
1

INTRODUCTION

Introduction

Water composition

Pure water

Salts and ions in water

Principal contaminants and ions in water and measurement methods

Sources of water

Water quality

Water quality regulations—legal structure

Rules and regulations for water quality control

Applications

Sample problem

Solution

Drinking water quality standards: USA and international standards

INTRODUCTION

This course is almost all about water and its treatment. In it we will look at all the phases of the water environment, the types and characteristics, and contaminants. We will also discuss briefly various elements of hydrology and hydraulics, but only in enough detail, to permit you to get familiar with each subject and recognize some pitfalls and common mistakes chemical engineers make when they deal with the water environment.

We will also look at the elements of biological treatment in some depth because it is important to know what the limits of biological systems are, and more important, where are they applicable and inapplicable. We will look at some of the pitfalls inherent in the measurement systems we use and even take a

brief look at the accuracy of our measurements so that we may adequately characterize the materials we discharge to the regulatory community.

WATER COMPOSITION

Water is composed of two parts hydrogen and one part oxygen. It is not the materials of the water but the contaminants in it that make it important. If we look at a chemical reaction, we would be happy with a yield of 99.95% purity. However, for water this level of impurity is unacceptable. We are dealing with a substance where the levels of contaminants that we often consider insignificant can spoil the quality or use of the product.

Examples of the forgoing are things like salinity or dissolved NaCl, which if present in levels of 500 ppm or higher render water marginally potable. Another shining example: the presence of as little as 1 ppm of lead, 10 ppm of nitrate, 10 ppm of sewage solids, or 5 ppm of the right detergent will render the water unusable.

PURE WATER

Characteristics:

Formula: H₂O

Dissolved Gases: The most important is oxygen and the second most important is nitrogen

Solubility of Gases in Water: Solubility (See Table 1.1).

The concentration of oxygen in water at any pressure is given by:

$$\begin{aligned} \ln C = & -139.34411 + (1.575701 \times 10^{+5}/T) - (6.642308 \times 10^{+7}/T^2) \\ & + (1.243800 \times 10^{+10}/T^3) - (8.621949 \times 10^{+11}/T^4) \\ & - \mathbf{Chl}[\{3.1929 \times 10^{+2}\} - \{1.9428 \times 10^{+1}/T\} + \{3.8673 \times 10^{+3}/T^2\}] \end{aligned}$$

where **Chl** is the chlorinity measured in grams/kilogram and is defined as:

$$\text{Chlorinity} = \text{Salinity}/1.80655$$

Salinity is approximately equal to total solids in water after carbonates have been converted to oxides and after all bromide and iodide have been replaced by chloride.¹

Nitrogen is soluble in water too, but the presence of nitrogen in the gaseous or N₂ form is essentially inert. Principal forms of nitrogen in water are ammonia, nitrate, and nitrite. The only time one has to worry about the solubility of nitrogen or other gases in water is when one is designing a pressure flotation system.

¹See Standard Methods Oxygen Dissolved Method 4500-O/Azide Modification.

TABLE 1.1 Solubility of Oxygen in Water Exposed to Water-Saturated Air at Atmospheric Pressure (101.3 kPa)¹

| Oxygen Solubility in mg/l | | | | | | |
|---------------------------|--------|--------|--------|--------|--------|--------|
| Temperature | | | | | | |
| Chlorinity: | 0 | 5 | 10 | 15 | 20 | 25 |
| 0 | 14.621 | 13.728 | 12.888 | 12.097 | 11.355 | 10.657 |
| 1 | 14.216 | 13.356 | 12.545 | 11.783 | 11.066 | 10.392 |
| 2 | 13.829 | 13.000 | 12.218 | 11.483 | 10.790 | 10.139 |
| 3 | 13.460 | 12.660 | 11.906 | 11.195 | 10.526 | 9.897 |
| 4 | 13.107 | 12.335 | 11.607 | 10.920 | 10.273 | 9.664 |
| 5 | 12.770 | 12.024 | 11.320 | 10.656 | 10.031 | 9.441 |
| 6 | 12.447 | 11.727 | 11.046 | 10.404 | 9.799 | 9.228 |
| 7 | 12.139 | 11.442 | 10.783 | 10.162 | 9.576 | 9.023 |
| 8 | 11.843 | 11.169 | 10.531 | 9.930 | 9.362 | 8.826 |
| 9 | 11.559 | 10.907 | 10.290 | 9.707 | 9.156 | 8.636 |
| 10 | 11.288 | 10.656 | 10.058 | 9.493 | 8.959 | 8.454 |
| 11 | 11.027 | 10.415 | 9.835 | 9.287 | 8.769 | 8.279 |
| 12 | 10.777 | 10.183 | 9.621 | 9.089 | 8.586 | 8.111 |
| 13 | 10.537 | 9.961 | 9.416 | 8.899 | 8.411 | 7.949 |
| 14 | 10.306 | 9.747 | 9.218 | 8.716 | 8.242 | 7.792 |
| 15 | 10.084 | 9.541 | 9.027 | 8.540 | 8.079 | 7.642 |
| 16 | 9.870 | 9.344 | 8.844 | 8.370 | 7.922 | 7.496 |
| 17 | 9.665 | 9.153 | 8.667 | 8.207 | 7.770 | 7.356 |
| 18 | 9.467 | 8.969 | 8.497 | 8.049 | 7.624 | 7.221 |
| 19 | 9.276 | 8.792 | 8.333 | 7.896 | 7.483 | 7.090 |
| 20 | 9.092 | 8.621 | 8.174 | 7.749 | 7.346 | 6.964 |
| 21 | 8.915 | 8.456 | 8.021 | 7.607 | 7.214 | 6.842 |
| 22 | 8.743 | 8.297 | 7.873 | 7.470 | 7.087 | 6.723 |
| 23 | 8.578 | 8.143 | 7.730 | 7.337 | 6.963 | 6.609 |
| 24 | 8.418 | 7.994 | 7.591 | 7.208 | 6.844 | 6.498 |
| 25 | 8.263 | 7.850 | 7.457 | 7.083 | 6.728 | 6.390 |
| 26 | 8.113 | 7.711 | 7.327 | 6.962 | 6.615 | 6.285 |
| 27 | 7.968 | 7.575 | 7.201 | 6.845 | 6.506 | 6.184 |
| 28 | 7.827 | 7.444 | 7.079 | 6.731 | 6.400 | 6.085 |
| 29 | 7.691 | 7.317 | 6.961 | 6.621 | 6.297 | 5.990 |
| 30 | 7.559 | 7.194 | 6.845 | 6.513 | 6.197 | 5.896 |
| 31 | 7.430 | 7.073 | 6.733 | 6.409 | 6.100 | 5.806 |
| 32 | 7.305 | 6.957 | 6.624 | 6.307 | 6.005 | 5.717 |
| 33 | 7.183 | 6.843 | 6.518 | 6.208 | 5.912 | 5.631 |
| 34 | 7.065 | 6.732 | 6.415 | 6.111 | 5.822 | 5.546 |
| 35 | 6.950 | 6.624 | 6.314 | 6.017 | 5.734 | 5.464 |
| 36 | 6.837 | 6.519 | 6.215 | 5.925 | 5.648 | 5.384 |
| 37 | 6.727 | 6.416 | 6.119 | 5.835 | 5.564 | 5.305 |
| 38 | 6.620 | 6.316 | 6.025 | 5.747 | 5.481 | 5.228 |
| 39 | 6.515 | 6.217 | 5.932 | 5.660 | 5.400 | 5.152 |
| 40 | 6.412 | 6.121 | 5.842 | 5.576 | 5.321 | 5.078 |
| 41 | 6.312 | 6.026 | 5.753 | 5.493 | 5.243 | 5.005 |

TABLE 1.1 (Continued)

| Oxygen Solubility in mg/l | | | | | | |
|---------------------------|-------|-------|-------|-------|-------|-------|
| Temperature | | | | | | |
| Chlorinity: | 0 | 5 | 10 | 15 | 20 | 25 |
| 42 | 6.213 | 5.934 | 5.667 | 5.411 | 5.167 | 4.933 |
| 43 | 6.116 | 5.843 | 5.581 | 5.331 | 5.091 | 4.862 |
| 44 | 6.021 | 5.753 | 5.497 | 5.252 | 5.017 | 4.793 |
| 45 | 5.927 | 5.665 | 5.414 | 5.174 | 4.944 | 4.724 |
| 46 | 5.835 | 5.578 | 5.333 | 5.097 | 4.872 | 4.656 |
| 47 | 5.744 | 5.493 | 5.252 | 5.021 | 4.801 | 4.589 |
| 48 | 5.654 | 5.408 | 5.172 | 4.947 | 4.730 | 4.523 |
| 49 | 5.565 | 5.324 | 5.094 | 4.872 | 4.660 | 4.457 |
| 50 | 5.477 | 5.242 | 5.016 | 4.799 | 4.591 | 4.392 |

Henry's law gives us some idea of the solubility of other gases.

Stating the pressure–concentration ratio as an equation and using the usual modern symbol for the Henry's law constant on a concentration basis give the following form of Henry's law:

$$p = K'_c c$$

In this form p is the partial pressure of the gas, c is its molar concentration, and K'_c is the Henry's law constant on the molar concentration scale. Henry's law is found to be an accurate description of the behavior of gases dissolved in liquids when concentrations and partial pressures are reasonably low. As the concentrations and partial pressures increase, deviations from Henry's law become noticeable. This behavior is very similar to the behavior of gases, which are found to deviate from the ideal gas law as pressures increase and temperatures decrease. For this reason, solutions that obey Henry's law are sometimes called ideal dilute solutions.

Values of the Henry's law constants for many gases in many different solvents have been measured. Table 1.2 gives a few selected values of the Henry's law constants for gases dissolved in water.

Values in this table are calculated from tables of molar thermodynamic properties of pure substances and aqueous solutes.

The inverse of the Henry's law constant, multiplied by the partial pressure of the gas above the solution, is the molar solubility of the gas. Thus oxygen at one atmosphere would have a molar solubility of $(1/756.7) \text{ mol/dm}^3$ or 1.32 mmol/dm^3 .

The following examples will help in understanding this concept.

TABLE 1.2 Molar Henry's Law Constants for Aqueous Solutions at 25°C

| Gas | Constant (Pa/(mol/dm ³)) | Constant (atm/(mol/dm ³)) |
|-----------------|---|--|
| He | $282.7 \times 10^{+6}$ | 2865.0 |
| O ₂ | $74.68 \times 10^{+6}$ | 756.7 |
| N ₂ | $155 \times 10^{+6}$ | 1600.0 |
| H ₂ | $121.2 \times 10^{+6}$ | 1228.0 |
| CO ₂ | $2.937 \times 10^{+6}$ | 29.76 |
| NH ₃ | $5.69 \times 10^{+6}$ | 56.9 |

Example 1: The amount of oxygen dissolved in air-saturated water under normal atmospheric conditions at 25°C can be calculated as follows. Normal atmospheric condition is 20.948 mol% oxygen, which makes the partial pressure of oxygen 0.20948 atm or 20.67 kPa. Using Henry's law, the concentration of oxygen is $0.20948 \text{ atm}/(756.7 \text{ atm}/(\text{mol}/\text{dm}^3))$, which is $2.768 \times 10^{-4} \text{ mol}/\text{dm}^3$ or $0.2768 \text{ mmol}/\text{dm}^3$, given the weight of 32 g/mol that comes out to be $0.0000088576 \text{ g}/\text{dm}^3$ or about 8.85 mg/l, which is to be compared with the tabular value of 8.23 mg/l from Table 1.2.

Example 2: If we want to run a dissolved air flotation system at 50 psig (115.23 ft of water pressure or 3.4473785 bar) for the pressure for flotation, how much nitrogen and oxygen will be produced when we release the pressure back to atmospheric?

The density of water is about $1 \text{ kg}/\text{dm}^3$ or $1000 \text{ kg}/\text{m}^3$. The pressure is approximately equal to a column of water 35.15344 m high. A column of water 35.15 m high would exert a pressure of $35153.44 \text{ kg}/\text{m}^2$ of its base, which converts to 344.73748 kPa pressure. The total system pressure is atmospheric pressure plus compression or $101.325 \text{ kPa} + 344.7375 \text{ kPa}$ or a total of 446.0625 kPa. (This is equivalent to $446.0625/101.325 = 4.4023 \text{ atm}$.) The pressure change of 3.4023 atm ($4.4023 \text{ atm} - 1 \text{ atm}$) will produce a concentration change of $3.4023/1600 = 0.0021264375 \text{ mol}/\text{dm}^3$.² (The pressure change of 344.738 kPa will cause a concentration change of $2.12644 \text{ mmol}/\text{dm}^3$). For each gallon of water the amount of nitrogen generated is $3.785 \times 2.12644 \text{ mmol} = 8.418 \text{ mmol}$ or 0.00666 ft^3 of nitrogen per gallon, or about 189 ml of nitrogen. For oxygen, the change is about $4.496 \text{ mmol}/\text{dm}^3$ or about 100.7 ml of O₂ per liter or about 382 ml per cubic foot. The total volume for flotation is about 571 ml of gas per cubic foot.

²Note that the difference in constants does cause some differences in the concentration and volume in the second and third decimal places and beyond.

The value of the Henry's law constant is temperature dependent. The value generally increases with increasing temperature. As a consequence, the solubility of gases generally decreases with increasing temperature. One example of this can be seen when water is heated on a stove. The gas bubbles appearing on the sides of the pan well below the boiling point of water are bubbles of air, which evolve due to the lowered solubility from hot water. The addition of boiled or distilled water to a fish tank will cause the fish to die of suffocation unless the water has been allowed to re-aerate before addition.

A very complete listing of many Henry's law constants can be found at <http://www.mpch-mainz.mpg.de/~sander/res/henry.html#3>. The file is in Adobe Acrobat and Zip formats. A computer program for calculating Henry's law coefficients can be found on the World Wide Web at http://www.syrres.com/esc/est_soft.htm. A specific value for a Henry's coefficient determined by one researcher may disagree with the same coefficient determined by another researcher by an order of magnitude.

If you have one value for a Henry's coefficient at a given set of conditions, ($\text{atm m}^3/\text{mol}$) it can be transformed to another set of conditions by the equation:

$$H_{TS} = H_R \times \exp[-\Delta H_{V,TS}/R_c(1/T_S - 1/T_R)]$$

where H_{TS} is the coefficient at temperature T_S , and T_R is the reference temperature in K (kelvin). The term $\Delta H_{V,TS}$ is the enthalpy of vaporization at T_S in units of cal/mol, and R_c is the gas constant, which has units of 1.9872 cal/mol K. The enthalpy can be obtained either from steam tables for water or chemical engineering tables for other fluids, or by using an alternative procedure for estimating the enthalpy of vaporization from the USEPA Web site: <http://www.epa.gov/athane/learn2model/part-two/onsite/esthenry-background.htm>.

The study of Henry's law has been of interest to the chemical engineering community for a long time. However, when the problems of benzene, toluene, and MTBE in groundwater were encountered, the subject regained renewed interest from the environmental community because of the use of Henry's law in strippers designed to remove the benzene, toluene, ethylbenzene, xylene, and MTBE resulting from a gasoline spill or tank release. MTBE cannot be removed effectively by stripping alone. Henry's coefficients may not really be considered a constant but will vary with temperature and pressure.

SALTS AND IONS IN WATER

There are a variety of salts in water. The most abundant salt in water is sodium chloride or NaCl. Table 1.3 shows the approximate concentration of the principal dissolved elements in seawater.

TABLE 1.3 Approximate Concentration of Principal Dissolved Elements in Seawater

| Element | Concentration | | Element | Concentration | |
|-----------|-----------------------|------------------|-----------|-----------------------|------------------|
| | Coefficient (mg/l) | Exponent (10) | | Coefficient (mg/l) | Exponent (10) |
| Oxygen | 8.57 | 5 | Potassium | 3.8 | 2 |
| Hydrogen | 1.08 | 5 | Bromine | 2.8 | 1 |
| Chlorine | 1.9 | 4 | Strontium | 8.1 | 0 |
| Sodium | 1.05 | 4 | Boron | 4.6 | 0 |
| Magnesium | 1.35 | 3 | Silicon | 3 | 0 |
| Sulfur | 8.85 | 2 | Fluorine | 3 | 0 |
| Calcium | 4 | 2 | Argon | 6 | -1 |

Source: Handbook of Chemistry and Physics – 66 ed.

Later on, we will see that sodium salt is the most important salt in water, while calcium and magnesium salts are the most abundant in freshwater, and the interactions between carbon dioxide and lime stone (calcium carbonate and magnesium carbonate formations) also play a significant role in water and water treatment.

PRINCIPAL CONTAMINANTS AND IONS IN WATER AND MEASUREMENT METHODS

If we are going to consider the concentrations of chemicals in water, we must also have some knowledge about the way in which the chemicals are measured. This is not a text on analytical chemistry but merely a brief mention of some of the methods of detecting the most common compounds dissolved in water.

In analytical industry there are two principal references on methods. The first and oldest one is *Standard Methods for the Examination of Water and Wastewater*, published by the American Water Works Association, the Water Environment Federation, and the American Public Health Association. The second one has become important not only because of its publisher: *SW-846, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, which was originally published by the United States Environmental Protection Agency (USEPA) Office of Solid Waste Research, principally for hazardous waste analyses, but also for many of the methods that are applicable to groundwater and wastewater. It has also become a de facto standard in the United States and elsewhere because of the many references in EPA-issued permits to the manual. The manual can be viewed and downloaded at <http://www.epa.gov/epaoswer/hazwaste/test/main.htm>. However, it often does not include as thorough an explanation of the methods

TABLE 1.4 Analytical Methods Used for Compounds in Water

| Element | Measurement Method | Element <i>n</i> | Measurement Method |
|------------------------------------|-------------------------------|---------------------------------------|--------------------------------|
| Aluminum | Flame ionization | Carbonate (CO ₃) | Calculation |
| Antimony | Flame ionization | Chloride (Cl) | Gravimetric |
| Arsenic | Flame ionization | Cyanide (CN) | Colorimetric |
| Calcium | Flame ionization | Fluoride (F) | Gravimetric |
| Chromium | Flame ionization | Hydronium (OH) | pH |
| Copper | Flame ionization | Hypochlorite (HClO ₂) | pH |
| Hydrogen | pH | Hypochlorous (ClO ₂) | pH |
| Iron | Flame ionization | Nitrate (NO ₃) | Colorimetric |
| Lead | Flame ionization | Nitrite (NO ₂) | Colorimetric |
| Magnesium | Flame ionization | Sulfate (SO ₄) | Colorimetric |
| Manganese | Flame ionization | Sulfite (S) | Colorimetric |
| Mercury | Flame ionization | OTHER | |
| Potassium | Flame ionization | Alkalinity | Colorimetric |
| Silica | Flame ionization | Total org. carbon | Gravimetric |
| Silver | Flame ionization | Diss. O ₂ | Azide titr or probe |
| Sodium | Flame ionization | Org. nitrogen | Kjeldahl |
| Zinc | Flame ionization | Chem O ₂ Demand | Digestion/titration |
| Ammonia | Kjeldahl or Nesslerization | Biochemical. O ₂ Demand | Difference in oxygen uptake |
| Bicarbonate (HCO ₃) | Calculation | | |

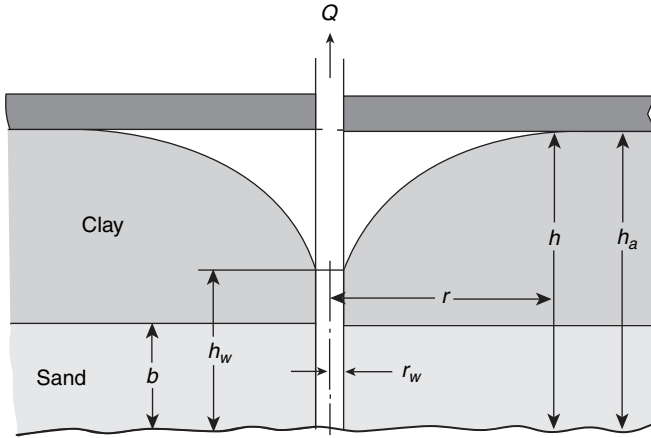
and the procedures as *Standard Methods*, and any good laboratory will have both. The test methods are slightly different, and in some cases, especially where more conventional parameters are involved, *SW-846* is silent.

SOURCES OF WATER

Groundwater

There are several sources for water. Groundwater serves the majority of the small communities in the United States, and elsewhere in the world. It is a source of drinking water. Groundwater is characterized by natural minerals in moderate to low concentrations. It is necessary to mention groundwater because it is most commonly ignored (being out of sight) and we do not often think about the need to protect the groundwater.

Flow regimens in groundwater are linear, and flow through porous media is analogous to heat transfer through solid in a solid medium. The overall equations used to calculate flow regimens are the Darcy equations, and they are laminar flow.



- r_w = Radius of well
- K = Coefficient of permeability
- h_w = Height of water in the well being pumped
- b = Thickness of aquifer
- h_a = Hydraulic head at nonpumping conditions
- Q = Pumping rate
- $Q = 2\pi r b K \frac{dh}{dr}$

$$h - h_w = \frac{Q}{2\pi K b} \ln \frac{r}{r_w} \text{ or } h - h_w = \frac{Q}{2\pi T} \ln \frac{r}{r_w}$$

FIGURE 1.1 Basic groundwater flow equations.

The basic groundwater flow equation is shown below. The equation is in SI units.

$$Q(\text{flow}) = \pi^* K [(H^2 - h^2)] / \log_e (\{D/2\} / \{d/2\})$$

where the characters apply to the drawing shown in Figure 1.1.

The constant K is known as the permeability coefficient and it is given in velocity units of gallons per day per square feet or CuM/D/SqM (M/D) units.

The model used above is the simplest in an extremely complex set of possible combinations because the ground is not a homogeneous medium. I

am raising this point because once contaminated, the groundwater is difficult, if not nearly impossible, to decontaminate. Groundwater protection must be a plant-wide priority.

Surface Water

Surface water has its origins in groundwater and in direct runoff from the ground. Determination of the quantity of water is not within the scope of this course and involves an entire discipline. However, there are a couple of points I do want to make about surface waters, which we will not discuss in relation to discharges. The first is that the surface waters can contain anything from suspended solids to bacteria, from nutrients to logs and automobile bodies.

The second is that you have to look closely at the surface waters when you are planning a discharge. Chances are good that you will be discharging to a surface supply and, perhaps, someone else's drinking water.

Permits for facilities discharging to the surface waters are often written on a "net" discharge basis, or on an average basis, and that represents a potential danger to the plant. Permitting engineers only know one type of distribution: regular or normal distribution. *Hydrologic events such as rainfall and runoff are not normally distributed. This is also true for contaminant loads.* There is ample evidence that the hydrologic events, which generate river flow and river water quality can be modeled by either a log-normal distribution or a Weibull type III distribution. We will talk about some of those distributions later. However, the point is that the permits are written around average statistics, which do not apply, and if you are not careful that can get you into a lot of trouble.

Storm Water

Storm water consists of rainfall, snow melt, hail, and other types of precipitation. It washes the atmosphere and transfers air contaminants into the rain. Hence, stormwater often contains carbonates and sulfates if the air is in an industrial area and the air pollution is bad. Acid rain is really harmful, and it can affect your plant operation.

In Louisiana a few years ago, a company, the author was working for, attempted to get the regulatory community to issue a permit allowance for acid rainfall in the plant discharge permit. The company had documented that the pH decreased substantially whenever they had a rainfall. This is the same type of documentation that the United States has experienced in the Acid Rain Debate where coal-fired boilers in the Midwest are emitting enough sulfur dioxide—which converts to sulfurous and then sulfuric acid—to

change the pH of the rainfall and cause lakes to change their pH, and as a result, their ecosystems. At that time, the request was reasonable, but it was rejected.

In a plant environment, one has to consider the design of the sewer system and the response time for sewer events. In general, if you are monitoring your plant sewer system, you will find a dramatic increase in pollution conveyed to the treatment plant because of the “first flush” phenomenon. As the storm continues, you may find unusual discharges because someone in the plant has decided to “get rid of” that tank of chemical X during the storm, hoping that no one will notice.

Loading operations incidents are also potentially troublesome at this time as well. This is both because the equipment may have physical problems during the rain, and because the operator really does not want to go out into the rain or stay in the rain to monitor the equipment the same way he will in dry weather. Wherever possible, it might be advisable to have loading areas covered so that you will not have to treat the volume of the spill plus the volume of the storm water if there is a spill somewhere close to the time of a rainfall event.

WATER QUALITY

Water is often ranked by its quality. However, there are many different measures of water quality, and the quality of the water often depends upon its use. Water used for drinking tastes flat if it does not have some small quantity of minerals and dissolved oxygen in it. However, that same water so preferred for drinking is terrible for use in a boiler. Similarly, moderate quantities of sulfate in drinking water will cause osmotic diarrhea in sensitive individuals as well as boiler corrosion.³ Dissolved oxygen corrodes boiler tubes, and calcium salts will form deposits on the tubes, reducing the heat transfer efficiency.

Potable water generally has total sodium salt concentrations below 200 mg/l. Salt concentrations greater than 70 mg/l cause the water to taste salty, and above 5000 mg/l of sodium, water is considered brackish and can cause problems with osmotic pressure in human beings.⁴ When the sodium concentration is above 100 there is some small risk to human beings sensitive to sodium in their diet, and various regulatory agencies have suggested maximum sodium concentrations between 100 and 160 mg/l for drinking water.

³EPA suggests that diarrhea can be caused by sulfate levels of more than 650 mg/l in infants and more than 1400 mg/l in adults. For more details see <http://www.epa.gov/safewater/standard/sfstudy.pdf>.

⁴The actual definition of brackish water is between 0.5% and about 1.8% salt (500–18,000 parts per thousand).

Water quality, especially freshwater quality, is often classified by its uses: recreational, drinking, fishing, and recharge. It is important to understand how the water upstream and downstream is being used because the downstream use will often dictate the overall water quality – and that will affect the discharge criteria for water discharge.

Example: There is an old joke about the quickest way to eliminate water pollution: Have the Municipalities build their drinking water intakes downstream of the effluent from the wastewater treatment plant. The most ironic thing about the joke is that with the current water shortages, the need for recycling is growing to the point where highly treated effluent are being put back into the drinking water reservoir in several communities. This effluent has a better quality than that of the reservoir, and the joke is really becoming true.

According to the current water quality control schemes in use in the United States, the highest use for water is for human consumption. Water for human consumption must meet two sets of standards: the river or stream source standards and the Primary and Secondary Water Quality Standards published by the USEPA and by the various States.

WATER QUALITY REGULATIONS—LEGAL STRUCTURE

Water quality standards are dependent upon the purposes for which the water is used.

Example: Cooling water's principal characteristic must be temperature and to a lesser extent lack of corrosiveness.

The United States, the United Nations and most of the countries have water quality standards for drinking water. Many countries have water quality standards for fishing and swimming waters depending upon their uses.

When dealing with the United States, it is important to remember that the goal of the USEPA is to have fishable and swimmable waters (fishing and recreation uses) for all U.S. waters. That goal has been in place since 1972 and still has not been achieved.

It is important to note that surface water quality standards are widely different from place to place and depend upon the use of the water.

The following pages contain the excerpts from the State of Georgia Water Quality Standards for Surface Waters. They have been annotated for better understanding because it is important to understand how the regulations are structured so that you have an adequate basis for knowing what the

regulatory community is charged to do, and what their priorities are. A few minutes study will give you an idea of how the philosophy of water quality goals and effluent limitations has developed.

RULES AND REGULATIONS FOR WATER QUALITY CONTROL

Chapter 391-3-6 Revised—July 2000

Several things have been annotated to provide you with a flavor for the subject and its complexity. Understand that the text was written by lawyers, and normally it is interpreted by the rest of us (unimportant preamble has been deleted).

- (4) Water Use Classifications. Water use classifications for which the criteria of this Paragraph are applicable are as follows:
 - (a) Drinking Water Supplies
 - (b) Recreation
 - (c) Fishing, Propagation of Fish, Shellfish, Game and Other Aquatic Life
 - (d) Wild River
 - (e) Scenic River
 - (f) Coastal Fishing
- (5) General Criteria for All Waters. The following criteria are deemed to be necessary and applicable to all waters of the State:

Note that the order of the text has been arranged in the order of priority.

General Provisions and Catchall Regulations

- (a) All waters shall be free from materials associated with municipal or domestic sewage, industrial waste or any other waste which will settle to form sludge deposits that become putrescent, unsightly or otherwise objectionable.
- (b) All waters shall be free from oil, scum and floating debris associated with municipal or domestic sewage, industrial waste or other discharges in amounts sufficient to be unsightly or to interfere with legitimate water uses.
- (c) 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.
- (d) **Turbidity.** The following standard is in addition to the narrative turbidity standard in Paragraph 391-3-6-.03(5)(c) above:
All waters shall be free from turbidity which results in a substantial visual contrast in a water body due to a man-made 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 which is located sufficiently downstream from the activity so as 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 Paragraph 391-3-6-.03(5)(d).

(e) All waters shall be free from toxic, corrosive, acidic and caustic substances discharged from municipalities, industries or other sources, such as nonpoint sources, in amounts, concentrations or combinations which are harmful to humans, animals or aquatic life.

In the above several things are important: the use of catchall provisions, see underlined material in Sections b, c, and d, and the use of a mixing zone in paragraph d.

The mixing zone is a very interesting concept because it is an artificial zone where dilution of the effluent is specifically permitted. Generally mixing zones are up to one-third of the volume of the stream and provide an undetermined length. The regulatory purpose of a mixing zone is to insure that the stream quality standards are not applied to the effluent at the point of discharge. However, when there is a small stream, which is intermittent, the tighter effluent standards will apply to the effluent.

Specific Chemical Limitations (Broadly Applicable)

(I) Instream concentrations of the following chemical constituents which are considered to be other toxic pollutants of concern in the State of Georgia shall not exceed the criteria indicated below under 7-day, 10-year minimum flow (7Q10) or higher stream flow conditions except within established mixing zones:

The term “7Q10” has an extremely conservative definition — it is the lowest flow that occurs for 7 consecutive days once in every 10 years. By definition this is during a drought cycle (summer) when water temperatures are the highest and dissolved oxygen is the lowest. This is also the baseline for all water quality standards in freshwater streams and rivers.

Specific Chemicals Followed by Concentrations

1. 2,4-Dichlorophenoxyacetic acid (2,4-D) 70 µg/l
2. Methoxychlor 0.03 µg/l*
3. 2,4,5-Trichlorophenoxy propionic acid (TP Silvex) 50 µg/l

(ii) Instream concentrations of the following chemical constituents listed by the U.S. Environmental Protection Agency as toxic priority pollutants

pursuant to Section 307(a)(1) of the Federal Clean Water Act (as amended) shall not exceed the acute criteria indicated below under 1-day, 10-year minimum flow (1Q10) or higher stream flow conditions and shall not exceed the chronic criteria indicated below under 7-day, 10-year minimum flow (7Q10) or higher stream flow conditions except within established mixing zones or in accordance with site specific effluent limitations developed in accordance with procedures presented in 391-3-6-.06. Unless otherwise specified, the criteria below are listed in their total recoverable form. Because most of the numeric criteria for the metals below are listed as the dissolved form, total recoverable concentrations of metals that are measured instream will need to be translated to the dissolved form in order to compare the instream data with the numeric criteria. This translation will be performed using guidance found in “Guidance Document of Dynamic Modeling and Translators August 1993” found in Appendix J of EPA’s Water Quality Standards Handbook: Second Edition, EPA-823-B-94-005a or by using other appropriate guidance from EPA.

Acute Chronic

1. Arsenic
 - (a) Freshwater 50 µg/l 50 µg/l 1 1
 - (b) Coastal and Marine Estuarine Waters 69 µg/l 36 µg/l 1 1
2. Cadmium
 - (a) Freshwater 1.7 µg/l 0.62 µg/l 1,2,3 1,2,3
 - (b) Coastal and Marine Estuarine Waters 43 µg/l 9.2 µg/l 1 1,2
3. Chromium III
 - (a) Freshwater 310 µg/l 100 µg/l 1,3 1,3
 - (b) Coastal and Marine Estuarine Waters – –
4. Chromium VI
 - (a) Freshwater 16 µg/l 11 µg/l 1 1
 - (b) Coastal and Marine Estuarine Waters 1,100 µg/l 50 µg/l 1 1
5. Copper
 - (a) Freshwater 8.8 µg/l 6.2 µg/l 1,2,3 1,2,3
 - (b) Coastal and Marine Estuarine Waters 2.4 µg/l 2.4 µg/l 1,2 1,2
6. Lead
 - (a) Freshwater 30 µg/l 1.2 µg/l 1,3 1,2,3
 - (b) Coastal and Marine Estuarine Waters 130 µg/l 5.3 µg/l 1 1,2
7. Mercury
 - (a) Freshwater 0.012 µg/l – 2
 - (b) Coastal and Marine Estuarine Waters 0.025 µg/l – 2
8. Nickel
 - (a) Freshwater 790 µg/l 88 µg/l 1,3 1,3
 - (b) Coastal and Marine Estuarine Waters 74 µg/l 8.2 µg/l 1 1,2

9. Selenium
 - (a) Freshwater – 5.0 µg/l 2
 - (b) Coastal and Marine Estuarine Waters – 71 µg/l 1
10. Silver – 4 4
11. Zinc
 - (a) Freshwater 64 µg/l 58 µg/l 1,3 1,3
 - (b) Coastal and Marine Estuarine Waters 90 µg/l 81 µg/l 1 1

The in-stream criterion is expressed in terms of the dissolved fraction in the water column. Conversion factors used to calculate dissolved criteria are found in 40 CFR 131.36 and the Federal Register, Volume 60, No. 86, Thursday, May 4, 1995. The in-stream criterion is lower than the EPD laboratory detection limits. The aquatic life criteria for these metals are expressed as a function of total hardness (mg/l) in a water body. Values in the table above assume a hardness of 50 mg/l CaCO₃. For other hardness values, the following equations from 40 CFR 131.36 should be used. The minimum hardness allowed for use in these equations shall not be less than 25 mg/l, as calcium carbonate and the maximum shall not be greater than 400 mg/l as calcium carbonate.

Cadmium

acute criteria = $(e)(1.136672 - [(\ln \text{hardness})(0.041838)]) \mu\text{g/l}$ (1.128[ln(hardness)] – 3.828)

chronic criteria = $(e)(1.101672 - [(\ln \text{hardness})(0.041838)]) \mu\text{g/l}$ (0.7852[ln(hardness)] – 3.490)

Chromium III

acute criteria = $(e) (0.316) \mu\text{g/l}$ (0.8190[ln(hardness)] + 3.688)

chronic criteria = $(e)(0.860) \mu\text{g/l}$ (0.8190[ln(hardness)] + 1.561)

Copper

acute criteria = $(e)(0.96) \mu\text{g/l}$ (0.9422[ln(hardness)] – 1.464)

chronic criteria = $(e)(0.96) \mu\text{g/l}$ (0.8545[ln(hardness)] – 1.465)

Lead

acute criteria = $(e)(1.46203 - [(\ln \text{hardness})(0.145712)]) \mu\text{g/l}$ (1.273[ln(hardness)] – 1.460)

chronic criteria = $(e)(1.46203 - [(\ln \text{hardness})(0.145712)]) \mu\text{g/l}$ (1.273[ln(hardness)] – 4.705)

Nickel

acute criteria = $(e)(.998) \mu\text{g/l}$ (0.8460[ln(hardness)] + 3.3612)

chronic criteria = $(e)(.997) \mu\text{g/l}$ (0.8460[ln(hardness)] + 1.1645)

Zinc

acute criteria = $(e)(0.978) \mu\text{g/l}$ (0.8473[ln(hardness)] + 0.8604)

chronic criteria = $(e)(0.986) \mu\text{g/l}$ (0.8473[ln(hardness)] + 0.7614)

This pollutant is addressed in 391-3-6-.06.4

Specific Organic Chemicals or Priority Pollutants (Established by Federal Decree)

(iii) Instream concentrations of the following chemical constituents listed by the U.S. Environmental Protection Agency as toxic priority pollutants pursuant to Section 307(a)(1) of the Federal Clean Water Act (as amended) shall not exceed criteria indicated below under 7-day, 10-year minimum flow (7Q10) or higher stream flow conditions except within established mixing zones or in accordance with site specific effluent limitations developed in accordance with procedures presented in 391-3-6-.06.

Specific Priority Pollutants (*Followed by Compounds—These Are Embodied in U.S. Federal Law*)

1. Chlordane
 - (a) Freshwater 0.0043 µg/l*
 - (b) Coastal and Marine Estuarine Waters 0.004 µg/l*
2. Cyanide
 - (a) Freshwater 5.2 µg/l*
 - (b) Coastal and Marine Estuarine Waters 1.0 µg/l*
3. Dieldrin 0.0019 µg/l*
4. 4,4'-DDT 0.001 µg/l*
5. a-Endosulfan
 - (a) Freshwater 0.056 µg/l*
 - (b) Coastal and Marine Estuarine Waters 0.0087 µg/l*
6. b-Endosulfan
 - (a) Freshwater 0.056 µg/l*
 - (b) Coastal and Marine Estuarine Waters 0.0087 µg/l*
7. Endrin 0.002 µg/l*
8. Heptachlor
 - (a) Freshwater 0.0038 µg/l*
 - (b) Coastal and Marine Estuarine Waters 0.0036 µg/l*
9. Heptachlor Epoxide
 - (a) Freshwater 0.0038 µg/l*
 - (b) Coastal and Marine Estuarine Waters 0.0036 µg/l*
10. Lindane [Hexachlorocyclohexane (g-BHC-Gamma)] 0.08 µg/l
11. Pentachlorophenol
 - (a) Freshwater 2.1 µg/l*
 - (b) Coastal and Marine Estuarine Waters 7.9 µg/l*
12. PCB-1016 0.014 µg/l
13. PCB-1221 0.014 µg/l
14. PCB-1232 0.014 µg/l
15. PCB-1242 0.014 µg/l

16. PCB-1248 0.014 µg/l
17. PCB-1254 0.014 µg/l
18. PCB-1260 0.014 µg/l
19. Phenol 300 µg/l
20. Toxaphene 0.0002 µg/l*

*The in-stream criterion is lower than the EPD⁵ laboratory detection limits.

(iv) Instream concentrations of the following chemical constituents listed by the U. S. Environmental Protection Agency as toxic priority pollutants pursuant to Section 307(a)(1) of the Federal Clean Water Act (as amended) shall not exceed criteria indicated below under annual average or higher stream flow conditions:

1. Acenaphthene **
2. Acenaphthylene **
3. Acrolein 780 µg/l
4. Acrylonitrile 0.665 µg/l
5. Aldrin 0.000136 µg/l
6. Anthracene 110000 µg/l
7. Antimony 4308 µg/l
8. Arsenic 50 µg/l
9. Benzidine 0.000535 µg/l
10. Benzo(a)Anthracene 0.0311 µg/l
11. Benzo(a)Pyrene 0.0311 µg/l
12. 3,4-Benzofluoranthene 0.0311 µg/l
13. Benzene 71.28 µg/l
14. Benzo(ghi)Perylene **
15. Benzo(k)Fluoranthene 0.0311 µg/l
16. Beryllium **
17. a-BHC-Alpha 0.0131 µg/l
18. b-BHC-Beta 0.046 µg/l
19. Bis(2-Chloroethyl)Ether 1.42 µg/l
20. Bis(2-Chloroisopropyl)Ether 170000 µg/l
21. Bis(2-Ethylhexyl)Phthalate 5.92 µg/l
22. Bromoform (Tribromomethane) 360 µg/l
23. Carbon Tetrachloride 4.42 µg/l
24. Chlorobenzene 21000 µg/l
25. Chlorodibromomethane 34 µg/l
26. 2-Chloroethylvinyl Ether **

⁵EPD is the Environmental Protection of the State of Georgia.

27. Chlordane 0.000588 µg/l
28. Chloroform (Trichloromethane) 470.8 µg/l
29. 2-Chlorophenol **
30. Chrysene 0.0311 µg/l
31. Dibenzo(a,h)Anthracene 0.0311 µg/l
32. Dichlorobromomethane 22 µg/l
33. 1,2-Dichloroethane 98.6 µg/l
34. 1,1-Dichloroethylene 3.2 µg/l
35. 1,3-Dichloropropylene (Cis) 1700 µg/l
36. 1,3-Dichloropropylene (Trans) 1700 µg/l
37. 2,4-Dichlorophenol 790 µg/l
38. 1,2-Dichlorobenzene 17000 µg/l
39. 1,3-Dichlorobenzene 2600 µg/l
40. 1,4-Dichlorobenzene 2600 µg/l
41. 3,3'-Dichlorobenzidine 0.077 µg/l
42. 4,4'-DDT 0.00059 µg/l
43. 4,4'-DDD 0.00084 µg/l
44. 4,4'-DDE 0.00059 µg/l
45. Dieldrin 0.000144 µg/l
46. Diethyl Phthalate 120000 µg/l
47. Dimethyl Phthalate 2900000 µg/l
48. 2,4-Dimethylphenol **
49. 2,4-Dinitrophenol 14264 µg/l
50. Di-n-Butyl Phthalate 12100 µg/l
51. 2,4-Dinitrotoluene 9.1 µg/l
52. 1,2-Diphenylhydrazine 0.54 µg/l
53. Endrin Aldehyde 0.81 µg/l
54. Endosulfan Sulfate 2.0 µg/l
55. Ethylbenzene 28718 µg/l
56. Fluoranthene 370 µg/l
57. Fluorene 14000 µg/l
58. Heptachlor 0.000214 µg/l
59. Heptachlor Epoxide 0.00011 µg/l
60. Hexachlorobenzene 0.00077 µg/l
61. Hexachlorobutadiene 49.7 µg/l
62. Hexachlorocyclopentadiene 17000 µg/l
63. Hexachloroethane 8.85 µg/l
64. Indeno(1,2,3-cd)Pyrene .0311 µg/l
65. Isophorone 600 µg/l

66. Lindane [Hexachlorocyclohexane (g-BHC-Gamma)] 0.0625 µg/l
67. Methyl Bromide (Bromomethane) 4000 µg/l
68. Methyl Chloride (Chloromethane) **
69. Methylene Chloride 1600 µg/l
70. 2-Methyl-4,6-Dinitrophenol 765 µg/l
71. 3-Methyl-4-Chlorophenol **
72. Nitrobenzene 1900 µg/l
73. N-Nitrosodimethylamine 8.12 µg/l
74. N-Nitrosodi-n-Propylamine **
75. N-Nitrosodiphenylamine 16.2 µg/l
76. PCB-1016 0.00045 µg/l
77. PCB-1221 0.00045 µg/l
78. PCB-1232 0.00045 µg/l
79. PCB-1242 0.00045 µg/l
80. PCB-1248 0.00045 µg/l
81. PCB-1254 0.00045 µg/l
82. PCB-1260 0.00045 µg/l
83. Phenanthrene **
84. Phenol 4,600,000 µg/l
85. Pyrene 11,000 µg/l
86. 1,1,2,2-Tetrachloroethane 10.8 µg/l
87. Tetrachloroethylene 8.85 µg/l
88. Thallium 6.3 µg/l
89. Toluene 200000 µg/l
90. 1,2-Trans-Dichloroethylene **
91. 1,1,2-Trichloroethane 41.99 µg/l
92. Trichloroethylene 80.7 µg/l
93. 2,4,6-Trichlorophenol 6.5 µg/l
94. 1,2,4-Trichlorobenzene **
95. Vinyl Chloride 525 µg/l

** These pollutants are addressed in 391-3-6-.06.

(v) Site specific criteria for the following chemical constituents will be developed on an as-needed basis through toxic pollutant monitoring efforts at new or existing discharges that are suspected to be a source of the pollutant at levels sufficient to interfere with designated uses:

1. Asbestos

(vi) Instream concentrations of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) must not exceed 0.0000012 µg/l under long-term average stream flow conditions.

(f) Applicable State and Federal requirements and regulations for the discharge of radioactive substances shall be met at all times.

(g) The dissolved oxygen criteria as specified in individual water use classifications shall be applicable at a depth of one meter below the water surface; in those instances where depth is less than two meters, the dissolved oxygen criterion shall be applied at a mid-depth. On a case specific basis, alternative depths may be specified.

(6) Specific Criteria for Classified Water Usage. In addition to the general criteria, the following criteria are deemed necessary and shall be required for the specific water usage as shown:

The following is a listing of Minimum Water Quality Criteria For a Public Drinking Water Surface Supply: note the differences between some of the standards above and the following.

Coliform or Bacterial Standard—the First Standard

(a) Drinking Water Supplies: Those waters approved as a source for public drinking water systems permitted or to be permitted by the Environmental Protection Division. Waters classified for drinking water supplies will also support the fishing use and any other use requiring water of a lower quality.

(I) Bacteria: For the months of May through October, when water contact recreation activities are expected to occur, fecal coliform not to exceed a geometric mean of 200 per 100 ml based on at least four samples collected from a given sampling site over a 30-day period at intervals not less than 24 hours. Should water quality and sanitary studies show fecal coliform levels from non-human sources exceed 200/100 ml (geometric mean) occasionally, then the allowable geometric mean fecal coliform shall not exceed 300 per 100 ml in lakes and reservoirs and 500 per 100 ml in free flowing freshwater streams. For the months of November through April, fecal coliform not to exceed a geometric mean of 1,000 per 100 ml based on at least four samples collected from a given sampling site over a 30-day period at intervals not less than 24 hours and not to exceed a maximum of 4,000 per 100 ml for any sample. The State does not encourage swimming in surface waters since a number of factors which are beyond the control of any State regulatory agency contribute to elevated levels of fecal coliform.

Dissolved Oxygen Standard—the Second Standard

(ii) Dissolved oxygen: A daily average of 6.0 mg/l and no less than 5.0 mg/l at all times for waters designated as trout streams by the Wildlife Resources Division. A daily average of 5.0 mg/l and no less than 4.0 mg/l at all times for water supporting warm water species of fish.

During the summer, when the water temperature is 68°F or warmer for smaller streams, the maximum dissolved oxygen concentration that the water can hold is approximately 9 mg/l. The requirement is about 67% of the maximum based upon a 30-day average.

pH Standard

- (iii) pH: Within the range of 6.0–8.5.

And Catchall Physical Standards Including Temperature Increase

(iv) No material or substance in such concentration that, after treatment by the public water treatment system, exceeds the maximum contaminant level established for that substance by the Environmental Protection Division pursuant to the Georgia Rules for Safe Drinking Water.

(v) Temperature: Not to exceed 90°F. At no time is the temperature of the receiving waters to be increased more than 5°F above intake temperature except that in estuarine waters the increase will not be more than 1.5°F. In streams designated as primary trout or smallmouth bass waters by the Wildlife Resources Division, there shall be no elevation of natural stream temperatures. In streams designated as secondary trout waters, there shall be no elevation exceeding 2°F of natural stream temperatures.

Water Quality for Recreation Activities (*The Second Highest Use Category*)

(b) Recreation: General recreational activities such as water skiing, boating, and swimming, or for any other use requiring water of a lower quality, such as recreational fishing. These criteria are not to be interpreted as encouraging water contact sports in proximity to sewage or industrial waste discharges regardless of treatment requirements:

- (I) Bacteria: Fecal coliform not to exceed the following geometric means based on at least four samples collected from a given sampling site over a 30-day period at intervals not less than 24 hours:
 - (II) (1) Coastal waters 100 per 100 ml
 - (2) All other recreational waters 200 per 100 ml
 - (3) Should water quality and sanitary studies show natural fecal coliform levels exceed 200/100 ml (geometric mean) occasionally in high quality recreational waters, then the allowable geometric mean fecal coliform level shall not exceed 300 per 100 ml in lakes and reservoirs and 500 per 100 ml in free flowing fresh water streams.
- (ii) Dissolved Oxygen: A daily average of 6.0 mg/l and no less than 5.0 mg/l at all times for waters designated as trout streams by the Wildlife Resources

Division. A daily average of 5.0 mg/l and no less than 4.0 mg/l at all times for waters supporting warm water species of fish.

(iii) pH: Within the range of 6.0–8.5.

(iv) Temperature: Not to exceed 90°F. At no time is the temperature of the receiving waters to be increased more than 5°F above intake temperature except that in estuarine waters the increase will not be more than 1.5°F. Instreams designated as primary trout or smallmouth bass waters by the Wildlife Resources Division, there shall be no elevation of natural stream temperatures. Instreams designated as secondary trout waters, there shall be no elevation exceeding 2°F natural stream temperatures.

Water Quality Catchall For Fishing (*Third Priority Use*)

(c) Fishing: Propagation of Fish, Shellfish, Game and Other Aquatic Life; secondary contact recreation in and on the water; or for any other use requiring water of a lower quality:

(i) Dissolved Oxygen: A daily average of 6.0 mg/l and no less than 5.0 mg/l at all times for water designated as trout streams by the Wildlife Resources Division. A daily average of 5.0 mg/l and no less than 4.0 mg/l at all times for waters supporting warm water species of fish.

(ii) pH: Within the range of 6.0–8.5.

(iii) Bacteria: For the months of May through October, when water contact recreation activities are expected to occur, fecal coliform not to exceed a geometric mean of 200 per 100 ml based on at least four samples collected from a given sampling site over a 30-day period at intervals not less than 24 hours. Should water quality and sanitary studies show fecal coliform levels from non-human sources exceed 200/100 ml (geometric mean) occasionally, then the allowable geometric mean fecal coliform shall not exceed 300 per 100 ml in lakes and reservoirs and 500 per 100 ml in free flowing freshwater streams. For the months of November through April, fecal coliform not to exceed a geometric mean of 1,000 per 100 ml based on at least four samples collected from a given sampling site over a 30-day period at intervals not less than 24 hours and not to exceed a maximum of 4,000 per 100 ml for any sample. The State does not encourage swimming in surface waters since a number of factors which are beyond the control of any State regulatory agency contribute to elevated levels of fecal coliform. For waters designated as approved shellfish harvesting waters by the appropriate State agencies, the requirements will be consistent with those established by the State and Federal agencies responsible for the National Shellfish Sanitation Program. The requirements are found in the National Shellfish Sanitation Program Manual of Operation, Revised 1988, Interstate Shellfish Sanitation Conference, U. S. Department of Health and Human Services (PHS/FDA), and the Center for Food Safety and Applied Nutrition. Streams designated as generally supporting shellfish are listed in Paragraph 391-3-6-.03(14).

(iv) Temperature: Not to exceed 90°F. At no time is the temperature of the receiving waters to be increased more than 5°F above intake temperature except that in estuarine waters the increase will not be more than 1.5°F. In streams designated as primary trout or smallmouth bass waters by the Wildlife Resources Division, there shall be no elevation of natural stream temperatures. In streams designated as secondary trout waters, there shall be no elevation exceeding 2°F natural stream temperatures.

Other Uses

(d) Wild River: For all waters designated in 391-3-6-.03(13) as “Wild River,” there shall be no alteration of natural water quality from any source.

(e) Scenic River: For all waters designated in 391-3-6-.03(13) as “Scenic River,” there shall be no alteration of natural water quality from any source.

(f) Coastal Fishing: This classification will be applicable to specific sites when so designated by the Environmental Protection Division.

For waters designated as “Coastal Fishing,” site specific criteria for dissolved oxygen will be assigned and detailed by footnote in Section 391-3-6-.03(3), “Specific Water Use Classifications.” All other criteria and uses for the fishing use classification will apply for coastal fishing.

Exemptions and Other General Requirements

(7) Natural Water Quality. It is recognized that certain natural waters of the State may have a quality that will not be within the generator specific requirements contained herein. This is especially the case for the criteria for dissolved oxygen, temperature, pH and fecal coliform. NPDES permits and best management practices will be the primary mechanisms for ensuring that discharges will not create a harmful situation.

(8) Treatment Requirements. Notwithstanding the above criteria, the requirements of the State relating to secondary or equivalent treatment of all waste shall prevail. The adoption of these criteria shall in no way preempt the treatment requirements.

(9) Streamflows. Specific criteria or standards set for the various parameters apply to all flows on regulated streams. On unregulated streams, they shall apply to all streamflows equal to or exceeding the 7-day, 10-year minimum flow (7Q10) and/or the 1-day, 10-year minimum flow. All references to 7-day, 10-year minimum flow (7Q10) and 1-day, 10-year minimum flow also apply to all flows on regulated streams. All references to annual average stream flow also apply to long-term average stream flow conditions.

(10) Mixing Zone. Effluents released to streams or impounded waters shall be fully and homogeneously dispersed and mixed insofar as practical with the main flow or water body by appropriate methods at the discharge point. Use of a reasonable and limited mixing zone may be permitted on receipt of satisfactory evidence that such a zone is necessary and that it will not create an

objectionable or damaging pollution condition. Protection from acute toxicity shall be provided within any EPD designated mixing zone to ensure a zone of safe passage for aquatic organisms. The procedure is as described in paragraph 391-3-6-.06(4)(d)(5)(vi), except that the numerical pass/fail criteria applies to the end-of-pipe without the benefit of dilution provided by the receiving stream.

(11) Toxic Pollutant Monitoring. The Division will monitor waters of the State for the presence or impact of Section 307(a)(1) Federal Clean Water Act toxic pollutants, and other priority pollutants. The monitoring shall consist of the collection and assessment of chemical and/or biological data as appropriate from the water column, from streambed sediments, and/or from fish tissue. Specific stream segments and chemical constituents for monitoring shall be determined by the Director on the basis of the potential for water quality impacts from toxic pollutants from point or nonpoint waste sources. Singularly or in combination, these constituents may cause an adverse effect on fish propagation at levels lower than the criteria. Instream concentrations will be as described in 391-3-6-.03 (5)(e). Additional toxic substances and priority pollutants will be monitored on a case specific basis using Section 304(a) Federal Clean Water Act guidelines or other scientifically appropriate documents.

(12) Fecal Coliform Criteria. The criteria for fecal coliform bacteria provide the Regulatory framework to support the USEPA requirement that States protect all waters for the use of primary contact recreation or swimming. This is a worthy national goal, although potentially unrealistic with the current indicator organism, fecal coliform bacteria, in use today. To assure that waters are safe for swimming indicates a need to test waters for pathogenic bacteria. However, analyses for pathogenic bacteria are expensive and results are generally difficult to reproduce quantitatively. Also, to ensure the water is safe for swimming would require a whole suite of tests be done for organisms such as Salmonella, Shigella, Vibrio, etc. as the presence/absence of one organism would not document the presence/absence of another. This type of testing program is not possible due to resource constraints. The environmental community in the United States has based the assessment of the bacteriological quality of water on testing for pathogenic indicator organisms, principally the coliform group. The assessment of streams, rivers, lakes, and estuaries in Georgia and other States is based on fecal coliform organisms. Coliform bacteria live in the intestinal tract of warm blooded animals including man. These organisms are excreted in extremely high numbers, averaging about 1.5 billion coliform per ounce of human feces. Pathogenic bacteria also originate in the fecal material of diseased persons. Therefore, waters with high levels of fecal coliform bacteria represent potential problem areas for swimming. However, there is no positive scientific evidence correlating elevated fecal coliform counts with transmission of enteric diseases. In addition, these bacteria can originate from any warm blooded animal or from the soil. Monitoring programs have documented fecal coliform levels in excess of the criteria in

many streams and rivers in urban areas, agricultural areas, and even in areas not extensively impacted by man such as national forest areas. This is not a unique situation to Georgia as similar levels of fecal coliform bacteria have been documented in streams across the nation. The problem appears to lie in the lack of an organism which specifically indicates the presence of human waste materials which can be correlated to human illness. Other organisms such as the Enterococci group and *E. coli* have been suggested by the USEPA as indicator organisms. However, testing using these organisms by States and the USEPA has indicated similar problems with these indicator organisms.

The Environmental Protection Division will conduct a monitoring project from 1993 through 1995 to evaluate the use of *E. coli* and Enterococci as indicators of bacteriological quality in Georgia. The Environmental Protection Division will also conduct studies to determine if a better human specific indicator can be found to replace current indicator organisms.

(13) Specific Water Use Classifications. Beneficial water uses assigned by the State to all surface waters. These classifications are scientifically determined to be the best utilization of the surface water from an environmental and economic standpoint. Streams and stream reaches not specifically listed are classified as Fishing.

The specific classifications are as follows:

Specific Stream Classification Standards

Savannah River Basin Classification

Chattooga River Georgia—North Carolina State Line to Tugaloo Reservoir - Wild and Scenic

West Fork Chattooga Confluence of Overflow Creek and Clear Creek to confluence with Chattooga River (7.3 mi.)—Wild and Scenic

Of course, there are more detailed water quality standards, but those are for Georgia and are not really of interest anywhere else.

APPLICATIONS

The single “Most Important Water Quality Parameter” is probably dissolved oxygen. Before we go on to drinking water, we will look at some of the concepts behind this because it impacts what and how we treat our wastes.

Dissolved oxygen is important because it determines what happens in the water, whether the water is “clean or dirty,” and dictates our perception of water quality.

Dissolved oxygen is measured by one of the several techniques. The preferred method is by Oxygen Electrode, but the older Winkler test is often used to calibrate the electrodes. The Winkler test uses a divalent manganese solution followed by a strong alkali to develop manganese hydroxide. Iodine

is then added along with starch, and the mixture is then back titrated with a standard solution of sodium thiosulfate. The end point is very sharp and the accuracy of the colorimetric test is accurate to about 0.01 mg/l.

BOD₅ is the 5-day Biochemical Oxygen Demand. It is a measure of how much dissolved oxygen is consumed by an acclimatized waste stream in 5 days by the organic carbon material in the waste stream. It is the broad measure of the strength of the organic matter in a waste stream. The test is conducted by preparation of a known quantity of nutrient dilution water rich in dissolved oxygen. Known aliquots of waste are measured and placed into special bottles where the seal prevents air from diffusing oxygen that is diffusing into the sample. The sample is then incubated at 20°C for 5 days in the dark. At the end of 5 days, the dissolved oxygen drop is measured and the oxygen demand of the waste is calculated from the size of the aliquot of waste entered into the bottle. According to legend, the BOD test was developed in England where no river required more than 5 days to flow to the sea. In the United States, domestic sewage has a BOD₅ of between 100 mg/l and 160 mg/l. The test is used as a reporting parameter, but it is useless for control and process purposes. Few wastewater treatment plants have a retention capacity of 5 days, and the majority of the plants are at a retention capacity of 12 h or less. The information provided by the BOD test is primarily for historical information because by the time the results are known, the waste from the effluent would be from at least 5 days travel time downstream. However, in the United States there is a dogged reluctance to utilize anything but BOD for measurement and reporting purposes, despite the fact that it is useless as a control parameter.

The accuracy of the BOD test is also questionable. *Standard Methods* reports the accuracy of the test as about ± 30.5 mg/l at a waste strength of 198 mg/l. The reported minimum accuracy of the test is 2 mg/l, but in practical terms, numbers below 10 mg/l are all in the same range of unreliability.

The BOD test must also be corrected for nitrification and waste acclimatization. Ammonia will oxidize and form nitrates, consuming oxygen in the process. This will cause the BOD to be overstated. The correction for this is an addition of ammonium chloride to the test bottle. The ammonium chloride will prevent nitrification. The challenge of waste acclimatization is more difficult. According to the test method, the dilution and seed water must contain quantities of bacteria that have grown on or have been acclimatized to the wastes being tested. For normal sewage this is not a problem. Industrial wastes often have specialized chemicals for which the bacterial population has not developed enzymes required for hydrolysis of the waste. In an unacclimatized waste, or one that contains traces of bactericides, the BOD test will report low values.

COD is chemical oxygen demand and is measured chemically by digestion with acid. There are two types of COD in use and one must be careful of the method. The United States uses a potassium dichromate digestion with a mercury catalyst. The COD test overstates the oxygen consumption by about 20%–50% on the basis of BOD measurements. Depending upon the waste stream, there may be a consistent relationship between COD and BOD, but it is highly waste dependent.

Be careful in comparing COD results from different countries. Germany and most of the Europe use a sulfuric acid digestion, which gives substantially different results and may be even stronger than the dichromate test method.

The COD test is determined in about 3 h from start to finish. As such it is a useful control parameter for oxidation operations, and given a consistent waste stream, a very good relationship can be developed between COD and BOD. The COD can also be used as a predictor of the BOD.

Sample calculation: Refer to the table on dissolved oxygen for an example of the maximum concentration of oxygen at any temperature. The rule of thumb is that the dissolved oxygen at saturation and sea level at about 20°C is about 9 mg/l. It is possible to supersaturate the oxygen in water, but it is rare without substantial turbulence.

In many rivers it is necessary to maintain a minimum dissolved oxygen concentration of about 2 mg/l. If the water gets below 2 mg/l, the fish die, and if below 0 ppm, foul smells and benthic organisms develop. An anaerobic stream is not pretty. As the dissolved oxygen level goes to or below zero, the nitrate is reduced to nitrite and then to ammonia and gaseous nitrogen, and the sulfates are reduced to H_2S . In time a stream may recover, but it is a slow and difficult process.

SAMPLE PROBLEM

Given that a stream may have 7 ppm dissolved oxygen (DO) and be flowing at 100 Cu M/h, how much waste can we place into the stream before it goes below 3 ppm? Our waste stream has 250 ppm BOD.

SOLUTION

Given that the flow is 100 CuM/h and the minimum DO is 3 ppm, which means that we have 4 ppm that we can use, if the regulatory authority will allow us to use the full 4 ppm, and if our waste is stable and does not vary above the 100 mg/l oxygen demand value.

So, $4 \text{ mg/l} = 4 \text{ ppm}$. Since a cubic meter contains 1000 l, it means that the oxygen load the stream carries, which is available to us, is: $4 \times 100 \times 1000 \text{ mg} = 400,000 \text{ mg/h} = 400 \text{ g/h}$.

Our waste stream has a strength of 250 mg/l . So by comparison, we can discharge $400,000 \text{ mg/h} / 250 \text{ mg/l} = 1600 \text{ l/h}$ or about 7.5 gallons/min. If the low flow in the river at 7Q10 is only 20 CuM/H then the regulatory authority will only allow us to discharge about 320 l/h or about 1.41 gallons/min.

However, if the regulatory authority only allows us to use one-third the capacity of the stream and hold the other two-thirds in reserve, then the calculations would look like the following:

| | |
|--|---------------------|
| Minimum concentration of oxygen required | = 4 mg/l |
| 7Q10 flow | = 20 CuM/H |
| Available oxygen at 7Q10 ($7 \text{ mg/l} - 4 \text{ mg/l}$) | = 3 mg/l |
| Available oxygen mg/l/h ($3 \times 20 \times 1000$) | = 60,000 |
| Waste allocation = Available oxygen/reserve factor | = 20,000 |
| Allowable waste discharge = $20,000 / 250$ | = 80 l/h |
| Flow rate | $80 / 3.785 / 60$ |
| | = 0.352 gallons/min |

DRINKING WATER QUALITY STANDARDS: USA AND INTERNATIONAL STANDARDS

The USEPA, the European Union (EU) and the World Health Organization (WHO) all have different sets of drinking water standards. The difference between a standard and a goal or a criterion is that neither of the latter two is enforceable but is merely an objective. With the rise of the Organic Chemical Industry in the past century, and the increased detection abilities of analytical equipment, we can today find compounds in drinking water that were not detectable even 10 years ago.

The purpose of setting drinking water standards is for the protection of public health. General criteria for setting the standards are based on the protection of the most sensitive segment of the population and the prevention of “additional” diseases specific to the population. This concept of “additional” ailment leads to the development of statistical arguments and analyses in the process of goal setting. The most common measurement used is “excess cancers per N people.” The N is most often between 10,000 and 1,000,000. The concept of excess cancers is, at the least, controversial because it assumes that one can detect the differences between normal cancer rates and excess cancer rates based upon animal studies and modeling. Many of the current water quality limits were developed using the “One Hit Model” where a laboratory animal, quite often a mouse, is exposed to certain

chemicals, and the exposure rates and cancer rates are measured and equated to human exposure and cancer rates. Additional factors are often used in setting the standards as well.

The USEPA has been known to add conservative exposure criteria when formulating the standard, including a resident population who takes their drinking water only from one source, who feeds on fish from that source, who showers (for volatile chemicals) daily using that water, and cooks using that water, for a period of 70 years. These assumptions can be and have been questioned unsuccessfully, as they are extremely conservative and have the effect of reducing exposure levels well beyond the measurable values.

Recently (2001), the cost benefits of drinking water standards have begun to be re-examined. A recent move by the EPA to reduce the drinking water concentrations or maximum contaminant levels (MCLs) for arsenic to 5 ug/l was rejected as being too expensive. The rationale posed by EPA was that the proposed arsenic standard would cost between \$28 and \$85 per user household (EPA Cost Data) after legal challenges and political review because the cost of protecting one individual life from arsenic exposure (the benefit) was determined to be excessive, and implementing the standard would have cost between \$700,000,000 and \$1,460,000,000 per year as compared with the EPA's cost estimate of approximately \$389,000,000 per year. The EPA cost estimates were about one-third or less than the corresponding estimates prepared by the American Water Works Association (AWWA). According to the comments supplied by the City of Albuquerque, NM, the cost per life saved was estimated at \$4.7 billion per year, approximately 770 times higher than the EPA's current regulatory cost benefit of \$6.1 million per year per life saved.⁶

From the comments submitted, the EPA's proposed regulatory scheme was also technologically flawed, in that the technology proposed by EPA for attainment of the arsenic limits was also deemed to be technologically unfeasible. The AWWA and others prevailed because they had better cost data, and because the EPA had prepared the recommended standards without adequate internal and external review of the technology and the costs. The burden on individual water treatment facilities for monitoring and treatment was also considered excessive. The proposed EPA standard was reviewed and reissued at a 10 µg/l arsenic concentration and was deemed both attainable and economically affordable, if not without some grumbling from the water utilities.

⁶For a discussion of the issues, see "Comments on EPA's Proposed Arsenic Rule..." submitted by City of Albuquerque, NM, September 20, 2001. Available at <http://www.cabq.gov/waterresources/docs/Arsenic%20Summary.pdf>.

It is possible to attain good quality water, but it has a cost.⁷ Under the arsenic rules, the smaller communities, which would be the most severely impacted by the cost of providing treatment to the 10 µg/l limit are those in the western United States where arsenic occurs naturally in the groundwater at levels well above the treatment standard. When it was discovered that an aquifer in Bangladesh and in West Bengal, India contained unacceptably high levels of arsenic in the groundwater (above the 50 µg/l WHO limit) and affected over 82 million people, the proposed solution for reducing the arsenic contamination in the groundwater was substantially simpler. Because the per capita income in the affected parts of India is quite low, it was imperative to find economical methods of removing arsenic to below the WHO standard. Several novel and innovative methods were tried, and it appears that the cheapest method is to aerate the water and then run it through a bucket filled with nails or iron pellets. The arsenic is first oxidized, and then is adsorbed onto the iron. The system is inexpensive and suitable for many of the small communities in India.

Water quality varies from place to place and country to country. In an effort to establish a generally accepted level of what contaminant levels are “safe” in drinking water, regulatory agencies such as the EPA, the EU, and the Health Departments or Ministries of various countries have each established their own drinking water standards. The WHO has also established drinking water standards. Although it is difficult to establish a comparison between the differing standards, there are a number of points of commonality with regard to metals and certain organic compounds. At one time the WHO standards were substantially more lax than the United States and EU standards, but in recent years that deficiency has been corrected. A comparison of the sets of standards for WHO and USEPA is shown side by side.

There is a difference in nomenclature between the standards that require some explanation. The USEPA uses Maximum Concentration Limit (MCL) and Maximum Concentration Limit Goal (MCLG) to express the current standards. The WHO uses the language of “guideline,” which is a strong suggestion but carries no legal weight because the WHO is neither a regulatory agency nor does it have a sovereign authority over any country (see Table 1.5).

⁷See Gurian PL, Small MJ, Lockwood JR, Schervish, M. Addressing Uncertainty and Conflicting Cost Estimates in Revising the Arsenic MCL. *Environmental Science & Technology* 2001, Vol. 35, pp 4414–4420.

TABLE 1.5 WHO's Guidelines for Drinking-water Quality—set up in Geneva, 1993, Which are the International Reference Point for Standard Setting and Drinking-water Safety

| Element/Substance | Symbol/Formula | Normally Found in Fresh Water/Surface Water/Ground Water | Health Based Guideline by the WHO | USEPA Maximum Contaminant Level (MCL) | Maximum Contaminant Level Guideline |
|-------------------|-------------------------------------|--|-----------------------------------|---------------------------------------|-------------------------------------|
| Aluminum | Al | | 200 µg/l | | |
| Ammonia | NH ₄ | <0.2 mg/l (up to 0.3 mg/l in anaerobic waters) | No guideline | | |
| Antimony | Sb | <4 µg/l | 5 µg/l | 6 µg/l | 6 µg/l |
| Arsenic | As | 0.01 mg/l | | 10 µg/l | zero |
| Asbestos | | | | 7,000,000 fibers/l | 7,000,000 fibers/l |
| Barium | Ba | | No guideline | 2000 µg/l | 2000 µg/l |
| Berillium | Be | <1 µg/l | No guideline | 4 µg/l | 4 µg/l |
| Boron | B | <1 mg/l | 300 µg/l | | |
| Cadmium | Cd | <1 µg/l | 3 µg/l | 5 µg/l | 5 µg/l |
| Chloride | Cl | | 250 mg/l | | |
| Chromium | Cr ³⁺ , Cr ⁶⁺ | <2 µg/l | 50 µg/l | 100 µg/l total | 100 µg/l |
| Color | | | No guideline | | |
| Copper | Cu | | 2000 µg/l | 1300 µg/l | 1300 µg/l |
| Cyanide | CN ⁻ | | 70 µg/l | 200 µg/l | 200 µg/l |
| Fluoride | F | 0–10 mg/l | 1500 µg/l | 4000 µg/l | 4000 µg/l |
| Iron | Fe | 0–50 mg/l | No guideline | | |
| Lead | Pb | | 10 µg/l | < 15 µg/l | zero |
| Manganese | Mn | | 500 µg/l | | |
| Mercury | Hg | <0.5 µg/l | 1 µg/l | 2 µg/l | 2 µg/l |
| Molybdenum | Mb | <10 µg/l | 70 µg/l | | |
| Nickel | Ni | <20 µg/l | 20 µg/l | | |

| | | | | | |
|---------------------|-------------------------------------|--------------|------------------------------|---|---|
| Nitrate and nitrite | NO ₃ and NO ₂ | | 50000 µg/l total Nitrogen | Nitrate 10000 µg/l Nitrite 1000 µg/l | Nitrate 10000 µg/l Nitrite 1000 µg/l |
| Turbidity | | | No guideline | | |
| Selenium | Se | <10 µg/l | 10 µg/l | | 50 µg/l |
| Silver | Ag | 5-50 µg/l | No guideline | | |
| Sodium | Na | <20000 µg/l | 20000 µg/l | | |
| Sulfate | SO ₄ | | 50000 µg/l | | |
| Tin | Sn | | No guideline | | |
| Thallium | Th | No guideline | No guideline | 2 µg/l | 0.5 µg/l |
| Uranium | U | | 1400 µg/l | | |
| Zinc | Zn | | 3000 µg/l | | |

Organic compounds

| Group | Substance | Formula | WHO Health Based Guideline |
|-------|-----------|---------|----------------------------|
|-------|-----------|---------|----------------------------|

Chlorinated alkanes

| | | | |
|--|-----------------------|--|--------------|
| | Carbon tetrachloride | CCl ₄ | 2 µg/l |
| | Dichloromethane | CH ₂ CCl ₂ | 20 µg/l |
| | 1,1-Dichloroethane | C ₂ H ₄ CCl ₂ | No guideline |
| | 1,2-Dichloroethane | ClCH ₂ CH ₂ Cl | 30 µg/l |
| | 1,1,1-Trichloroethane | CH ₃ CCl ₃ | 2000 µg/l |

Chlorinated ethenes

| | | | |
|--|--------------------|---|---------|
| | 1,1-Dichloroethene | C ₂ H ₂ Cl ₂ | 30 µg/l |
| | 1,2-Dichloroethene | C ₂ H ₂ Cl ₂ | 50 µg/l |
| | Trichloroethene | C ₂ HCl ₃ | 70 µg/l |
| | Tetrachloroethene | C ₂ Cl ₄ | 40 µg/l |

Aromatic hydrocarbons

| | | | |
|--|---------|--------------------------------|----------|
| | Benzene | C ₆ H ₆ | 700 µg/l |
| | Toluene | C ₇ H ₈ | 500 µg/l |
| | Xylenes | C ₈ H ₁₀ | 300 µg/l |

TABLE 1.5 (Continued)

| Element/Substance | Symbol/Formula | Normally Found in Fresh Water/Surface Water/Ground Water | Health Based Guideline by the WHO | USEPA Maximum Contaminant Level (MCL) | Maximum Contaminant Level Guideline |
|------------------------------------|--|--|-----------------------------------|---------------------------------------|-------------------------------------|
| Chlorinated benzenes | Ethylbenzene | C ₈ H ₁₀ | 20 µg/l | | |
| | Styrene | C ₈ H ₈ | | | |
| | Polynuclear Aromatic Hydrocarbons (PAHs) | C ₂ H ₃ N ₁ O ₅ P ₁ 3 | 0.7 µg/l | | |
| Dichlorobenzenes (DCBs) | Monochlorobenzene (MCB) | C ₆ H ₅ Cl | 300 µg/l | | |
| | 1,2-Dichlorobenzene (1,2-DCB) | C ₆ H ₄ Cl ₂ | 1000 µg/l | 60–75 µg/l | 60–75 µg/l |
| | 1,3-Dichlorobenzene (1,3-DCB) | C ₆ H ₄ Cl ₂ | No guideline | 60–75 µg/l | 60–75 µg/l |
| Miscellaneous organic constituents | 1,4-Dichlorobenzene (1,4-DCB) | C ₆ H ₄ Cl ₂ | 300 µg/l | 60–75 µg/l | 60–75 µg/l |
| | Trichlorobenzene | C ₆ H ₃ Cl ₃ | 20 µg/l | | |
| | Di(2-ethylhexyl)adipate (DEHA) | C ₂₂ H ₄₂ O ₄ | 80 µg/l | | |
| Nitrioltriacetic acid (NTA) | Di(2-ethylhexyl)phthalate (DEHP) | C ₂₄ H ₃₈ O ₄ | 8 µg/l | | |
| | Acrylamide | C ₃ H ₅ NO | 0.5 µg/l | | |
| | Epichlorohydrin (ECH) | C ₃ H ₅ ClO | 0.4 µg/l | | |
| | Hexachlorobutadiene (HCBD) | C ₄ Cl ₆ | 0.6 µg/l | | |
| | Ethylenediaminetetracetic acid (EDTA) | C ₁₀ H ₁₂ N ₂ O ₈ | 200 µg/l | | |

Organotin

| | | | |
|--|------------------------------------|--------------|---------|
| Dialkyltins | R_2SnX_2 | No guideline | |
| Tributyl oxide (TBTO) | $C_{24}H_{54}O Sn_2$ | 2 µg/l | |
| Alachlor | $C_{14}H_{20}ClNO_2$ | 20 µg/l | zero |
| Aldicarb | $C_7H_{14}N_2O_4S$ | 10 µg/l | |
| Aldrin and dieldrin | $C_{12}H_8Cl_6$ | 0.03 µg/l | |
| Atrazine | $C_{12}H_8Cl_6O$ | 2 µg/l | 3 µg/l |
| Bentazone | $C_8H_{14}ClN_5$ | 30 µg/l | |
| Carbofuran | $C_{10}H_{12}N_2O_3S$ | 5 µg/l | 40 µg/l |
| Chlordane | $C_{12}H_{15}NO_3$ | 0.2 µg/l | zero |
| Chlorotoluron | $C_{10}H_6Cl_8$ | 30 µg/l | |
| DDT | $C_{10}H_{13}ClN_2O$ | 2 µg/l | |
| 1,2-Dibromo-3-chloropropane | $C_{14}H_9Cl_5$ | 1 µg/l | |
| 2,4-Dichlorophenoxyacetic acid (2,4-D) | $C_3H_5Br_2Cl$ | 30 µg/l | |
| 1,2-Dichloropropane | $C_8H_6Cl_2O_3$ | No guideline | zero |
| 1,3-Dichloropropane | $C_3H_6Cl_2$ | 20 µg/l | |
| 1,3-Dichloropropene | $C_3H_6Cl_2$ | No guideline | |
| Ethylene dibromide (EDB) | $CH_3CHClCH_2Cl$ $BrCH_2CH_2Br$ | No guideline | |
| Heptachlor and heptachlor epoxide | $C_{10}H_5Cl_7$ | 0.03 µg/l | |
| Hexachlorobenzene (HCB) | $C_{10}H_5Cl_7O$ | 1 µg/l | |
| Isoproturon | $C_{12}H_{18}N_2O$ | 9 µg/l | |
| Lindane | $C_6H_6Cl_6$ | 2 µg/l | |
| MCPA | $C_9H_9ClO_3$ | 2 µg/l | |

(Continued)

TABLE 1.5 (Continued)

| Element/Substance | Symbol/Formula | Normally Found in Fresh Water/Surface Water/Ground Water | Health Based Guideline by the WHO | USEPA Maximum Contaminant Level (MCL) | Maximum Contaminant Level Guideline |
|---|-----------------------------------|---|-----------------------------------|---------------------------------------|-------------------------------------|
| | Methoxychlor | (C ₆ H ₄ OCH ₃) ₂ CHCCl ₃ | 20 µg/l | | |
| | Metolachlor | C ₁₅ H ₂₂ ClNO ₂ | 10 µg/l | | |
| | Molinate | C ₉ H ₁₇ NOS | 6 µg/l | | |
| | Pendimethalin | C ₁₃ H ₁₉ O ₄ N ₃ | 20 µg/l | | |
| | Pentachlorophenol (PCP) | C ₆ HCl ₅ O | 9 µg/l | | |
| | Permethrin | C ₂₁ H ₂₀ Cl ₂ O ₃ | 20 µg/l | | |
| | Propanil | C ₉ H ₉ Cl ₂ NO | 20 µg/l | | |
| | Pyridate | C ₁₉ H ₂₃ ClN ₂ O ₂ S | 100 µg/l | | |
| | Simazine | C ₇ H ₁₂ ClN ₅ | 2 µg/l | | |
| | Trifluralin | C ₁₃ H ₁₆ F ₃ N ₃ O ₄ | 20 µg/l | | |
| Chlorophenoxy herbicides (excluding 2,4-D and MCPA) | | | | | |
| | 2,4-DB | C ₁₀ H ₁₀ Cl ₂ O ₃ | 90 µg/l | | |
| | Dichlorprop | C ₉ H ₈ Cl ₂ O ₃ | 100 µg/l | | |
| | Fenoprop | C ₉ H ₇ Cl ₃ O ₃ | 9 µg/l | | |
| | MCPB | C ₁₁ H ₁₃ ClO ₃ | No guideline | | |
| | Mecoprop | C ₁₀ H ₁₁ ClO ₃ | 10 µg/l | | |
| | 2,4,5-T | C ₈ H ₅ Cl ₃ O ₃ | 9 µg/l | | |
| | 2-Chlorophenol (2-CP) | C ₆ H ₅ ClO | No guideline | | |
| | 2,4-Dichlorophenol (2,4-DCP) | C ₆ H ₄ Cl ₂ O | No guideline | | |
| | 2,4,6-Trichlorophenol (2,4,6-TCP) | C ₆ H ₃ Cl ₃ O | 200 µg/l | | |