperature. Water temperature also increases when warm water is discharged into streams from industries.

Woody Debris

Depending on the size and gradient of a channel, the amount and size of woody debris in the channel can have a dramatic effect on the habitat quality and productivity of a channel. Woody debris serves as a scour element, meaning that during high flows water is accelerated in a downward direction around the woody debris and scours out a hole around the bottom of the debris. This hole serves as a pool between storms. The wood itself provides cover, or hiding places, for the fish using the pool. When a stream is



surveyed via electroshocking methods, many of the fish are found in the pools below and around woody debris. In sandy-bottomed streams, wood serves as the best food source and growth platform for aquatic invertebrates. In Coastal Plain streams in Georgia, more than 60% of the food source for fish comes from invertebrates grown on the woody debris. To protect the quality of habitat in a stream or river, it is necessary to maintain a forested riparian corridor from which large woody debris can fall into the channel.

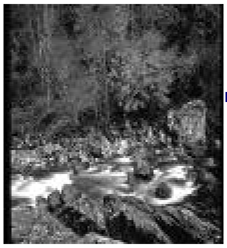
Channel Morphology/Human Channel Manipulation

Channel morphology encompasses all aspects of a channel’s shape, structure, habitat characteristics, and substrate and also the response of a channel to changes in physical inputs. Channel morphology is a function of climate, topography, geology, land use, riparian condition, sediment loading, and flows. Physical water quality considers all aspects of channel morphology, as illustrated above, but also considers temperature and direct human alteration of streams and rivers. A stream that has been placed in a culvert obviously retains few ecological functions.

Culverts and other fish passage barriers such as tide gates are physical alterations that can have large impacts on regional fish populations. A fish population within a given small stream is always in danger of extirpation due to habitat disturbance (a big flood, a chemical spill, a landslide, etc.). As long as this local population can interact with the metapopulation downstream, the habitat can be recolonized. If an impassable culvert prevents upstream migration, however, the total habitat area for a species is reduced. A fish can only swim so fast and so long, and therefore a long culvert with high velocity water prevents upstream migration.

Bacteria

Bacteria and viruses from human and animal wastes carried to streams can cause disease. Fecal coliform, found in the intestines of warm-blooded animals, is the bacteria for which many states’ surface water quality standards are written. Fecal coliform bacteria do not cause disease but are used as an indicator of disease causing pathogens in the aquatic environment. The GA standard is 200 colonies per 100 ml of sample water, but the State of California Water Pollution Control Board recommends concentrations of less than 5 colonies per 100 ml of sample for shellfish culture. Typical sources of bacteria are sewage from septic system failure and stormwater overflows, poor pasture management and animal-keeping practices, pet waste, and urban runoff. High bacteria levels can limit the uses of water for swimming or contaminate drinking water in groundwater wells. The presence of excessive bacteria also may indicate other problems, such as low DO.



Indicator Species or Guilds

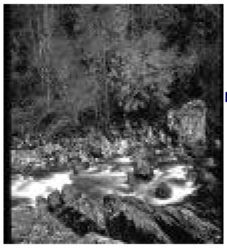
The physiology or life history of certain aquatic species makes them very good biological indicators of physical and chemical water quality. Essentially, some species are more sensitive to chemical or physical water quality impairment, and if these species are reduced in numbers or not present in a portion of their range, this often indicates a problem with water quality. Surveys of the presence and abundance of aquatic species, therefore, can reveal locations of water quality problems.

If poor water quality conditions eliminate the more sensitive species from an ecosystem, then one would expect the species richness and diversity to decline. Species richness is the total number of species in a system, while diversity is typically defined as the ratio of the richness to the total number of individuals. Based on this concept, aquatic scientists have developed a series of metrics known as Indices of Biological Integrity (IBIs), which are statistical metrics accounting for species richness, species abundance, and diversity. IBIs can be calculated for invertebrate communities or fish communities. IBI scores have been shown to be negatively correlated with percent urbanization of a watershed. The more a watershed is developed, the lower the IBI score becomes. IBIs are relatively easy to measure, so overall water quality conditions can be mapped over entire landscapes using IBIs.

Overall Water Quality

The chemical, physical, and biological aspects of water quality are inter-related and must be considered together. For example, higher water temperature reduces the solubility of dissolved oxygen, and may cause a dissolved oxygen shortage that kills more sensitive fish species. The rotting fish carcasses may contribute to a bacterial bloom that makes some human swimmers or boaters ill.

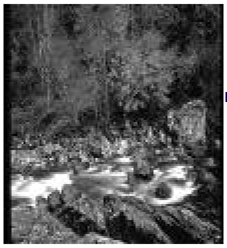
Water quality is highly variable over time due to both natural and human factors. Water temperature, photosynthetic activity, and flows vary with season. Flows, and therefore suspended sediment, can vary daily with rainfall. Nutrient loads can vary with season (homeowners fertilizing in the spring), flow (runoff mechanisms affect pollutant wash-off), and human management (nitrogen is released after a clear-cut). A comprehensive characterization of natural water quality therefore requires a large amount of data. Water quality data is expensive and time-consuming to acquire, however, so water quality managers usually deal with a large amount of uncertainty.



The Environmental Protection Agency (EPA) is the federal agency charged with regulating water quality in the United States. They have set standards for acceptable levels of many aquatic contaminants in drinking water. They have also set targets or guidelines for some water quality characteristics directed at aquatic ecosystem health, fisheries concerns, and safety for human recreation. Table 1 summarizes some of the EPA guidelines for common water quality constituents.

Table B-1. Effects and Drinking Water Standards for Some Water Quality Characteristics

Water Quality Characteristic of Concern	Ecological or Health Effect	Standard	Notes
Dissolved Oxygen	High levels of dissolved oxygen are necessary for fish respiration.	5.0 mg/l average 4.0 mg/l minimum	GA water quality standards.
Temperature	Fish suffer metabolic stress at high temperatures.	90 °F maximum	GA water quality standards.
pH	pH affects the solubility of other water quality contaminants.	6.0 - 9.5	GA water quality standards.
Fecal coliform	Fecal coliforms do not pose a health threat but serve as an indicator for bacteria that can cause illness in humans and aquatic life.	200 col/100ml (May-Oct) 1000 col/100 ml (Nov - April) 4000 col/100 ml (anytime)	GA water quality standards.
Phosphorus	Macronutrient affects aquatic productivity and trophic state.	No effective standard in GA	Any existing standards are waterbody-specific
Total Nitrogen	Macronutrient affects aquatic productivity and trophic state.	4.0 mg/l	GA water quality standards.
Nitrate	Causes blue baby syndrome.	10 mg/l	Federal Drinking Water Std.
Metals: Arsenic Cadmium Chromium Copper Lead Mercury Silver	Heavy metals cause a variety of problems including interfering with vitamin uptake, neurological disorders, and disruption of renal function. These problems result from chronic and cumulative exposure.	mg/l 0.05 0.01 0.05 1.0 0.05 0.002 0.05	Federal Drinking Water Standards.
TDS	General indicator of ion concentrations. Affects taste.	500 mg/l	Federal Drinking Water Std.



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