THE Science OF Wastewater

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Preface

THE "Science of" series, *The Science of Water*, *The Science of Air*, *The Science of Environmental Pollution*, and *The Science of Renewable Energy,* have all been hailed as masterly accounts for the general reader, the environmental practitioner, and the student. The critics have stated that these books were written in Frank R. Spellman's trademark: with an engaging and highly readable style. *The Science of Wastewater* continues this trend.

As with all my works, the text follows a pattern that is nontraditional; that is, the paradigm (model or prototype) used here is based on real-world experience—not on theoretical gobbledygook. Clearly written and user-friendly, this timely edition builds on years of research, training, and practical application of scientific principles in treating wastewater. Written as an information source and reference, it should be pointed out that this text is not limited in its potential for other uses. For example, while this work can be utilized by wastewater practitioners to provide valuable insight into the substance he or she works hard to collect, treat, and resupply for its intended purpose, it can just as easily provide important information for the policymaker who may be tasked with making decisions concerning water resource utilization. Consequently, this book will serve a varied audience—students, lay personnel, regulators, technical experts, attorneys, business leaders, and concerned citizens.

What makes *The Science of Wastewater* different from other available science and technical books? Consider the following:

- The author has worked in and around water/wastewater treatment and taught water/wastewater science, operations, safety, and math for several years at the apprenticeship level and at numerous college levels for students and operator short courses.
- The author has sat at the table of licensure examination preparation boards to review, edit, and write state wastewater licensure exams.

- This step-by-step manual provides concise, practical knowledge that practitioners and operators must have to pass licensure/certification tests.
- The text is user-friendly; no matter the difficulty of the problem to be solved, each operation is explained in straightforward, plain English. Moreover, several hundred example math problems are presented to enhance the learning process.
- Thankfully, many users of my previous texts have provided constructive criticism, advice, and suggestions. All of these inputs from actual users have been incorporated into this new text.
- This text is written by an author who has personally spent a considerable portion of his adult life wading into rivers to study, sample, and assess such moving water bodies as the Teton, Yellowstone, Shoshone, Columbia-Snake, and Flathead Rivers and also into the somewhat warmer waters of the Virgin River and Moose and Bitch Creeks of Idaho.
- The material in this text is presented in manageable chunks to make learning quick and painless with clear explanations to give you understanding fast; it is packed with worked examples and exercises.

A knowledgeable reader might ask: Is it not the case that wastewater treatment and other work with wastewater is more of an art than a science? In answering this question it should be pointed out that the study of wastewater is a science. It is a science that is closely related and/or interrelated to other scientific disciplines such as biology, microbiology, chemistry, mathematics, hydrology, and others. Note that in this text, the biology of wastewater is not discussed. This topic is reserved for and fully discussed in the companion text, *The Biology of Wastewater*. Therefore, to solve the problems and to understand the issues related to wastewater, wastewater practitioners need a broad base of scientific information from which to draw. Moreover, it might be easier to bring up a situation—for the purist, an analogy. Consider, the example (analogy) I often use to make the point: the thoracic surgeon (thoracic surgery is the major league of surgery, according to a thoracic surgeon I know), has a reputation as being an artist with a scalpel. This information might be encouraging to the would-be patient who is to be operated on by such a surgeon. However, this same patient might further inquire about the surgeon's education, training, experience; about her knowledge of the science of medicine. If I were the patient, I would want her (the artful surgeon) to understand the science of my heart and other vital organs before she took the scalpel in hand to perform her artful surgery. Wouldn't you?

Frank R. Spellman
Norfolk, Virginia

To the Reader

WHETHER it is labeled contaminated, dirty, filthy, grimy, greasy, spoiled, soiled, fouled, murky, polluted, sullied, slimy, skuzzy, unsanitary, and so on and so forth, to understand the science of wastewater not only must you understand the basic science involved but also you must have some real understanding of what wastewater really is. Again, the ability to translate basic scientific principles and profile them in a tailored fashion for easy understanding of the science involved in the science of wastewater would be an exercise without merit and/or wasteful unless the reader understands what wastewater really is. My experience with college level students studying environmental topics that include water and wastewater sciences and operations and treatments is that when they are asked to define wastewater they sort of stumble a bit. Consider some of their responses:

- "Well, . . . you know . . . wastewater is poop . . . and toothpaste and mouthwash we spittoon (sic) into the toilet . . . and pee . . . all mixed."
- "Well, wastewater is whatever we flush down the toilet."
- "It's poop and toilet paper and my left-over grease and kitchen waste I flush."
- "Well, if we flush it or dump it into the toilet or drain it in my sinks, it's wastewater."
- "Wastewater? Well, anything that goes down the toilet."
- "Mr. Crapper defined it well . . . it is crap and the associated rest."
- "Hmmmmmmmmmmmmmm, well, you know . . . it is that dirty four letter word beginning with S and ending with T mixed with urine and toilet paper."

The readers might think these responses are comical, or maybe they think they are true to life; to the point, you might say. What do I think? Thanks for asking. I think (I know) they are typical; those are typical responses from people who do not understand the science of wastewater. You must understand the mindset. The mindset? Flush it, drain it, pour it out—and so forth—because out of sight is out of mind. "It is just waste, isn't it?" And it is—well, to a point, that is.

Let's cut to the chase and get to the definition at hand; that is, the one we need to know now. Wastewater, what is it? Simply, wastewater is any water that has been adversely affected in quality by anthropogenic (fancy word meaning caused by humans) influence. Municipal wastewater is usually conveyed in a combined sewer or sanitary sewer, and treated at a wastewater treatment facility. Treated wastewater is discharged into receiving water via an effluent sewer (an outfall). In areas where centralized sewer systems are not accessible, wastewater is typically discharged to on-site systems. These on-site systems typically comprise a septic tank, drain field, and optionally an on-site treatment unit. With regard to the management of wastewater, for human excreta, solid waste, and stormwater (drainage), the all-encompassing term "sanitation" is generally used.

It is not unusual to hear people speak of sewage and wastewater as being one and the same thing. This is a misconception. Sewage is the subset of wastewater that is contaminated with feces or urine. Sewage includes domestic, municipal, or industrial liquid waste products disposed of, usually via a sanitary or combined sewer (pipe network); sometimes in a cesspool or cesspit emptier. A cesspool is used to describe an underground holding tank (sealed at the bottom) or a soak pit (not sealed). It is used as a temporary collection and storage of feces, excreta, or fecal sludge as part of an on-site sanitation and has similarities with septic tanks. Typically, it is a deep cylindrical chamber dug into the earth (like a hand-dug water well), having approximate dimensions of 1 m diameter and 2–3 m depth.

Another term that is sometimes intermixed with wastewater and sewage is sewerage. Sewerage is the physical infrastructure, including pipes, pumps, screens, channels, and so forth, used to convey sewage from its origin to the point of treatment or disposal. With the exception of on-site septic systems, sewerage is found in all types of sewage treatment.

Let's get back to wastewater. Well, back to the origin of wastewater. Wastewater can come from any of the following sources:

- Human waste
- Cesspool leakage
- Septic tank discharge
- Wastewater treatment plant discharge
- Washing water
- Rainfall collected
- Groundwater infiltration
- Surplus manufactured liquids
- Urban runoff
- Seawater ingress

- Ingress of river water
- Illegal ingress of pesticides, used oils, etc.
- Highway drainage
- Stormwater
- Industrial site drainage
- Organic and biodegradable waste
- pH waste
- Toxic waste
- Emulsion waste
- Agricultural drainage
- Hydraulic fracturing
- Produced water (natural gas production)

The actual composition of wastewater varies widely. For example, it may contain:

- Water (more than 95% used for flushing)
- Pathogens
- Nonpathogenic bacteria
- Organic particles
- Soluble organic material (urea, sugars, proteins, drugs, etc.)
- Inorganic particles such as sand, grit, and metals, etc.
- Small fish and macroinvertebrates
- Soluble inorganic material, road-salt, sea-salt, cyanic, hydrogen sulfide, etc.
- Macro-solids such as 100 dollar bills (drug flushing), bags of cocaine and heroin, guns, dead animals, plants, fetuses, sanitary napkins, etc.
- Gases such as methane, carbon dioxide, hydrogen sulfide, etc.
- Emulsions such as adhesives, mayonnaise, hair colorants, paints, etc.
- Pharmaceuticals and hormones
- Personal care products such as perfumes, body lotions, shampoo, tanning lotions, lipstick, etc.
- Pesticides, poisons, herbicides, etc.

The reader should now have a better feel or understanding for what wastewater is. Again, before we delve into the meat of this text, this is important. However, before we begin our journey through *The Science of Wastewater*, I think it important that I leave the reader with some food for thought. That is, after having studied, swam in, fallen into (by accident, of course) millions of gallons of wastewater over the past 45 years, it has become apparent to me that maybe the label wastewater is incorrect. Incorrect? Yes. Okay, if that be the case, what should we call it? Simply, wastewater should be called used water. Why? Again, simply, because wastewater is not wasted; it is either recycled by natural processes (the water cycle) or by humans copying nature's way of treating wastewater.

Part 1
Basic Wastewater Science

Wastewater Math Operations

To operate a wastewater treatment plant, and to pass the examination for an operator's license, you must know how to perform certain mathematical operations. However, do not panic, as Price points out, "Those who have difficulty in math often do not lack the ability for mathematical calculation, they merely have not learned, or have been taught, the 'language of math,'" (Price 1991).

1.1. INTRODUCTION

Without the ability to perform mathematical calculations, operators would have difficulty in properly operating wastewater systems. In reality, most of the calculations operators need to perform are not difficult. Generally, math ability through basic algebra is all that is needed. Experience has shown that skill with math operations used in wastewater system operations is an acquired skill that is enhanced and strengthened with practice.

Note: Keep in mind that mathematics is a *language*—a universal language. Mathematical symbols have the same meaning to people speaking many different languages throughout the globe. The key to learning mathematics is to learn the language—the symbols, definitions, and terms of mathematics which allow you to understand the concepts necessary to perform the operations.

In Chapter 1, we assume the reader is well grounded in basic math principles and operations. Thus, we do not cover basic operations such as addition, subtraction, multiplying, and dividing.

1.2. CALCULATION STEPS

As with all math operations, many methods can be successfully used to solve wastewater system problems. We provide one of the standard methods of problem solving in the following:

1. If appropriate, make a drawing of the information in the problem.
2. Place the given data on the drawing.
3. Determine "what is the question?" This is the first thing you should ask as you begin to solve the problem, along with, "What are they really looking for?" Writing down exactly what is being looked for is always smart. Sometimes the answer has more than one unknown. For instance, you may need to find x, and then find y.
4. If the calculation calls for an equation, write it down.
5. Fill in the data in the equation—look to see what is missing.
6. Rearrange or transpose the equation, if necessary.
7. If available, use a calculator.
8. Always write down the answer.
9. Check any solution obtained.

1.3. TABLE OF EQUIVALENTS, FORMULAE, AND SYMBOLS

In order to work mathematical operations to solve problems (for practical application or for taking licensure examinations), it is essential to understand the language, equivalents, symbols, and terminology used.

Because this book is designed for use in practical on-the-job applications, equivalents, formulae, and symbols are included as a ready reference in Table 1.1.

TABLE 1.1. **Equivalents, Formulae, and Symbols.**

Equivalents		
12 inches	=	1 foot
36 inches	=	1 yard
144 inches^2	=	1 foot^2
9 feet^2	=	1 yard^2
43,560 feet^2	=	1 acre
1 foot^3	=	1,728 inch^3
1 foot^3 of water	=	7.48 gallons
1 foot^3 of water weighs	=	62.4 pounds
1 gallon of water weighs	=	8.34 pounds
1 liter	=	1.000 milliliters
1 gram	=	1.000 milligrams
1 million gallon/day	=	694 gallons/minute
	=	1.545 cubic feett/second
average BOD/capita/day	=	0.17 pounds
average SS/capita/day	=	0.20
average daily flow	=	assume 100 gallon/capita/day

(continued)

TABLE 1.1 (continued). **Equivalents, Formulae, and Symbols.**

Symbols		
A	=	area
V	=	velocity
t	=	time
SVI	=	sludge volume index
Vol	=	volume
#	=	pounds (lb)
eff	=	effluent
W	=	width
D	=	depth
L	=	length
Q	=	flow
r	=	radius
π	=	pi (3.14)
WAS	=	waste activated sludge
RAS	=	return activated sludge
MLSS	=	mixed liquor suspended solids
MLVSS	=	mixed liquor volatile suspended solids

Formulae		
SVI	=	$\frac{\text{Volume}}{\text{Concentration}} \times 100$
Q	=	$A \times V$
Detention Time	=	$\frac{\text{Volume}}{Q}$
volume	=	$L \times W \times D$
area	=	$W \times L$
circular area	=	$\pi \times D^2 (= 0.785 \times D^2)$
circumference	=	πD
hydraulic loading rate	=	$\frac{Q}{A}$
Sludge age	=	$\frac{\text{\#MLSS in Aeration Tank}}{\text{\#SS in primary eff/day}}$
MCRT	=	$\frac{\text{\#SS in secondary system (aeration tank + sec. clarifier)}}{\text{\#WAS/day + SS in eff/day}}$
Organic loading rate	=	$\frac{\text{\#BOD/day}}{\text{Volume}}$

1.4. BASIC WASTEWATER MATH OPERATIONS

1.4.1. Arithmetic Average (or Arithmetic Mean) and Median

During the day-to-day operation of a wastewater treatment plant, considerable mathematical data is collected. The data, if properly evaluated, can provide useful information for trend analysis and can indicate how well the plant or unit process is operating. However, because there may be much variation in the data, it is often difficult to determine trends in performance.

Arithmetic average refers to a statistical calculation used to describe a series of numbers such as test results. By calculating an average, a group of data is represented by a single number. This number may be considered typical of the group. The *arithmetic mean* is the most commonly used measurement of average value.

Note: When evaluating information based on averages, remember that the "average" reflects the general nature of the group and does not necessarily reflect any one element of that group.

Arithmetic average is calculated by dividing the sum of all of the available data points (test results) by the number of test results.

$$\frac{\text{Test }1+\text{Test }2+\text{Test }3+\ldots+\text{Test }N}{\text{Number of Tests Performed }(N)} \tag{1.1}$$

Example 1.1

Problem:

Effluent BOD test results for the treatment plant during the month of September are shown below.

Test 1	21 mg/L
Test 2	32 mg/L
Test 3	24 mg/L
Test 4	16 mg/L

What is the average effluent BOD for the month of September?

Solution:

$$\text{Average} = \frac{21\text{ mg/L}+32\text{ mg/L}+24\text{ mg/L}+16\text{ mg/L}}{4} = 23.25\text{ mg/L}$$

Example 1.2

Problem:

For the primary influent flow, the following composite-sampled solids concentrations were recorded for the week:

Monday	305 mg/L SS
Tuesday	302 mg/L SS
Wednesday	305 mg/L SS
Thursday	300 mg/L SS
Friday	310 mg/L SS
Saturday	322 mg/L SS
Sunday	310 mg/L SS
Total	2,154 mg/L SS

Solution:

$$\text{Average SS} = \frac{\text{Sum of all measurements}}{\text{Number of measurement used}}$$

$$= \frac{2{,}154 \text{ mg/L SS}}{7}$$

$$= 307.7 \text{ mg/L SS}$$

Example 1.3

Problem:

A wastewater operator takes a chlorine residual measurement every day. We show part of the operating log as follows:

Daily Chlorine Residual Results

	Chlorine Residual (mg/L)
Monday	0.8
Tuesday	1.1
Wednesday	1.0
Thursday	1.1
Friday	0.9
Saturday	1.2
Sunday	0.9

Find the mean.

Solution:

Add up the seven chlorine residual readings: 0.8 + 1.1 + 1.0 + 1.1 + 0.9 + 1.2 + 0.9 = 7.0. Next, divide by the number of measurements (in this case seven): 7.0 ÷ 7 = 1.0. The mean chlorine residual for the week was 1.0 mg/L.

Definition:

The *median* is defined as the value of the central item when the data are arrayed by size. First, arrange all of the readings in either ascending or descending order. Then find the middle value.

Example 1.4

Problem:

In our chlorine residual example, what is the median?

Solution:

Arrange the values in ascending order:

0.8
1.1
1.0
1.1
0.9
1.2
0.9

The middle value is the fourth one: 1.1. Therefore, the median chlorine residual is 1.1 mg/L. (Usually, the median will be a different value than the mean).

If the data contains an even number of values, you must add one more step, since no middle value is present. You must find the two values in the middle, and then find the mean of those two values.

Example 1.5

Problem:

A small wastewater storage system has four tanks with the following capacities: 115 gpm, 100 gpm, 125 gpm, and 90 gpm. What are the mean and the median storage capacities?

Solution:

$$\text{Mean average} = \frac{115\text{ gpm} + 100\text{ gpm} + 125\text{ gpm} + 90\text{ gpm}}{4} = 107.5\text{ gpm}$$

To find the median, arrange the values in order:

90 gpm
100 gpm
115 gpm
125 gpm

With four values, there is no single "middle" value, so we must take the mean of the two middle values:

$$\frac{100 \text{ gpm} + 115 \text{ gpm}}{2} = 07.5 \text{ gpm}$$

Note: At times, determining what the original numbers were like is difficult (if not impossible) when dealing only with averages.

Example 1.6

Problem:

A small wastewater system has four storage tanks. Three of them have a capacity of 100,000 gal each, while the fourth has a capacity of 1,000,000 gal. What is the mean capacity of the storage tanks?

Solution:

The mean capacity of the storage tanks is

$$\frac{100{,}000 + 100{,}000 + 100{,}000 + 1{,}000{,}000}{4} = 325{,}000 \text{ gal}$$

Note: Notice that no tank in Example 1.6 has a capacity anywhere close to the mean. The median capacity requires us to take the mean of the two middle values; since they are both 100,000 gal, the median is 100,000 gal. Although three of the tanks have the same capacity as the median, this data offers no indication that one of these tanks holds a million gallons—information that could be important for the operator to know.

1.4.2. Units and Conversions

Most of the calculations made in the wastewater operations involve using *units*. While the number tells us how many, the units tell us what we have. Examples of units include inches, feet, square feet, cubic feet, gallons, pounds, milliliters, milligrams per liter, pounds per square inch, miles per hour, and so on.

Conversions are a process of changing the units of a number to make the number usable in a specific instance. Multiplying or dividing into another number to change the units of the number accomplishes conversions. Common conversions in wastewater operations are:

- gpm to cfs
- Million gallons to acre-feet
- Cubic feet to acre-feet

- Cubic feet of water to weight
- Cubic feet of water to gallons
- Gallons of water to weight
- Gallons per minute to million gallons per day
- Pounds per square inch to feet of head (the measure of the pressure of water expressed as height of water in feet—1 psi = 2.31 feet of head).

In many instances, the conversion factor cannot be derived—it must be known. Therefore, we use tables such as Table 1.2 to determine the common conversions.

Note: Conversion factors are used to change measurements or calculated values from one unit of measure to another. In making the conversion from one unit to another, you must know two things:

1. The exact number that relates the two units
2. Whether to multiply or divide by that number

Most operators memorize some standard conversions. This happens because of using the conversions, not because of attempting to memorize them.

$$\text{Weight} = \text{Concentration} \times \text{Flow or Volume} \times \text{Factor} \tag{1.2}$$

Table 1.3 summarizes weight, volume, and concentration calculations. With practice, many of these calculations become second nature to operators; the calculations are important relationships and are used often in water/wastewater treatment process control calculations, so on-the-job practice is possible.

1.4.3. Temperature Conversions

An example of a type of conversion typical in wastewater operations is provided in this section on temperature conversions.

Note: Operators should keep in mind that temperature conversions are only a small part of the many conversions that must be made in real world systems operations.

Most wastewater operators are familiar with the formulas used for Fahrenheit and Celsius temperature conversions:

$$°C = 5/9(°F - 32°) \tag{1.3}$$

$$°F = (9/5°C) + 32° \tag{1.4}$$

These conversions are not difficult to perform. The difficulty arises when we must recall these formulas from memory.

TABLE 1.2. **Common Conversions.**

To Convert	Multiply By	To Get
Feet	12	Inches
Yards	3	Feet
Yards	36	Inches
Inches	2.54	Centimeters
Meters	3.3	Feet
Meters	100	Centimeters
Meters	1,000	Millimeters
Square Yards	9	Square Feet
Square Feet	144	Square inches
Acres Square	43,560	Feet
Cubic Yards	27	Cubic Feet
Cubic Feet	1,728	Cubic Inches
Cubic Feet (water)	7.48	Gallons
Cubic Feet (water)	62.4	Pounds
Acre-Feet	43,560	Cubic Feet
Gallons (water)	8.34	Pounds
Gallons (water)	3.785	Liters
Gallons (water)	3,785	Milliliters
Gallons (water)	3,785	Cubic Centimeters
Gallons (water)	3,785	Grams
Liters	1,000	Milliliters
Days	24	Hours
Days	1,440	Minutes
Days	86,400	Seconds
Million Gallons/Day	1,000,000	Gallons/Day
Million Gallons/Day	1.55	Cubic Feet/Second
Million Gallons/Day	3.069	Acre-Feet/Day
Million Gallons/Day	36.8	Acre-Inches/Day
Million Gallons/Day	3,785	Cubic Meters/Day
Gallons/Minute	1,440	Gallons/Day
Gallons/Minute	63.08	Liters/Minute
Pounds	454	Grams
Grams	1,000	Milligrams
Pressure, psi	2.31	Head, feet (water)
Horsepower	33,000	Foot-Pounds/Minute
Horsepower	0.746	Kilowatts
To Get	**Divide By**	**To Convert**

TABLE 1.3. **Weight, Volume, and Concentration Calculations.**

To Calculate	Formula
Pounds	Concentration, mg/L × Tank Vol. M × 8.34 lb/MG/mg/L
Pounds/Day	Concentration, mg/L × Flow, MGD × 8.34 lb/MG/mg/L
Million Gallons/Day	$\frac{\text{Quantity, lb/day}}{(\text{Conc., mg/L} \times 8.34\ \text{lb/mg/L/MG})}$
Milligrams/Liter	$\frac{\text{Quantity, lb}}{(\text{Tank Volume, MG} \times 8.34\ \text{lb/mg/L/MG})}$
Kilograms/Liter	Conc., mg/L × Volume, MG × 3.785 lb/MG/mg/L
Kilograms/Day	Conc., mg/L × Flow, MGD × 3.785 lb/MG/mg/L
Pounds/Dry Ton	Conc. Mg/kg × 0.002 lb/dt/mg/kg

Probably the easiest way to recall these important formulas is to remember three basic steps for both Fahrenheit and Celsius conversions:

1. Add 40°.
2. Multiply by the appropriate fraction (5/9 or 9/5).
3. Subtract 40°.

Obviously, the only variable in this method is the choice of 5/9 or 9/5 in the multiplication step. To make the proper choice, you must be familiar with two scales. On the Fahrenheit scale the freezing point of water is 32°, and 0° on the Celsius scale. The boiling point of water is 212° on the Fahrenheit scale and 100° on the Celsius scale.

Note, for example, that at the same temperature, higher numbers are associated with the Fahrenheit scale and lower numbers with the Celsius scale. This important relationship helps you decide whether to multiply by 5/9 or 9/5 Let us look at a few conversion problems to see how the three-step process works.

Example 1.7

Problem:

Convert 220°F to Celsius. Using the three-step process, we proceed as follows:

Solution:

Step (1): Add 40°F.

$$220°\text{F} + 40°\text{F} = 260°\text{F}$$

Step (2): 260°F must be multiplied by either 5/9 or 9/5. Since the conversion is to the *Celsius* scale, you will be moving to number *smaller* than 260. Through reason and observation, obviously we see that multiplying 260 by 9/5 would almost be the same as multiplying by 2, which would double 260, rather than make it smaller. On the other hand, multiplying by 5/9 is about the same as multiplying by 1/2, which would cut 260 in half. Since in this problem you wish to move to a smaller number, you should multiply by 5/9:

$$(5/9)(260°C) = 144.4°C$$

Step (3): Now subtract 40°.

$$144.4°C – 40.0°C = 104.4°$$

Therefore, 220°F = 104.4°C.

Example 1.8

Problem:

Convert 22°C to Fahrenheit.

Step (1): Add 40°.

$$22°F + 40°F = 62°F$$

Because you are converting from Celsius to Fahrenheit, you are moving from a smaller to larger number, and should use 9/5 in the multiplication:

Step (2):

$$(9/5)(62°) = 112°$$

Step (3): Subtract 40°.

$$112° – 40° = 72°$$

Thus, 22°C = 72°F.

Obviously, knowing how to make these temperature conversion calculations is useful. However, in practical (real world) operations, you may wish to use a temperature conversion table.

1.4.4. Milligrams Per Liter (Parts Per Million)

One of the most common terms for concentration is *milligrams per liter* (mg/L). For example, if a mass of 15 mg of oxygen is dissolved in a volume of 1 L of water, the concentration of that solution is expressed simply as 15 mg/L.

Very dilute solutions are more conveniently expressed in terms of *micrograms per liter* (µg/L). For example, a concentration of 0.005 mg/L is preferably written as its equivalent 5 μg/L. Since 1,000 μg = 1 mg, simply move the decimal point three places to the right when converting from mg/L to μl. Move the decimal three places to the left when converting from μg/L, to mg/L. For example, a concentration of 1,250 μ/L is equivalent to 1.25 mg/L.

One liter of water has a mass of 1 kg. But 1 kg is equivalent to 1,000 g or 1,000,000 mg. Therefore, if we dissolve 1 mg of a substance in 1 liter of water, we can say that there is 1 mg of solute per 1 million mg of water—or in other words, one *part per million* (ppm).

Note: For comparative purposes, we like to say that 1 ppm is analogous to a full shot glass of water sitting in the bottom of a full standard swimming pool.

Neglecting the small change in the density of water as substances are dissolved in it, we can say that, in general, a concentration of 1 milligram per liter is equivalent to one part per million: 1 mg/L = 1 ppm. Conversions are very simple; for example, a concentration of 18.5 mg/l is identical to 18.5 ppm.

The expression mg/L is preferred over ppm, just as the expression μg/l is preferred over its equivalent of ppb. However, both types of units are still used, and the waterworks operator should be familiar with them.

1.4.5. Solving for the Unknown

Many wastewater treatment calculations involve the use of formulae and equations. To make these calculations, you must first know the values for all but one of the terms of the equation to be used. The obvious question is "What is an equation?" Simply, an equation is a mathematical statement that tells us that what is on one side of an equal sign (=) is equal to what is on the other side. For example: $4 + 5 = 9$.

Now suppose we decide to add 4 to the left side, $4 + 4 + 5$. What must we do? We must add 4 to the right side, $4 + 9$.

Let's try another equation: $6 + 2 = 8$. If we subtract 3 from the left side: $6 + 2 - 3$, what comes next? We must subtract 3 from the right side: $8 - 3$.

It follows that if the right side were multiplied by a certain number we would have to multiply the left side by that same number. Finally, if one side is divided by 4, for example, 4 must also divide the other side.

The bottom line: What we do to one side of the equation, we must do to the other side. This is the case, of course, because the two sides, by definition, are always equal.

1.4.5.1. Equations

An *equation* is a statement that two expressions or quantities are equal in value. The statement of equality $6x + 4 = 19$ is an equation; that is, it is algebraic shorthand for, "The sum of 6 times a number plus 4 is equal to 19." It can be seen that the equation $6x + 4 = 19$ is much easier to work with than the equivalent sentence.

When thinking about equations, it is helpful to consider an equation as being similar to a balance. The equal sign tells you that two quantities are "in balance" (i.e., they are equal).

Back to equation $6x + 4 = 19$. The solution to this problem may be summarized in three steps.

Step (1): $6x + 4 = 19$

Step (2): $6x = 15$

Step (3): $x = 2.5$

Note: Step 1 expresses the whole equation. In step 2, 4 has been subtracted from both sides of the equation. In step 3, both sides have been divided by 6.

Key Point: An equation is, therefore, kept in balance (both sides of the equal sign are kept equal) by subtracting the same number from both members (sides), adding the same number to both, or dividing or multiplying by the same number.

The expression $6x + 4 = 19$ is called a *conditional equation*, because it is true only when x has a certain value. The number to be found in a conditional equation is called the *unknown number*, the *unknown quantity*, or, more briefly, the *unknown*.

Let's take a look at another equation:

$$W = F \times D$$

Where:

W = work
F = force
D = distance

$$\text{Work} = \text{Force (lb)} \times \text{Distance (ft or in)}$$
$$= \text{ft-lb or in-lb}$$

1.4.5.2. Solving Equations

Suppose we have this equation:

$$x - 8 = 2$$

How can we determine the value of x? By following the example below, the solution to the unknown is quite simple.

Example 1.9

Problem:

Find the value of x if $x - 8 = 2$.

Organic detritus Any loose organic material in streams—such as leaves, bark, or twigs—removed and transported by mechanical means, such a disintegration or abrasion.

Organic soil Soil that contains more than 20% organic matter in the upper 16 in.

Organochlorine compound Synthetic organic compounds containing chlorine. As generally used, term refers to compounds containing mostly or exclusively carbon, hydrogen, and chlorine.

Outwash Soil material washed down a hillside by rainwater and deposited upon more gently sloping land.

Overland flow The flow of rainwater or snowbelt over the land surface toward stream channels.

Oxidation When a substance either gains oxygen, or loses hydrogen or electrons in a chemical reaction. One of the chemical treatment methods.

Oxidizer A substance that oxidizes another substance.

Parts per million The number of weight or volume units of a constituent present with each one million units of the solution or mixture. Formerly used to express the results of most water and wastewater analyses, PPM is being replaced by milligrams per liter M/L. For drinking water analyses, concentration in parts per million and milligrams per liter are equivalent. A single PPM can be compared to a shot glass full of water inside a swimming pool.

Pathogen Type of microorganism that can cause disease.

Perched groundwater Unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone.

Percolation The movement, under hydrostatic pressure, of water through interstices of a rock or soil (except the movement through large openings such as caves).

Perennial stream A stream that normally has water in its channel at all times.

Periphyton Microorganisms that coat rocks, plants, and other surfaces on lake bottoms.

Permeability The capacity of a rock for transmitting a fluid; a measure of the relative ease with which a porous medium can transmit a liquid.

pH A measure of the acidity (less than 7) or alkalinity (greater than 7) of a solution; a pH of 7 is considered neutral.

Phosphorus A nutrient essential for growth that can play a key role in stimulating aquatic growth in lakes and streams.

Photosynthesis The synthesis of compounds with the aid of light.

Physical treatment Any process that does not produce a new substance (e.g., screening, adsorption, aeration, sedimentation, and filtration).

Point source Originating at any discrete source.

Polar covalent bond The shared pair of electrons between two atoms are not equally held. Thus, one of the atoms becomes slightly positively charged and the other atom becomes slightly negatively charged.

Polar covalent molecule (water) One or more polar covalent bonds result in a molecule that is polar covalent. Polar covalent molecules exhibit partial positive and negative poles, causing them to behave like tiny magnets. Water is the most common polar covalent substance.

Pollutant Any substance introduced into the environment that adversely affects the usefulness of the resource.

Pollution The presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as a man-made or man-induced alteration of the physical, biological, and radiological integrity of water.

Polychlorinated biphenyls (PCBs) A mixture of chlorinated derivatives of biphenyl, marketed under the trade name Aroclor with a number designating the chlorine content (such as Aroclor 1260). PCBs were used in transformers and capacitors for insulating purposes and in gas pipeline systems as a lubricant. Further sale or new use was banned by law in 1979.

Polycyclic aromatic hydrocarbon (PAH) A class of organic compounds with a fused-ring aromatic structure. PAHs result from incomplete combustion of organic carbon (including wood), municipal solid waste, and fossil fuels, as well as from natural or anthropogenic introduction of uncombusted coal and oil. PAHs included benzo(a)pyrene, fluoranthene, and pyrene.

Population A collection of individuals of one species or mixed species making up the residents of a prescribed area.

Porosity The ratio of the volume of voids in a rock or soil to the total volume.

Potable water Water that is safe and palatable for human consumption.

Precipitation Any or all forms of water particles that fall from the atmosphere, such as rain, snow, hail, and sleet. The act or process of producing a solid phase within a liquid medium.

Pretreatment Any physical, chemical, or mechanical process used before the main water treatment processes. It can include screening, presedimentation, and chemical addition.

Primary Drinking Water Standards Regulations on drinking water quality (under SWDA) considered essential for preservation of public health.

Primary treatment The first step of treatment at a municipal wastewater treatment plant. It typically involves screening and sedimentation to remove materials that float or settle.

Public-supply withdrawals Water withdrawn by public and private water suppliers for use within a general community. Water is used for a variety of purposes such as domestic, commercial, industrial, and public water use.

Public water system As defined by the Safe Drinking Water Act, any system, publicly or privately owned, that serves at least 15 service connections 60 days out of the year or serves an average of 25 people at least 60 days out of the year.

Publicly owned treatment works (POTW) A waste treatment works owned by a state, local government unit, or Indian tribe, usually designed to treat domestic wastewaters.

Rain shadow A dry region on the lee side of a topographic obstacle, usually a mountain range, where rainfall is noticeably less than on the windward side.

Reach A continuous part of a stream between two specified points.

Reaeration The replenishment of oxygen in water from which oxygen has been removed.

Receiving waters A river, lake, ocean, stream, or other water source into which wastewater or treated effluent is discharged.

Recharge The process by which water is added to a zone of saturation, usually by percolation from the soil surface.

Recharge area (groundwater) An area within which water infiltrates the ground and reaches the zone of saturation.

Reference dose (RfD) An estimate of the amount of a chemical that a person can be exposed to on a daily basis that is not anticipated to cause adverse systemic health effects over the person's lifetime.

Representative sample A sample containing all the constituents present in the water from which it was taken.

Return flow That part of irrigation water that is not consumed by evapotranspiration and that returns to its source or another body of water.

Reverse osmosis (RO) Solutions of differing ion concentration are separated by a semipermeable membrane. Typically, water flows from the chamber with lesser ion concentration into the chamber with the greater ion concentration resulting in hydrostatic or osmotic pressure. In RO, enough external pressure is applied to overcome this hydrostatic pressure, thus reversing the flow of water. This results in the water on the other side of the membrane becoming depleted in ions and demineralized.

Riffle A shallow part of the stream where water flows swiftly over completely or partially submerged obstructions to produce surface agitation.

Riparian Pertaining to or situated on the bank of a natural body of flowing water.

Riparian rights A concept of water law under which authorization to use water in a stream is based on ownership of the land adjacent to the stream.

Riparian zone Pertaining to or located on the bank of a body of water, especially a stream.

Runoff That part of precipitation or snowmelt that appears in streams or surface-water bodies.

Rural withdrawals Water used in suburban or farm areas for domestic and livestock needs. The water generally is self-supplied and includes domestic use, drinking water for livestock, and other uses such as dairy sanitation, evaporation from stock-watering ponds, and cleaning and waste disposal.

Safe Drinking Water Act (SDWA) A federal law passed in 1974 with the goal of establishing federal standards for drinking water quality, protecting underground sources of water, and setting up a system of state and federal cooperation to assure compliance with the law.

Saline water Water that is considered unsuitable for human consumption or for irrigation because of its high content of dissolved solids; generally expressed as milligrams per liter of dissolved solids; seawater is generally considered to contain more than 35,000 mg/L of dissolved solids. A general salinity scale is:

Concentration of dissolved solids in mg/L

Slightly saline	1,000–3,000
Moderately saline	3,000–10,000
Very saline	10,000–35,000
Brine	More than 35,000

Saturated zone A subsurface zone in which all the interstices or voids are filled with water under pressure greater than that of the atmosphere.

Screening A pretreatment method that uses coarse screens to remove large debris from the water to prevent clogging of pipes or channels to the treatment plant.

Secondary Drinking Water Standards Regulations developed under the Safe Drinking Water Act that established maximum levels of substances affecting the aesthetic characteristics (taste, color, or odor) of drinking water.

Secondary maximum contaminant level (SMCL) The maximum level of a contaminant or undesirable constituent in public water systems that, in the judgment of US Environmental Protection Agency (EPA), is required to protect the public welfare. SMCLs are secondary (non-enforceable) drinking water regulations established by the EPA for contaminants that may adversely affect the odor or appearance of such water.

Secondary treatment The second step of treatment at a municipal wastewater treatment plant. This step uses growing numbers of microorganisms to digest organic matter and reduce the amount of organic waste. Water leaving this process is chlorinated to destroy any disease-causing microorganisms before its release.

Sedimentation A physical treatment method that involves reducing the velocity of water in basins so that the suspended material can settle out by gravity.

Seep A small area where water percolates slowly to the land surface.

Seiche A sudden oscillation of the water in a moderate size body of water, caused by wind.

Sinuosity The ratio of the channel length between two points on a channel to the straight-line distance between the same two points; a measure of meandering.

Soil horizon A layer of soil that is distinguishable from adjacent layers by characteristic physical and chemical properties.

Soil moisture Water occurring in the pore spaces between the soil particles in the unsaturated zone from which water is discharged by the transpiration of plants or by evaporation from the soil.

Solution Formed when a solid, gas, or another liquid in contact with a liquid becomes dispersed homogeneously throughout the liquid. The substance, called a solute, is said to dissolve. The liquid is called the solvent.

Solvated When either a positive or negative ion becomes completely surrounded by polar solvent molecules.

Sorb To take up and hold either by absorption or adsorption.

Sorption General term for the interaction (binding or association) of a solute ion or molecule with a solid.

Specific yield The ratio of the volume of water that will drain under the influence of gravity to the volume of saturated rock.

Spring Place where a concentrated discharge of groundwater flows at the ground surface.

Surface runoff Runoff that travels over the land surface to the nearest stream channel.

Surface tension The attractive forces exerted by the molecules below the surface upon those at the surface, resulting in them crowding together and forming a higher density.

Surface water All water naturally open to the atmosphere, and all springs, wells, or other collectors that are directly influenced by surface water.

Surface Water Treatment Rule (SWTR) A federal regulation established by the EPA under the Safe Drinking Water Act that imposes specific monitoring and treatment requirements on all public drinking water systems that draw water from a surface water source.

Suspended sediment Sediment that is transported in suspension by a stream.

Suspended solids Different from suspended sediment only in the way that the sample is collected and analyzed.

Synthetic organic chemicals (SOCs) Generally applied to manufactured chemicals that are not as volatile as volatile organic chemicals. Included are herbicides, pesticides, and chemicals widely used in industries.

Total head The height above a datum plane of a column of water. In a groundwater system, it is composed of elevation head and pressure head.

Total suspended solids (TSS) Solids present in wastewater.

Transpiration The process by which water passes through living organisms, primarily plants, into the atmosphere.

Trihalomethanes (THMs) A group of compounds formed when natural organic compounds from decaying vegetation and soil (such as humic and fulvic acids) react with chlorine.

Turbidity A measure of the cloudiness of water caused by the presence of suspended matter, which shelters harmful microorganisms and reduces the effectiveness of disinfecting compounds.

Unconfined aquifer An aquifer whose upper surface is a water table free to fluctuate under atmospheric pressure.

Unsaturated zone A subsurface zone above the water table in which the pore spaces may contain a combination of air and water.

Vehicle of disease transmission Any nonliving object or substance contaminated with pathogens.

Vernal pool A small lake or pond that is filled with water for only a short time during the spring.

Wastewater The spent or used water from individual homes, a community, a farm, or an industry that contains dissolved or suspended matter.

Water budget An accounting of the inflow to, outflow from, and storage changes of water in a hydrologic unit.

Water column An imaginary column extending through a water body from its floor to its surface.

Water demand Water requirements for a particular purpose, such as irrigation, power, municipal supply, plant transpiration, or storage.

Water table The top water surface of an unconfined aquifer at atmospheric pressure.

Waterborne disease Water is a potential vehicle of disease transmission, and waterborne disease is possibly one of the most preventable types of communicable illness. The application of basic sanitary principles and technology have virtually eliminated serious outbreaks of waterborne diseases in developed countries. The most prevalent waterborne diseases include typhoid fever, dysentery, cholera, infectious hepatitis, and gastroenteritis.

Water softening A chemical treatment method that uses either chemicals to precipitate or a zeolite to remove those metal ions (typically Ca^{2+}, Mg^{2+}, Fe^{3+}) responsible for hard water.

Watershed The land area that drains into a river, river system, or other body of water.

Wellhead protection The protection of the surface and subsurface areas surrounding a water well or well field supplying a public water system from contamination by human activity.

Yield The mass of material or constituent transported by a river in a specified period of time divided by the drainage area of the river basin.

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