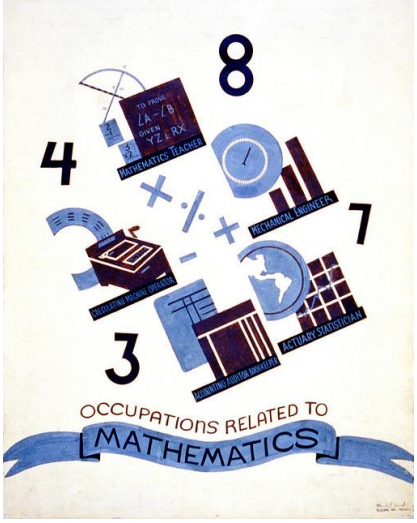
ADVANCED WATERWORKS MATHEMATICS

Learning and Understanding Mathematical Concepts in the Areas of Water Distribution and Water Treatment

(5th Edition)



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COLLEGE OF THE CANYONS

WATER SYSTEMS TECHNOLOGY PROGRAM

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SECTION 1
UNIT DIMENSIONAL ANALYSIS (UDA)
Cancelling of Units

$$\frac{Units}{Units} \; x \; \frac{Units}{Units}$$

The converting (or cancelling) of units is the most important concept in waterworks mathematics. You may be working with million gallons, cubic feet, acre feet, feet per second, gallons per minute, milligrams per liter, pounds per gallon, yard, ounce, parts per billion, etc., etc., etc. Units are the "driver" for problem solving in many waterworks math questions. The reason for this has to do with how processes are measured. For example, many water meters measure usage in hundred cubic feet. However, when Utility Managers report total usage by a class of customers it is typically expressed as acre feet or million gallons. Another example can be when dosage calculations are performed. Many times flow rates are measured as gallons per minute, but dosage computations require million gallons per day. These are just a couple of examples demonstrating the common conversion between units.

In an introductory water mathematics course unit conversion is typically explained in a "unit by unit" break down. Here we are converting from cfs (cubic feet per sec) to gpm (gallon per minute).

$$\frac{1\ \cancel{cf}}{\cancel{sec}} \; x \; \frac{60\ \cancel{sec}}{1\ min} \; x \; \frac{7.48\ gal}{1\ \cancel{cf}} = \frac{448.8\ gal}{min}$$

In the example above, it takes two steps to convert cfs to gpm, one step to convert the seconds to minutes and the other step to convert cubic feet to gallons. This is the preferred method to avoid costly careless errors and minimize mistakes. However, as you become more familiar with water related math problems you will notice recurring numbers such as 448.8. Numbers like this can be used as conversion factors as well.

For example, 448.8 gpm is equivalent to 1 cfs. The conversion factor would look like this;

$$\frac{1\ cfs}{448.8\ gpm} \quad or \quad \frac{448.8\ gpm}{1\ cfs}$$

$$\frac{1\ \cancel{cfs}}{1} \; x \; \frac{448.8\ gpm}{1\ \cancel{cfs}} = 448.8\ gpm$$

Instead of breaking up cubic feet per second into the units cubic feet and seconds, cubic feet per seconds are kept together as cfs. There are several of these "combined" conversion factors.

Exercise 1

Demonstrate how each of the following "combined" conversion factors are calculated.

1. 1 cfs = 448.8 gpm

2. 1 MGD = 1.55 cfs

3. 1 cfs = 0.646 MGD

4. 1 day = 1,440 minutes

5. 1 cf = 62.4 lbs

Exercise 1.1

Solve the following conversion problems using combined conversion factors when possible.

1. Convert 3 cfs to gpm

2. Convert 10.55 MGD to cfs

3. A pipe is flowing at a rate of 5.65 cfs. If this pipe flowed 10 hours per day for 365 days, how many AFY would this produce?

4. A water tank has 3,200,000 gallons in it. How much does the water weigh in lbs?

5. A faucet is dripping at a rate of 3 drops per 15 seconds. How many gallons will leak out of this faucet in 30 days? (Assume 18 drops equals 1 ounce)

6. A well flows at a rate of 1,250 gpm. How many MGD can this well produce?

7. A water utility operator needs to report the total annual production from 3 wells. The report needs to be expressed in AFY. Well 1 pumps at a rate of 750 gpm and runs for 7 hours per day. Well 2 pumps at a rate of 3,400 gpm and runs for 10 hours per day. Well 3 pumps at a rate of 1,340 gpm and runs for 5 hours per day.

8. A water utility has a fleet of 10 vehicles. Group A vehicles drove 13,330 miles last year, Group B vehicles drove 12,200 miles year, and Group C vehicles drove 9,540 miles last year. What were the average miles per day that each vehicle grouping drove? (Assume that the vehicles were only operated during the week)

9. Water flows through an aqueduct at a velocity of 0.55 fps. How many miles will the water travel in one day?

10. How many gallons will flow into a tank in 5 hours if the rate is 500 gpm?

SECTION 1.1 APPLYING THE MATH OF UDA

"Will I ever use UDA in real life?" This sort of question usually pops into the heads of students in all subjects, but in math it happens quite often. In a practical sense, UDA can be looked at as converting between currencies. If you travel to Europe for example, you will want to know how many Euros equal a dollar. Or you may want to figure out how fast you are driving, in which case you would need to convert kilometers per hour into miles per hour.

However, in the "world" of water, converting of units is common place. The following few questions are written with the perspective of "real world" scenarios.

Exercise 1.2

1. A water utility manager has been asked to prepare an end of year report for the utility's Board of Directors. The utility has 4 groundwater wells and two connections to a surface water treatment plant. Complete the table below.

Source of Supply	Flow Rate (gpm)	Daily Operation (Hrs)	Total Flow (MGD)	Annual Flow (AFY)
Well 1	800	10		
Well 2	1,000	8		
Well 3	650	16		
Well 4	2,250	11		
SW Pump 1	1,750	7		
SW Pump 2	1,500	9		

2. Using the information from the above problem, fill in the table below.

Source of Supply	**Annual Production (AFY)**	**Cost per AF ($/AF)**	**Total Annual Cost ($)**
Well 1		60	
Well 2		60	
Well 3		95	
Well 4		95	
SW Pump 1		450	
SW Pump 2		450	
Total Annual Cost			

3. A water utility has 12,300 service connections. 80% of the connections are residential, 15% commercial, and 5% industrial. Complete the following table. (Assume an average month has 30 days)

Connection Type	**Number of Connections**	**Average usage per day per connection (gallons)**	**Average Monthly Usage per Connection Type (CCF)**
Residential		835	
Commercial		1,370	
Industrial		2,200	

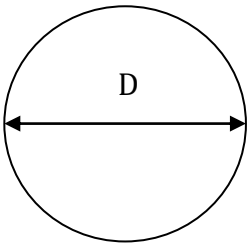
4. Based on the total combined monthly usage and a unit cost of water equaling $1.15/CCF, how much money will the utility generate in one year?

SECTION 2
GEOMETRIC SHAPES
The Shapes of Things

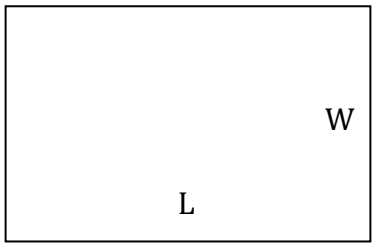
In order to transport water from the source, to treatment, to the distribution system, and eventually to the customer, it needs to flow through geometric shapes. An aqueduct brings water from Northern California to Southern California. Reservoirs and tanks store water before it enters the treatment process. Pipes flow water throughout the treatment plant and through the distribution system. Above ground storage tanks and elevated storage tanks hold water and provide pressure to the distribution system. This is a crude description of the path water takes, but it illustrates the point of different structures and shapes that water must transfer through.

<u>Areas</u>

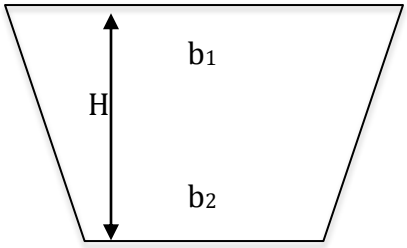
Calculating areas is the first step in working with geometric shapes. Areas are used to determine how much paint to buy, how much water can flow through a pipe, and many other things. A circle, a rectangle, and a trapezoid are probably the most common shapes you will encounter in the water industry. However, a sphere, a triangle, a half circle with a rectangle can also be found. These are the structures we will focus on in this chapter.



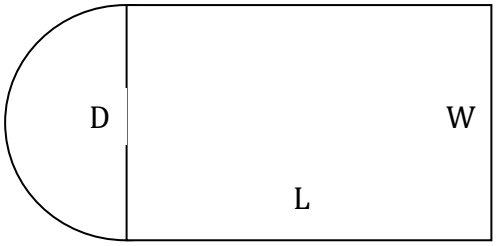
$0.785D^2$



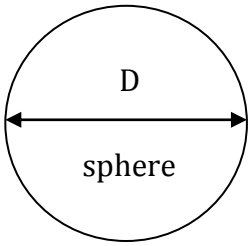
LW



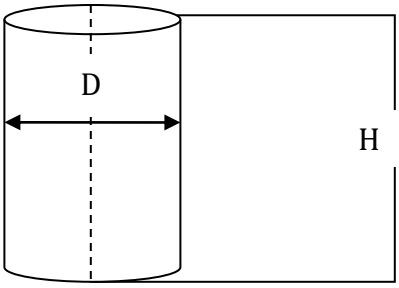
$\left(\frac{b_1 + b_2}{2}\right)H$



$\frac{(0.785D^2)}{2} + LW$



$4(0.785D^2)$



πDH

Circles

To calculate the area of a circle, multiply 0.785 by the diameter squared. This means multiply the diameter times the diameter times 0.785. If you recall from the 030 course, we use 0.785 in the "area" formula.

$A = 3.14 \times r^2$ or $A = 0.785 \times d^2$

0.785 replaces Pi and diameter replaces radius. Diameter squared is four times greater than radius squared and 0.785 is one fourth of Pi.

Take special note of the units for the diameter. Many times (especially when talking about pipes) the diameter will be given on some other unit besides feet (e.g. inches). Converting the diameter to feet as your first step will avoid ending up with squared units other than square feet. Sometimes the diameter of a pipe might be given in metric units. This is common when working with the California Department of Transportation.

Examples

What is the area for each of the following diameters listed below?

Given Diameter	Conversion	Formula	Answer
24 in	24 in / 12 in = 2 ft	$0.785 \times (2\text{ ft})^2$	3.14 ft^2
130 in	130 in / 12 in = 10.8 ft	$0.785 \times (10.8\text{ ft})^2$	91.5 ft^2
813 mm	813 mm / 304.5 mm = 2.67 ft	$0.785 \times (2.67\text{ ft})^2$	5.6 ft^2

Rectangles

Calculating the area of a rectangle or a square simply involves multiplying the length by the width. If you are painting the walls, ceiling or floors of a room the perspective changes slightly. For example, the dimensions of a wall might look like a width and height when you are standing looking at it. A floor might look like a width and a length. Regardless of the perspective, the area formula is the same.

Examples

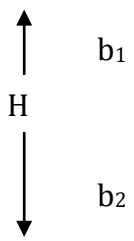
What is the area for each of the following rectangles listed below?

Length = 30 ft, width = 10 ft $\longrightarrow$ $30\text{ ft} \times 10\text{ ft} = 300\text{ ft}^2$
Height = 15 ft, width = 7 ft $\longrightarrow$ $15\text{ ft} \times 7\text{ ft} = 105\text{ ft}^2$

Trapezoids

Trapezoids are most commonly the shape of an aqueduct. Aqueducts are typically miles and miles of trapezoidal shaped concrete channels. They have flat narrow bottoms that slope up to wider distances at the top. In order to calculate the varying distances across a trapezoid, add the distance (width, b_2) across the bottom to the distance (width, b_1) across the top and divide by 2. This gives the average width. Then multiply the average width by the height or depth of the trapezoid to calculate the area.

Examples



Widths = 5 ft and 7 ft, height = 6 ft
(5 ft + 7 ft) / 2 x 6 ft = 36 ft^2

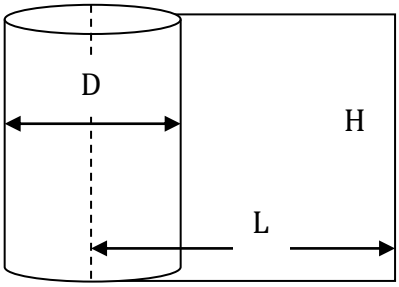
Widths = 8 ft and 12 ft, depth = 10 ft
(8 ft + 12 ft) / 2 x 10 ft = 100 ft^2

Spheres and Other Shapes

As previously stated, circles, rectangles, and trapezoids are the most common shapes in the water industry. However, large standpipes shaped like a cylinder with a sphere on top or an elevated storage tank shaped like a sphere can be very common in the mid-west. Half circles and rectangles can also be found as reservoirs or sedimentation basins. Therefore, understanding how to calculate the area for these types of structures is also important.

The distance around the cylinder is calculated as Pi (3.14) multiplied by the diameter. Pi is a unitless constant. It can also be looked at as the "length" around a cylinder. Once the "length" is calculated multiply this number by the height or depth to get the area.

Examples



D = 100 ft, height = 20 ft
3.14 x 100 ft = 314 ft (which is "L")
314 ft x 20 ft = 6,280 ft^2

When the area is calculated for a sphere, it is the entire surface area of a "ball." Spheres can be common place in the mid-west as elevated storage structures. The formula for the area of a sphere is 4 times 0.785 times the diameter squared.

Examples

D = 50 ft $\quad$ $4 \times 0.785 \times (50\ ft)^2 = 7{,}850\ ft^2$

D = 35 ft $\quad$ $4 \times 0.785 \times (35\ ft)^2 = 3{,}845\ ft^2$

<u>Exercise 2.1</u>

1. What is the area of the opening of a 10" diameter pipe?

2. A rectangular channel flows millions of gallons of water through it and dumps into a storage reservoir. The channel is 2 miles long 3 feet wide and 2 feet deep. What is the area of the channel opening?

3. A channel is 3 feet wide at the bottom and 5 feet wide at the top and the water is 4 feet deep when the channel is full. What is the area of the channel?

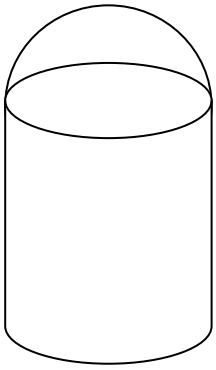
4. An elevated storage tank is shaped like a sphere and needs to be recoated. If the diameter of the tank is 65 feet, what is the surface area?

5. A standpipe needs to be painted. What is the surface area of the entire standpipe? It has a diameter of 30 feet and is 80 feet tall.

6. What is the surface area of a spherical structure that has a 42 foot diameter?

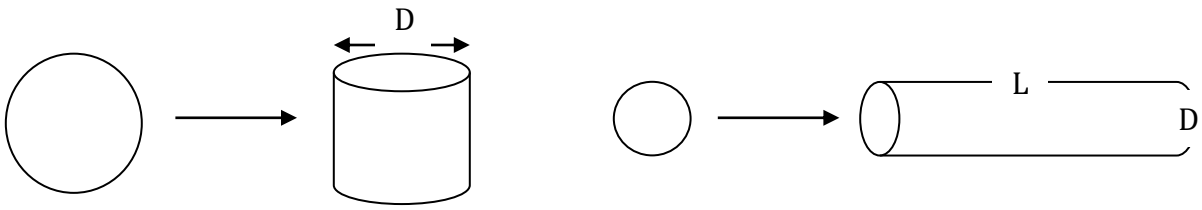
7. A box structure needs to be painted. It is 20 feet wide, 30 feet long and 10 feet tall. What is the total area of all six surfaces (inside only)?

8. What is the inside surface area of a 32" diameter pipe that is 1,000 feet long and is capped with half a sphere at the end? (Assume the sphere diameter is not included in the length)

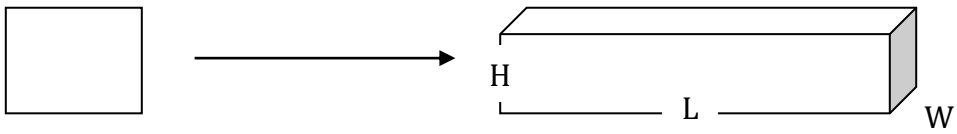


Volumes

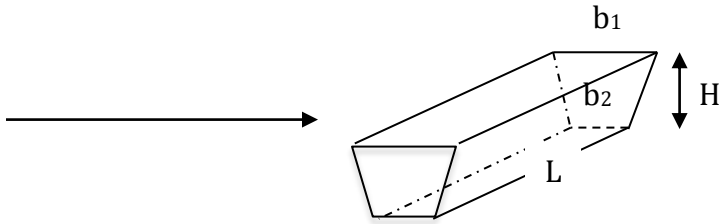
In order to calculate the volume inside a structure, a third dimension needs to be included in the "area" formula. For example, if a circle is given a length or height, it becomes a cylinder and a volume can be calculated. If a trapezoid or a rectangle has a length it becomes a three dimensional structure with a volume that can be calculated. The following formulas and examples demonstrate this concept.



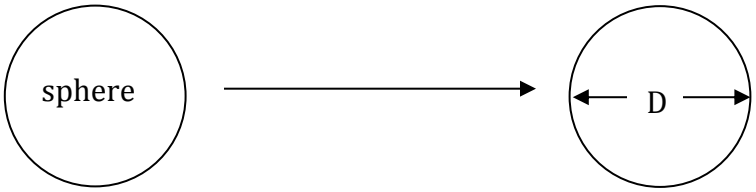
$0.785D^2$ $\quad$ $0.785D^2H$ $\quad$ $0.785D^2$ $\quad$ $0.785D^2L$



LW $\quad$ LWH



$\left(\frac{b_1+b_2}{2}\right)H$ $\quad$ $\left(\frac{b_1+b_2}{2}\right)HL$



$4(0.785D^2)$ $\quad$ $\frac{\pi D^3}{6}$

Exercise 2.2

1. What is the volume of a 30 foot diameter sphere?

2. What is the volume in 2,000 feet of 18 inch diameter pipe?

3. A 5 mile long aqueduct is 5 feet wide at the bottom and 8 feet wide at the water line. If the water depth is 6 ½ feet, how many acre-feet of water are in the aqueduct?

4. A sedimentation basin is 100 feet long, 30 feet wide, and 20 feet deep. How many gallons can it hold?

5. A standpipe is 80 feet tall and has a 25 foot diameter. Assuming the top of the standpipe is a half sphere shape, how many gallons will it hold?

SECTION 2.1 APPLYING THE MATH OF GEOMETRIC SHAPES

As with all mathematical computations there is an element of "Will I ever use this outside of the classroom?". The answer is most likely "sometimes." An operator might calculate the volume of water in a storage structure or pipeline to determine how much chlorine is needed to disinfect the structure. A contractor might calculate the internal surface area of a tank to determine the amount of coating that is required. Or, you might be asked to paint the interior walls of a room. Putting practical use to mathematical equations can help in the student's overall understanding. The following problems are some "real world examples" you might find working as a water utility operator.

Exercise 2.1.1

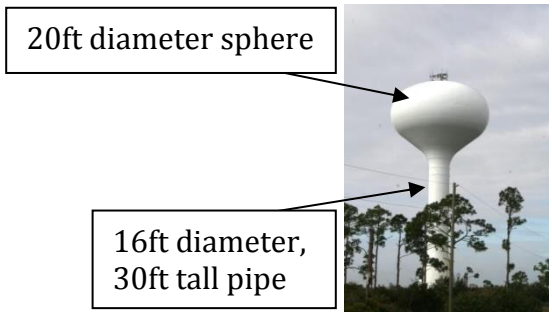
1. A water utility operator needs to determine how many gallons of paint are needed to paint the outside of an above ground storage tank and the cost of the paint. The tank has a 120 foot diameter and is 32 feet tall. (Assume that one gallon of paint can cover 125 ft^2 and costs $25.75 per gallon.)

2. A utility manager needs to find a site for a 3.1 MG storage tank. The tank cannot be taller than 33 feet. What diameter should this tank have?

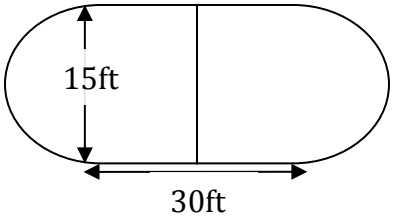
3. A construction crew will be installing 1,250 feet of 10 inch diameter pipe. The width of the trench will be 30 inches and the depth 36 inches. After the pipe has been installed, how many cubic yards of dirt will be needed to backfill the trench? (Assume the trench will be backfilled up to 6 inches from the ground surface.)

4. In the above problem, the construction crew also needs to place 6 inches of aggregate base on top of the fill. How many cubic feet of base is needed?

5. A water quality technician needs to disinfect an elevated storage tank, but first she needs to calculate the volume of water in the tank. The 20 foot diameter storage tank sits on a 16 foot diameter, 30 foot tall pipe. How many gallons are in the structure?



6. A private contractor needs water for a grading project. In a similar sized job he used 155 tank loads from a water tower. The tower is shaped like a "pill." Each end has a 15 foot diameter and the center section is 30 feet long. If the water costs $425 an acre-foot, how much does the contractor need to budget for water?



7. A maintenance crew is replacing a 12" meter at a well. The specifications state that there needs to be 3 times the pipe diameter in feet of straight pipe before the meter and 5 times the pipe diameter in feet of straight pipe after the meter. Currently the well has 10" diameter pipe. How many feet of 12" pipe are needed?

8. A 1.25 mile section of trapezoidal shaped aqueduct needs to be drained. The aqueduct is 5 feet wide at the base and 10 feet wide at the water line. If there is 9 acre feet of water in the aqueduct, what is the depth?

9. A contractor just installed 350 feet of 8" diameter pipe, 430 feet of 12" diameter pipe, and 275 feet of 16" diameter pipe. The pipe needs to be filled, but the inflow flow rate is only 10 gpm. How long will it take to fill all this pipe? (Give answer in the best time format.)

10. A water utility manager is determining what shaped storage tank should be used to store water for a small mobile home park. The mobile home park needs 110,000 gallons of storage. There is room for a 25 foot diameter and 30 foot tall cylinder shaped tank or a 30 foot diameter sphere shaped tank. Which tank will provide the adequate storage?

11. In the problem above, how much shorter expressed as a percentage is the smaller tank?

SECTION 3
DENSITY AND SPECIFIC GRAVITY
It's All About The Weight

Water is essential for the survival of all life forms. It makes up approximately 60% of our total body weight and as much as 75% of the earth's surface. So, how much does water actually weigh? There are a few variables, such as temperature, that determine the weight of water, but for all practical purposes in waterworks mathematics, water weighs 8.34 pounds per gallon. The density (mass per unit volume) of water is 1.00. This is also referred to as specific gravity. When discussing specific gravity, many things are compared to water. For example, if something has a specific gravity less than water (<1), then the substance will float on water. Conversely, if a substance has a specific gravity greater than 1, it will sink in water.

The table below lists common specific gravities/densities and weight of substances used in the waterworks industry. Remember, these are only examples and should not be put to memory. On any State exam, you will be given the specific gravity or corresponding weight of the substance in the question.

Substance	Specific Gravity	Weight
Crude Oil	0.815	6.80 lbs/gal
Water	1.00	8.34 lbs/gal
Chlorine (g)	2.49	20.77 lbs/gal
Calcium hypochlorite	2.35	19.60 lbs/gal
Alum	1.16 – 1.40	9.67 – 11.68 lbs/gal
Ferric chloride	1.43	11.93 lbs/gal

Examples

Since water is the reference, then a specific gravity (SG) of 1 and a weight of 8.34 lbs/gal are the numbers needed to calculate the SG and weight of other substances.

What is the weight of a substance in lbs/gal if it has a SG of 1.25? Remember, anything that has a SG >1 will weigh more than 8.34 lbs/gal.

$$\frac{8.34\ lbs/gal}{1\ SG}\ x\ \frac{1.25\ SG}{1} = \frac{10.43\ lbs/gal}{}$$

What is the SG of a substance that weighs 5.75 lbs/gal? Remember, anything with a weight <8.34 lbs/gal will have a SG <1.

$$\frac{1\ SG}{8.34\ lbs/gal}\ x\ \frac{5.75\ lbs/gal}{1} = \frac{0.69\ SG}{}$$

Exercise 3

Solve the following density related problems.

1. Liquid sodium hypochlorite has a specific gravity of 1.47. What is the corresponding weight in pounds per gallon?

2. Chlorine gas has formed into a liquid state. It weighs 19.75 lbs/gal. What is the specific gravity?

3. What is the weight difference between 75 gallons of water and 42 gallons of sodium hypochlorite with a specific gravity of 1.42?

4. A treatment operator has 50 gallons of 12.5% sodium hypochlorite. How many pounds of the 50 gallons are available chlorine?

5. How much does 45 gallons of 25% Alum weigh if the specific gravity is 1.35?

6. Ferric chloride weighs 14.25 lbs/gal. What is the specific gravity?

7. Chemical A has a specific gravity of 2.31 and chemical B has a specific gravity of 1.95. Chemical A is what percent heavier than chemical B?

8. How many pounds of ferric chloride are in 250 gallons of 22% strength? (Assume the specific gravity is 1.41)

9. What is the weight in lbs/cf of a substance that has a specific gravity of 2.05?

10. A shipment of crude oil has a specific gravity of 0.825. What is the weight in lbs/cf?

SECTION 3.1 PARTS PER HUNDRED VS. PARTS PER MILLION

It is important to understand the relationship between percentage and parts per million (ppm)**.** Most of the time, chemical concentrations are expressed in percentages (parts per hundred, pph.) However, in chemical dosage related problems, concentrations are expressed in ppm. Therefore, it shouldn't be too difficult to convert percentage to ppm and ppm to percentage. It is simply a difference of 10,000.

If you divide 1,000,000 or 1 ppm by 100 or 100% you get the following.

$$1{,}000{,}000 \div 100 = 10{,}000$$

This translates a 1% solution concentration to 10,000 ppm.

$$1\% = 10{,}000 \text{ ppm}$$

In other words, just multiply the percent solution by 10,000 to calculate ppm. See the table below for other examples of percent concentration to ppm equivalents.

Percent Concentration	**ppm**
1%	10,000 ppm
2%	20,000 ppm
3%	30,000 ppm
10%	100,000 ppm

Another concept that needs to be addressed is the difference between ppm, parts per billion (ppb), and parts per trillion (ppt.) As water quality regulations become more stringent and laboratory analysis techniques get better and better, contaminants are being identified at lower and lower levels. Most water quality standards are expressed in ppm or milligrams per liter (mg/L), but many are expressed in ppb or micrograms per liter (ug/L), and a few are expressed in ppt or nanograms per liter (ng/L). A simple exercise can help with understanding the different ways to express the amount of contaminant in water supplies.

1,000,000 – million
1,000,000,000 – billion
1,000,000,000,000 – trillion

1 ppm = 1,000 ppb = 1,000,000 ppt

The expression above says that 1 part of a small number (ppm) equals 1,000 parts of a smaller number (ppb) which equals 1,000,000 parts of an even smaller number (ppt.)

Exercise 3.1

Solve the following problems. Think of the "%" symbol as "pph" (parts per hundred)

1. A 12.5% chlorine solution has a ppm concentration of?

2. What is the percent concentration of a 100 ppm solution?

3. A Water Utility uses a 0.8% sodium hypochlorite solution to disinfect a well. What is the ppm concentration of the solution?

4. A container of liquid chlorine has a concentration of 1,250 ppm. What is the percent concentration of the solution?

5. If a 100 gallon container is ¾ full with a 5.25% solution and is then filled with fresh water, what would the resulting ppm of the water be?

6. Complete the following table with the corresponding unit for the various water quality Maximum Contaminant Levels (MCL).

Constituent	ppm	ppb	ppt
Arsenic		10	
Chromium	0.05		
Nitrate (NO3)	45		
Perchlorate			6,000
Vinyl chloride		0.5	

SECTION 4
CHEMICAL DOSAGE ANALYSIS
It's a Pound Formula!

It's pretty easy to calculate how many pounds of chlorine are needed to provide a certain dosage if we are using 100% gas chlorine. Most operators in the water industry have put to memory the "Pound Formula" by multiplying the flow or volume of water in MG or MGD by 8.34 pounds per gallon and then by the dosage in ppm, the pounds of chlorine needed is calculated.

$$\mathbf{MG\ x\ \frac{8.34\ lbs}{gallon}\ x\ ppm\ =\ lbs}$$

or

$$\mathbf{\frac{MG}{Day}\ x\ \frac{8.34\ lbs}{gallon}\ x\ ppm\ =\ \frac{lbs}{day}}$$

However, in many treatment plants and at treatment sites within distribution systems, the use of gas chlorine is in decline, unless the plant is of considerable size. The reduction in chlorine gas usage is primarily due to safety concerns and other forms of chlorine being more cost competitive. For example, groundwater wells are commonly disinfected with solid (calcium hypochlorite) or liquid (sodium hypochlorite) forms of chlorine. In addition, other chemicals such as Alum, ferric chloride, sodium hydroxide are used in varying concentration strengths at treatment plants in addition to chlorine. Most often these chemicals are not in the pure 100% form.

When solving dosage problems with chemicals of different strength the following two statements are helpful in remembering whether you need to multiply or divide by the percent concentration.

"If you are solving for pounds you divide by the percent concentration."

"If pounds are given you multiply by the percent concentration."

Therefore, if you are calculating for the amount of pounds needed you divide by the decimal equivalent of the percent concentration. You need more of the chemical since it is not 100% and dividing by a number less than one yields a larger number. If the amount of pounds is known, then by multiplying by the decimal equivalent of the percent concentration you will calculate how much of that chemical is available in the total pounds of the substance. Multiplying by a number less than one yields a smaller number. Once you understand the concept behind the problem it makes solving them easier. Think of it this way...it takes much more 10% ferric chloride in the coagulation process than let's say ferric chloride at 75% strength. The same is true if you are using calcium

hypochlorite as opposed to gas chlorine, because gas is a greater strength than calcium hypochlorite. Similarly if you have 100 pounds of 65% calcium hypochlorite, you don't have 100 pounds of chlorine. Only 65% or 65 pounds of the substance is actually chlorine. As opposed to 100 pounds of gas chlorine which is 100 pounds of available chlorine. When using chemicals of different strengths, the pound formula can be looked at like this:

$$\frac{\mathbf{MG\ x\ \frac{8.34\ lbs}{gallon}\ x\ ppm}}{\mathbf{\%\ concentration}} = \mathbf{lbs}$$

$$\frac{\mathbf{\frac{MG}{Day}\ x\ \frac{8.34\ lbs}{gallon}\ x\ ppm}}{\mathbf{\%\ concentration}} = \mathbf{\frac{lbs}{day}}$$

Placing the decimal equivalent of the percent concentration of the chemical being used under the left side of the equation will allow the appropriate amount of chemical needed to be calculated. In addition, if MG or ppm are the unknowns, the percent would be multiplied by the weight of the chemical in pounds. Examples are provided later in this section.

The last chemical dosage concept we need to look at is when the chemical being used is in the form of a liquid. Since the Pound Formula is after all measuring chemicals in "pounds," then the chemical needs to be expressed as pounds. In Section number 3, we learned about specific gravity and how it affects the weight of a substance. You will need to use that information when presented with a pound formula question where the chemical used is a liquid.

Finally, a general understanding about chlorine dosage is needed. The concept is straightforward. The reason drinking water is disinfected is to prevent pathogenic organisms from contaminating the supply causing illness to the population drinking the water. The amount of disinfectant added is not always what is measured later by a water utility operator. Typically the amount of disinfectant measured after the original dosage occurs is lower than the dosage measured which is referred to as the residual. What happens to the disinfectant? The chlorine that "disappears" is the chlorine demand. It is the amount of chlorine that is inactivating the pathogens. Once the demand is satisfied, the remaining chlorine is termed the **residual**. This formula is provided below.

$$\mathbf{dosage = residual + demand}$$

Examples

Ex. 1 How many pounds of chlorine are needed to dose 2 MG of water to a dosage of 3.25 ppm?

MG x 8.34 lbs/gal x ppm = lbs

2 MG x 8.34 lbs/gal 3.25 ppm = 54.21 lbs

In the example above, it is a straightforward chemical dosage problem.

Ex. 2 How many pounds of 10% Alum are needed to dose a treatment flow of 5 MGD to a dosage of 10 ppm?

$$\frac{\frac{5\text{ MG}}{\text{Day}} \text{ x } \frac{8.34\text{ lbs}}{\text{gallon}} \text{ x } 10\text{ ppm}}{0.1} = \frac{\text{lbs}}{\text{day}}$$

$$\frac{417}{0.1} = \frac{4,170\text{ lbs}}{\text{day}}$$

It takes 417 lbs of Alum to dose 5 MGD to 10 ppm. However, in this problem the Alum being used is only a 10% concentration. Therefore, you need to divide by 10% (or 0.1) to calculate the total amount of this form of Alum that is needed.

Ex. 3 How many gallons of 15% strength sodium hypochlorite are needed to dose a well flowing 1,500 gpm to a dosage of 1.75 ppm? (Assume the sodium hypochlorite has a specific gravity of 1.42).

First the flow rate needs to be converted to MGD.

1,500 gpm x 1440 = 2,160,000 GPD or 2.16 MGD

$$\frac{\frac{2.16\text{ MG}}{\text{Day}} \text{ x } \frac{8.34\text{ lbs}}{\text{gallon}} \text{ x } 1.75\text{ ppm}}{0.15} = \frac{210\text{ lbs}}{\text{day}}$$

210 lbs of 15% sodium hypochlorite are needed to dose 1,500 gpm to 1.75 ppm. Now the 210 lbs needs to be converted to gallons.

$$\frac{210\text{ lbs}}{\text{Day}} \text{ x } \frac{\text{gallons}}{8.34\text{ lbs x } 1.42} = \frac{17.75\text{ gal}}{\text{day}}$$

Exercise 4

Solve the following chemical dosage problems. Be sure to account for the differences in chemical percent concentrations.

1. How many gallons of water can be treated with 100 pounds of 65% High Test Hypochlorite (HTH) to a dosage of 2.55 mg/L?

2. An operator added 165 pounds of 25% ferric chloride to a treatment flow of 10.5 MGD. What was the corresponding dosage?

3. How many pounds of 12.5% sodium hypochlorite are needed to dose a well with a flow rate of 1,000 gpm to a dosage of 1.75 ppm? (Assume the well runs 17 hours a day).

4. In the above problem, how many gallons of chemical are needed per hour? (Assume the SG is 1.4).

5. A treatment operator has set a chemical pump to dose 75 gallons of NaOH (sodium hydroxide) per day for a flow rate of 2.25 MGD. What is the corresponding dosage? (Assume the SG is 1.65).

6. 11,250 feet of 18" diameter main line needs to be dosed to 50 ppm. Answer the following questions.

   a. How many gallons of 12.5% (SG = 1.44) sodium hypochlorite are needed?

   b. How many pounds of 65% HTH are needed?

   c. Assuming the following costs, which one is least expensive?

      i. Sodium hypochlorite = $2.45 per gallon

      ii. HTH = $1.65 per pound

7. A water treatment operator adjusted the amount of 20% Alum dosage from 85 mg/L to 70 mg/L. Based on a treatment flow of 10 MGD, what is the cost savings if 100% pure Alum costs $2.50 per pound?

8. A water utility produced 11,275 AF of water last year. The entire amount was dosed at an average rate of 1.5 ppm. If the chemical of choice was 65% HTH at a per pound cost of $1.85, what was the annual budget?

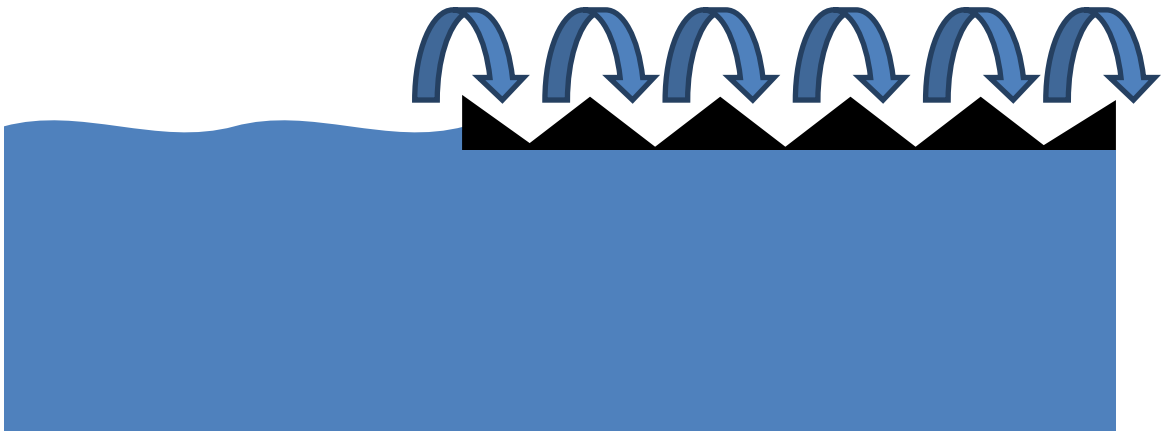
9. Ferric chloride is used as the coagulant of choice at a 5.75 MGD rated capacity treatment plant. If the plant operated at the rated capacity for 75% of the year and operated at 60% of rated capacity for 25% of the year, how many pounds of the coagulant was needed to maintain a dosage of 45 mg/L?

10. A water softening treatment process uses 25% NaOH during 20% of the year and 50% NaOH for 80% of the year. Assuming a constant flow rate of 1,100 gpm and a dosage of 70 mg/L, what is the annual budget if the 25% NaOH (SG = 1.18) costs $0.95 per gallon and the 50% NaOH (SG = 1.53) costs $1.70 per gallon?

11. An operator added 275 gallons of 12.5% (SG=1.32) in to 2,550 ft of 12" diameter pipe. After 24 hours, the residual was measured at 10.25 ppm. What was the demand?

SECTION 5
WEIR OVERFLOW RATE
What's a Weir?

A weir is an overflow structure that is used to alter flow characteristics. In the example below, the water is flowing from left to right. The black triangular shaped structure is the weir. It is impeding the flow of water causing the water to flow over the weir structure. It raises the level of flow to evenly disperse the water. A weir meters flow to a specific rate known as the Weir Overflow Rate (WOR.) WORs are expressed as the flow of water by the length of the weir, typically as MGD per foot (MGD/ft) or gpm per foot (gpm/ft).

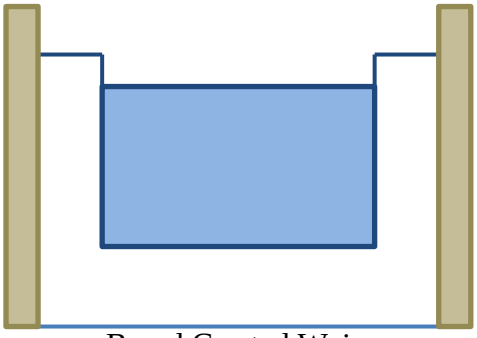


Weir Overflow Rate Formula

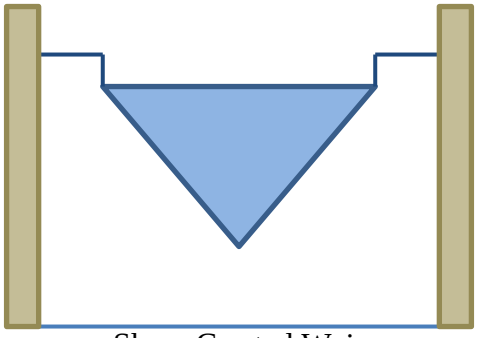
$$\textbf{Weir Overflow Rate}\left(\frac{\textbf{gpm}}{\textbf{ft}}\right) = \frac{\textbf{Flow (gpm)}}{\textbf{Length of Weir (ft)}}$$

Calculating the length of the weir is required in order to calculate the WOR. Sometimes the weir can be a circular structure requiring the circumference to be calculated in order to find the actual length. Other times it is a linear structure, in which case the length would be known.

Weirs can either be sharp-crested or broad-crested. Broad-crested weirs are flat-crested structures and are commonly used in damn spillways. Sharp-crested weirs (most common are "V" notch) allow the water to fall cleanly away from the weir and are typically found in water treatment plants.



Broad Crested Weir



Sharp Crested Weir

Exercise 5

1. What is the weir overflow rate through a 7 MGD treatment plant if the weir is 30 feet long? (Express your answer in MGD/ft and gpm/ft).

2. A drainage channel has a 10 foot weir and a weir overflow rate of 7 gpm/ft. What is the daily flow expressed in MGD?

3. What is the length of a weir if the daily flow is 8.45 MG and the weir overflow rate is 28 gpm/ft?

4. A 60 ft diameter circular clarifier has a weir overflow rate of 15 gpm/ft. What is the daily flow in MGD?

5. A treatment plant processes 15 MGD. The weir overflow rate through a circular clarifier is 29.5 gpm/ft. What is the diameter of the clarifier?

6. An aqueduct that flowed 36,000 acre-feet of water last year has a weir over flow structure to control the flow. If the weir is 250 feet long, what was the average weir overflow rate in gpm/ft?

7. A 75 mile aqueduct is being reconstructed to widen the width across the top. The width across the bottom is 10 feet and the average water depth is 15 feet. The aqueduct must maintain a constant weir overflow rate of 25 gpm per foot with a daily flow of 0.63 MGD. What is the length of the weir?

8. An engineering report determined that a minimum weir overflow rate of 15 gpm per foot and a maximum weir overflow rate of 20 gpm per foot were needed to meet the water quality objectives of a certain treatment plant. The existing weir is 80 feet long. What is the daily treatment flow range of the plant?

9. A circular clarifier processes 12.5 MGD with a detention time of 2.35 hours. If the clarifier is 50 feet deep, what is the diameter?

10. A water treatment plant is in the process of redesigning their sedimentation basin. The plant treats 4.5 MGD with an average detention time of 1.85 hours. Portable storage tanks will be used when the basin is under construction. The portable storage tanks are 25 ft tall and 20 ft in diameter. How many tanks will be needed?

SECTION 6
WATER TREATMENT MATH DETENTION TIME
It's a Lag in Time

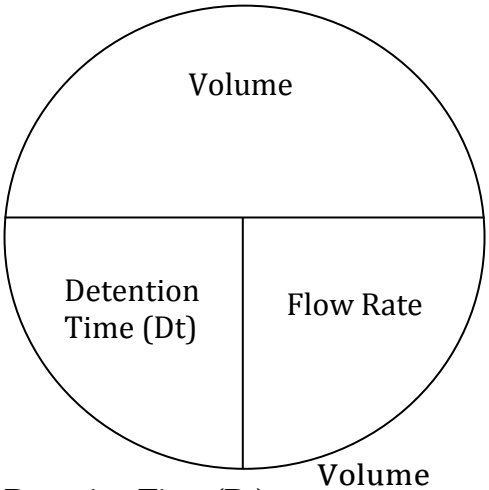
Detention Time is an important process that allows large particles to "settle out" from the flow of water through gravity, prior to filtration. It is the time it takes a particle to travel from one end of a sedimentation basin to the other end. Conventional filtration plants require large areas of land in order to construct sedimentation basins and employ the detention time process. Not all treatment plants have the available land and may decide that direct filtration is suitable. Therefore, in direct filtration plants the sedimentation process is eliminated. However, in direct filtration plants, the filters have shorter run times and require more frequent backwashing cycles to clean the filters.

A term used that is interchangeable with detention time is contact time. Contact times represent how long a chemical (typically chlorine) is in contact with the water supply prior to delivery to customers. For example, contact time can be measured from the time a well is chlorinated until it reaches the first customer within a community. Or, it could be how long the water mixes in a storage tank before it reaches a customer.

Calculating the Detention Time and Contact Time requires two elements, the volume of the structure holding the water (sedimentation basin, pipeline, and storage tank) and the flow rate of the water (gallons per minute, million gallons per day, etc.) Since detention times and contact times are typically expressed in hours, it is important that the correct units are used. When solving Dt problems be sure to convert to the requested unit of time.

As with all water math related problems, there are other parameters that can be calculated within the problem. For example, if the detention time and volume are known, then the flow rate can be calculated. Or, if the flow rate and detention time are known, the volume can be calculated. Sometimes the flow rate and the desired detention time is known and the size of the vessel holding the water needs to be designed. In this example, the area or dimensions of the structure can be calculated.

The chart to the right shows a simple way of calculating the variables. If the variables are next to each other (Dt and Flow Rate) then multiply. If they are over each other (Volume and Dt or Volume and Flow Rate) then divide.



The Detention Time formula is → Detention Time (Dt) $= \frac{\text{Volume}}{\text{Flow}}$

When solving this equation make sure the units are correct.

Making sure the units are correct is important before solving this equation. Take a look at the examples below.

$$Dt = \frac{\text{Volume}}{\text{Flow}} \longrightarrow \frac{\text{gallons}}{\text{gallons/minute}} \quad \frac{\text{cubic feet}}{\text{cubic feet/second}} \quad \frac{\text{gallons}}{\text{million gallons/day}}$$

In the first two examples above the terms can be divided. However, in the third example they cannot. Dt should be expressed as a unit of time (i.e., sec, min, hours). If you divide the first two examples (gal/gpm and cf/cfs), you will end up with **minutes** and **seconds** respectively. However, in the third example, **gallons** and **million gallons** cannot cancel each other out. Therefore if you had 100,000 gallons as the volume and 1 MGD as the flow rate;

$$\frac{100{,}000 \text{ gallons}}{1 \text{ MGD}}$$

Then you would need to convert 1 MGD to 1,000,000 gallons per day in order to cancel the unit gallons. The gallons then cancel leaving "day" as the remaining unit.

$$\frac{100{,}000 \text{ gallons}}{\frac{1{,}000{,}000 \text{ gallons}}{1 \text{ day}}} = 0.1 \text{ day}$$

Converting to hours from days is easy, simply multiply by 24 hours per day.

$$\frac{0.1 \text{ day}}{} = \frac{24 \text{ hours}}{1 \text{ day}} = 2.4 \text{ hours}$$

Sometimes this can be the simplest way to solve detention time problems. However, people can be confused when they get an answer such as 0.1 days. There are other ways to solve these problems. One way is to convert MGD to gpm. Using the above example, convert 1 MGD to gpm.

$$\frac{1{,}000{,}000 \text{ gallons}}{1 \text{ day}} \text{ x } \frac{1 \text{ day}}{1{,}440 \text{ minutes}} = 694.4 \text{ gpm}$$

Now solve for the Detention Time.

$$\frac{100{,}000 \text{ gallons}}{\frac{694.4 \text{ gallons}}{\text{min}}} = 144 \text{ minutes x } \frac{1 \text{ hour}}{60 \text{ minutes}} = 2.4 \text{ hours}$$

If the question is asking for hours there still needs to be a conversion. However, 144 minutes is more understandable than 0.1 days.

Exercise 6

Solve the following problems. Be sure you provide the answer in the correct units.

1. What is the detention time in hours of a 100 ft by 20 ft by 10 ft sedimentation basin with a flow of 5 MGD?

2. What is the detention time in a circular clarifier with a depth of 30 ft and a 70 ft diameter if the daily flow is 4.5 MG. (Express your answer in hours:minutes.)

3. A water utility engineer is designing a sedimentation basin to treat 10 MGD and maintain a minimum detention time of 2 hours 15 minutes. The basin cannot be longer than 80 feet and wider than 40 feet. Under this scenario, how deep must the basin be?

4. Chlorine is injected into an 18" diameter pipe at a well site. The pipeline is 2,000 ft long before it reaches the first customer. Assuming a well flow rate of 1,700 gpm, what is the detention time (contact time) in minutes?

5. A water utility is designing a transmission pipeline collection system in order to achieve a chlorine contact time of 40 minutes once a 2,250 gpm well is chlorinated. How many feet of 24" diameter pipe are needed?

6. A fluoride tracer study is being conducted at a 15.5 MGD capacity water treatment plant. The contact time through the coagulation and flocculation process is 2.45 hours. If the sedimentation basin has a capacity of 500,000 gallons, what is the total detention time through the 3 processes?

7. The chlorine residual decay rate is 0.2 mg/L per ½ hour in a 5 MG water storage tank. If the storage tank needs to maintain a minimum chlorine residual of 10.0 mg/L what is the required dosage if the tank is filling at a rate of 1,500 gpm until the tank is full?

8. A drinking water well serves a community of 2,000 people. The customer closest to the well is 1,250 feet away. The above ground portion of the well piping is 12" diameter and 25 feet long. The below ground portion is 750 feet of 10" diameter and 475 feet of 8" diameter piping. What is the chlorine contact time in minutes from the well head to the first customer? Assume a constant flow rate of 3.90 cfs.

9. An aqueduct has a weir that is 5 feet narrower than the distance across the aqueduct. Assuming a constant weir overflow rate of 28.75 gpm/ft, an average depth of 12 feet, a distance across the bottom of 8 feet, a length of 22 miles, and a daily flow of 0.85 MG, what is the capacity of the aqueduct in AF?

10. A 32 foot tall water storage tank is disinfected with chloramines through an onsite disinfection system. The average constant effluent from the tank is 550 gpm through a 16 inch diameter pipe. If the first customer that receives water from the tank is 3,220 feet from the tank, would the required 45 minute contact time be achieved?

11. A 90 foot diameter, 20 foot deep clarifier maintains a constant weir overflow rate of 15.25 gpm/ft. What is the detention time in hours:min?

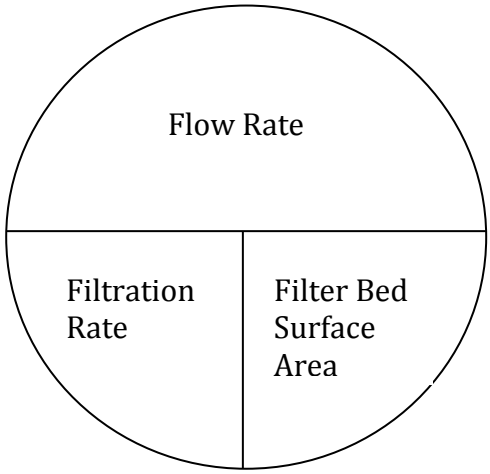
SECTION 6.1 FILTRATION RATES

One of the most important processes in a Water Treatment Plant is FILTRATION. It is the last barrier between the treatment process and the customer. Filters trap or remove particles from the water further reducing the cloudiness or turbidity. There are different shapes, sizes, and types of filters containing one bed or a combination of beds of sand, anthracite coal, or some other form of granular material.

Slow sand filters are the oldest type of municipal water filtration and have filtration rates varying from 0.015 to 0.15 gallons per minute per square foot of filter bed area, depending on the gradation of filter medium and raw water quality. Rapid sand filters on the other hand can have filtration rates ranging from 2.0 to 10 gallons per minute per square foot of filter bed area. Typically rapid sand filters will require more frequent backwash cycles to remove the trapped debris from the filters.

Backwashing is the reversal of flow through the filters at a higher rate to remove clogged particles from the filters. Backwash run times can be anywhere from 5 – 20 minutes with rates ranging from 8 to 25 gallons per minute per square foot of filter bed area, depending on the quality of the pre-filtered water.

Filtration and backwash rates are calculated by dividing the flow rate through the filter by the surface area of the filter bed. Typically these rates are measured in gallons per minute per square foot of filter bed area.



$$\frac{\text{Flow Rate (gpm)}}{\text{Surface Area (sqft)}} = \text{Filtration Rate}$$

Although filtration rates are commonly expressed as gpm/ft^2 they are also expressed as the distance of fall (in inches) within the filter per unit of time (in minutes). During backwashing it is expressed with the same units only per "rise" in the filter. See the example below.

$$\text{Filtration Rate} = \frac{\text{Fall (inches)}}{\text{Time (min)}}$$

$$\text{Backwash Rate} = \frac{\text{Rise (inches)}}{\text{Time (min)}}$$

Examples

Express 2.5 gpm/ft^2 as in/min.

First, convert gpm to cfm. The purpose of this is to begin matching the unit of "inches" in in/min to the "cubic feet in cfm.

$$\frac{2.5\ \text{gal/min}}{\text{sqft}} \text{ x } \frac{1\ \text{cf}}{7.48\ \text{gal}} = \frac{0.33\ \text{cfm}}{\text{sqft}} \qquad \frac{2.5\ \text{gpm}}{\text{sqft}} \text{ x } \frac{1\ \text{cf}}{7.48\ \text{gal}} = \frac{0.33\ \text{cfm}}{\text{sqft}}$$

If you look at the above answer of $\frac{0.33\ \text{cf/m}}{\text{sqft}}$ more closely you can see that it can also be expressed as $\frac{0.33\ \text{ft}}{\text{min}}$ since the sqft and cf cancel each other to FEET.

Once you have "feet per min" you can easily convert to "inches per min" by multiplying by 12.

$$\frac{0.33\ \text{ft}}{\text{min}} \text{ x } \frac{12\ \text{in}}{1\ \text{ft}} = \frac{4\ \text{in}}{\text{min}}$$

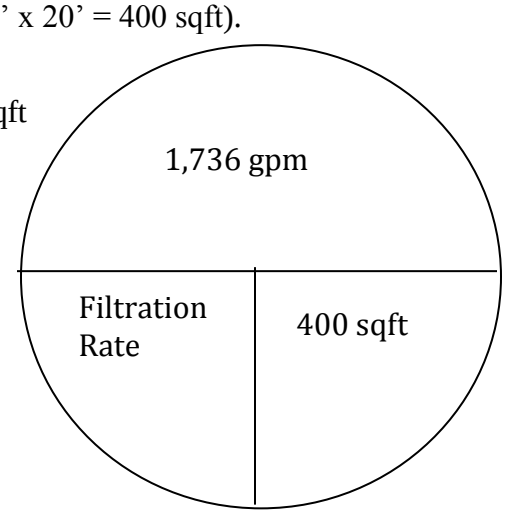
Let's try another example: What is the filtration rate through a 20' by 20' filter if the average flow through the treatment is 2.5 MG?

First, convert 2.5 MGD to gpm. To do this divide 2.5 MGD by 1,440.

$$\frac{2{,}500{,}000\ \text{gal}}{\text{day}} \text{ x } \frac{1\ \text{day}}{1{,}440\ \text{min}} = 1{,}736\ \text{gpm}$$

Then divide the flow by the area of the filter (20' x 20' = 400 sqft).

$$\frac{1{,}736\text{gpm}}{400\text{sqft}} = 4.34\text{gpm/sqft}$$



Now, calculate the inches per minute.

Instead of 7.48 gallons per cubic foot and 12 inches per foot, there is a conversion factor that can also be used.

1.6 in/min = 1 gpm/sqft

Exercise 6.1

1. A water treatment plant processes 10.5 MGD. What is the required filter bed area needed to maintain a filtration rate of 1.75 gpm/ft^2?

2. A 15 ft by 17 ft filter needs to be back washed at a rate of 17 gpm/ft^2 for a minimum of 20 minutes. How many gallons are used during the backwashing process?

3. In order to properly back wash a certain filter a back wash rate of 20 inches per minute rise is needed. If the filter is 20 ft by 25 ft, what is the backwash flow rate in gpm?

4. A water treatment plant processes a maximum of 18.65 MGD. The plant has 6 filters measuring 20 ft by 22 ft each. Assuming that each filter receives an equal amount of flow what is the filtration rate in gpm/ft^2?

5. A water treatment plant processes 4.55 MGD through a 35 ft by 35 ft filter. What is the corresponding inches per minute through the filter?

6. A filter is backwashed at a rate of 15.5 inches per minute for 25 minutes. If the filter is 150 ft^2, how many gallons were used?

7. An Engineer is designing a circular filter to handle 5.75 MGD and maintain a filtration rate of 1.75 inches per minute. What will the diameter be?

8. A filter needs to be backwashed when the fall rate exceeds 3.1 inches per minute. It was determined that this rate is reached after 2.3 MG through a 17 ft by 17 ft filter. How often does the filter need backwashing? Give your answer in the most logical time unit.

SECTION 7
CT CALCULATIONS
How Much For How Long?

CT stands for Concentration and Time. As soon as a disinfectant is added to water it begins the disinfection process. What is the concentration of the disinfectant and how long is it in contact with the water? It takes "time" to complete the disinfection process. In addition, there are other variables that can delay the disinfection process such as, pH, water temperature, turbidity, and the amount of pathogens in the water among other things. Therefore, knowing the CT (concentration of the disinfectant and the time the disinfectant has to do its "work") is very important in ensuring that the water is properly disinfected and safe for human consumption.

As part of the Safe Drinking Water Act, there are a set of regulations known as the Surface Water Treatment Rule (SWTR.) The first version of the SWTR enacted in 1989 required inactivation percentages for *Giardia* of 99.9% and for viruses of 99.99%, among other things. In 1998, the Interim Enhanced Surface Water Treatment Rule (IESWTR) was introduced adding the 99% inactivation of *Cryptosporidium* to the list. In 2002, the Long Term 1 Enhanced Surface Water Treatment Rule was announced with the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) following soon after in 2003. This text focuses on the basic elements of CT calculations and the inactivation of *Giardia* and viruses.

In order to be in compliance with the SWTR, drinking water treatment plants must meet the following inactivation requirements:

Giardia lamblia – 3.0 Log or 99.9% Inactivation

Viruses – 4.0 Log or 99.99% Inactivation

Cryptosporidium parvum – 2.0 Log or 99% Inactivation

The table below compares the Log and Percent Inactivation values.

Table 7.1. Log Percent and Inactivation values.

Log Inactivation	Expressed as Log	Log Value	Percent Inactivation
0.5	$10^{0.5}$	3.162	68.38
1.0	$10^{1.0}$	10	90.00
2.0	$10^{2.0}$	100	99.00
3.0	$10^{3.0}$	1,000	99.90
4.0	$10^{4.0}$	10,000	99.99
5.0	$10^{5.0}$	100,000	99.999
6.0	$10^{6.0}$	1,000,000	99.9999
7.0	$10^{7.0}$	10,000,000	99.99999

Updated versions of the act were published in 2002 and 2003 as the LT1ESWTR and LT2ESWTR respectively. A simple calculation can be used to determine the percent inactivation or the log inactivation if one or the other is known. The following formula can be used to calculate the percent inactivation if the log inactivation is known.

Converting from Log to Percentage
Example

0.5 Log

$$\left(1-\frac{1}{10^{\text{log inactivation}}}\right) \text{ x } 100$$

$$\left(1-\frac{1}{10^{0.5}}\right) \text{ x } 100$$

$$\left(1-\frac{1}{3.16}\right) \text{ x } 100 = 68\%$$

3.0 Log

$$\left(1-\frac{1}{10^{\text{log inactivation}}}\right) \text{ x } 100$$

$$\left(1-\frac{1}{10^{3}}\right) \text{ x } 100$$

$$\left(1-\frac{1}{1000}\right) \text{ x } 100 = 99.9\%$$

The following formula can be used to calculate the log inactivation if the percent inactivation is known.

Converting from Percentage to Log
Example

68.38%

$$\frac{100}{100-\text{Percent Inactivation}} = \text{ Log Inactivation}$$

$$\frac{100}{100-68.38} = 3.162$$

$$3.162 = 10^{0.5} = 0.5 \text{ Log}$$

Use the Log or exponent function on your calculator to solve $10^{0.5}$ to get 3.162.

99.9%

$$\frac{100}{100 - \text{Percent Inactivation}} = \text{Log Inactivation}$$

$$\frac{100}{100 - 99.9} = 1{,}000$$

$$1{,}000 = 10^3 = 3 \text{ Log}$$

Although the above formulas can be used, we typically only deal with *Giardia* (3 Log or 99.9%), viruses (4 Log or 99.99%), and *Cryptosporidium* (varies) so you only need to remember a few values. *Cryptosporidium* will not be discussed in this class due to the complexities of the LT2ESWTR regulations.

Surface water must go through some type of treatment. Disinfection can be used as the sole means of meeting the CT requirements. However, various treatment processes account for some of the inactivation or removal of pathogens. Therefore, the SWTR provides "credits" toward the inactivation of *Giardia* and viruses. For example, the CT requirement for viruses is 4 Log. If a treatment process received 1 Log credit, then the disinfection requirement for viruses would be 3 Log (4 – 1 = 3.) The table below shows the various credits and resulting disinfection requirements.

Table 7.2. Treatment Credits and Log Inactivation Requirements

Treatment	Log Inactivation Requirements		Removal Credit Logs		Required Log Inactivation from Disinfection	
	Giardia	Viruses	*Giardia*	Viruses	*Giardia*	Viruses
Conventional	3	4	2.5	2	0.5	2
Direct Filtration, DE, or Slow Sand	3	4	2	1	1	3

As previously mentioned CT stands for Concentration and Time. Concentrations are expressed in mg/L and Time in min, therefore CT is expressed as (mg/L · min). When solving CT problems, the concentration of the disinfectant is typically provided in the question. However, there may be times when the chemical dosage formula is needed. In order to calculate the time (contact time to be exact), the detention time or "plug flow" formula will be needed.

Time is defined as the time the disinfectant is in contact with the water to the point where the Concentration is measured. These times are easily calculated through pipelines and reservoirs, but sometimes they can be difficult to calculate through various treatment processes. In this case, Tracer Studies are sometimes conducted. T_{10} represents the time for 10% of an applied tracer mass to be detected through a treatment process or, the time that 90% of the water and pathogens are exposed to the disinfectant within a given treatment process. Some problems will require the calculation of the contact time while others will provide T_{10} values.

Once the actual CT values have been calculated, the final step in the CT calculation process involves CT Tables. The U.S. Environmental Protection Agency (USEPA) as part of the SWTR, created a series of tables that list the type of disinfectant, the pH of the water, the concentration of the disinfectant, the contact time, and the pathogen in question. Using all this information, the required CT (mg/L · min) values can be found. For your reference, the CT Tables are provided at the end of this text. They can be confusing at first, but once you understand what information you need to look for, the CT values can be easily found.

In the paragraph above, two terms were used; "actual CT" and "required CT." Actual CT is the actual concentration through the treatment process and the actual time the disinfectant is in contact with the water. For example, if the contact time is 10 minutes and the concentration is 0.2 mg/L then the actual CT is 0.2 mg/L times 10 minutes which equals 2 mg/L · min. The CT Tables give you the required CT, the required concentration time needed to inactivate either *Giardia* or viruses. The ratio of the actual CT and the required CT is then calculated. If the actual CT is <u>equal to or greater than</u> the required CT then the ratio is equal to or greater than 1.0 and CT is met. If the actual CT is <u>less than</u> the required CT then the ratio would be less than 1.0 and CT would not be met. The following examples show how to calculate CT problems from start to finish.

Example

A typical question will provide the pH, the temperature, the pathogen of interest, the type of disinfectant, the dosage or a way to calculate the dosage, and the type of treatment. An example of this data is provided below.

pH – 7.5
Temperature – 10°C
Disinfectant – Free chlorine
Dosage – 0.2 mg/L
Pathogen – *Giardia*
Treatment – Direct Filtration

Use this information to find the appropriate CT Table to use. You should discover that Table C-3 is the correct table to use for this data set. For a quick reference this table is presented on the next page.

Table C-3. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 10°C

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivation						pH=6.5 Log Inactivation						pH=7.0 Log Inactivation						pH=7.5 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	12	24	37	49	61	73	15	29	44	59	73	88	17	35	52	69	87	104	21	42	63	83	104	125
0.6	13	25	38	50	63	75	15	30	45	60	75	90	18	36	54	71	89	107	21	43	64	85	107	128
0.8	13	26	39	52	65	78	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131
1	13	26	40	53	66	79	16	31	47	63	78	94	19	37	56	75	93	112	22	45	67	89	112	134
1.2	13	27	40	53	67	80	16	32	48	63	79	95	19	38	57	76	95	114	23	46	69	91	114	137
1.4	14	27	41	55	68	82	16	33	49	65	82	98	19	39	58	77	97	116	23	47	70	93	117	140
1.6	14	28	42	55	69	83	17	33	50	66	83	99	20	40	60	79	99	119	24	48	72	96	120	144
1.8	14	29	43	57	72	86	17	34	51	67	84	101	20	41	61	81	102	122	25	49	74	98	123	147
2	15	29	44	58	73	87	17	35	52	69	87	104	21	41	62	83	103	124	25	50	75	100	125	150
2.2	15	30	45	59	74	89	18	35	53	70	88	105	21	42	64	85	106	127	26	51	77	102	128	153
2.4	15	30	45	60	75	90	18	36	54	71	89	107	22	43	65	86	108	129	26	52	79	105	131	157
2.6	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131	27	53	80	107	133	160
2.8	16	31	47	62	78	93	19	37	56	74	93	111	22	45	67	89	112	134	27	54	82	109	136	163
3	16	32	48	63	79	95	19	38	57	75	94	113	23	46	69	91	114	137	28	55	83	111	138	166

CHLORINE CONCENTRATION (mg/L)	pH=8.0 Log Inactivation						pH=8.5 Log Inactivation						pH=9.0 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	25	50	75	99	124	149	30	59	89	118	148	177	35	70	105	139	174	209
0.6	26	51	77	102	128	153	31	61	92	122	153	183	36	73	109	145	182	218
0.8	26	53	79	105	132	158	32	63	95	126	158	189	38	75	113	151	188	226
1	27	54	81	108	135	162	33	65	98	130	163	195	39	78	117	156	195	234
1.2	28	55	83	111	138	166	33	67	100	133	167	200	40	80	120	160	200	240
1.4	28	57	85	113	142	170	34	69	103	137	172	206	41	82	124	165	206	247
1.6	29	58	87	116	145	174	35	70	106	141	176	211	42	84	127	169	211	253
1.8	30	60	90	119	149	179	36	72	108	143	179	215	43	86	130	173	216	259
2	30	61	91	121	152	182	37	74	111	147	184	221	44	88	133	177	221	265
2.2	31	62	93	124	155	186	38	75	113	150	188	225	45	90	136	181	226	271
2.4	32	63	95	127	158	190	38	77	115	153	192	230	46	92	138	184	230	276
2.6	32	65	97	129	162	194	39	78	117	156	195	234	47	94	141	187	234	281
2.8	33	66	99	131	164	197	40	80	120	159	199	239	48	96	144	191	239	287
3	34	67	101	134	168	201	41	81	122	162	203	243	49	97	146	195	243	292

Source: AWWA, 1991.

Finding Required CT

The title of the table tells you which CT value the table will provide. This table is for *Giardia*, with free chlorine as the disinfectant, at a temperature of 10°C. Now you need the other information (pH and dosage concentration.) There are seven (7) boxes in the table each with different pH values. Look for the one that says pH = 7.5. On the far left of the table, you can find the varying disinfectant concentrations, starting with less than or equal to 0.4 mg/L going up to 3 mg/L. Since the problem states a dosage of 0.2 mg/L, you'll need to use the first row of the table. You now need the last bit of information, the treatment process. In this instance it is Direct Filtration. Remember, *Giardia* has an inactivation requirement of 3 Log. If there was no treatment process you would be looking at the last column under pH of 7.5. However, referring back to Table 7.1 you can identify the Log credit and resulting disinfection inactivation requirements. You should come up with a required inactivation from disinfection of 1 Log. Using the first row for disinfectant concentration and the second column from the 7.5 pH portion of the table, you should come up with a required CT of 42 mg/L · min.

Calculating Actual CT

There can be multiple locations where a disinfectant is added to the water during the treatment process. Sometimes the water is pre-chlorinated in the raw water pipeline leaving a storage reservoir prior to entering the treatment facility. Sometimes the water is disinfected before the coagulation flocculation process and many times the water is disinfected after filtration prior to delivery to customers. Every time chlorine is added to the water supply it counts towards the inactivation of pathogens. Each step of the way CT will need to be calculated. The example information below will help illustrate this concept.

Free chlorine is added at a concentration of 0.2 mg/L in a 12" diameter 5,000 foot long pipeline leaving a storage reservoir prior to entering the treatment plant. The flow through the pipeline is 2 MGD.

Using this information, the time 0.2 mg/L of free chlorine is in contact with the water can be determined using the Detention Time formula.

$$Dt = \frac{\text{Volume}}{\text{Flow}}$$

Volume = 0.785 x D^2 x L

Volume = 0.785 x 1' x 1' x 5,000' x 7.48 gal/ft^3 = 29,359 gallons

Flow = 2 MGD = 1,389 gpm

$$Dt = \frac{29{,}359 \text{ gal}}{1{,}389 \text{ gpm}} = 21 \text{ minutes}$$

Multiply the detention time by the concentration and you get CT.

0.2 mg/L x 21 minutes = 4.2 mg/L · min

So, the actual CT through the pipeline is 4.2 mg/L · min.

Tracer studies (T_{10}) have determined that a free chlorine concentration of 1.2 mg/L through the treatment plant is 20 minutes.

With this information you can calculate the CT through the plant.

1.2 mg/L x 20 minutes = 24 mg/L · min

Since both sections are disinfected with the same chemical, the two CT values can be added together.

4.2 mg/L · min + 24 mg/L · min = 28.2 mg/L · min

The following table is used to organize the data.

Location and Type of Disinfection	**Actual CT**	**Required CT**	**CT Ratio**
Pipeline + Plant (free chlorine)	28.2 mg/L · min	42 mg/L · min	0.67

Since the ratio of actual to required CT is less than 1.0, then CT is not met. If a treatment plant does not meet CT it can either increase the detention time through the pipeline or plant or it can increase the dosage.

In a situation where two different disinfection chemicals are used, the required CT values would be different and you would not add the different disinfecting locations together. The next example illustrates this scenario.

Example

A conventional water treatment plant receives water with a 0.4 mg/L free chlorine residual from 9,000 feet of 3 foot diameter pipe at a constant flow rate of 10 MGD. The water has a pH of 7.5 and a temperature of 10°C. Tracer studies have shown a contact time (T_{10}) for the treatment plant to be 30 minutes. The plant maintains a chloraminated residual of 1.2 mg/L. Does the plant meet CT compliance for *Giardia*?

The first step should be setting up the table and identifying the CT Tables to use to find the required CT values. This particular problem uses CT Tables C-3 and C-10 (your instructor should hand these out in class). Remember to subtract out the 2.5 Log credit for conventional treatment.

Location and Type of Disinfection	**Actual CT**	**Required CT**	**CT Ratio**
Pipeline (free chlorine)		21 mg/L · min	
Plant (chloramines)		310 mg/L · min	

Now, the actual CT needs to be calculated.

Volume of the 9,000 feet of 3 foot diameter pipe.

Volume = 0.785 x 3ft x 3ft x 9,000ft x 7.48 gal/ft^3 = 475,616 gallons

Flow rate = 10 MGD = 6,944 gpm

$$Dt = \frac{475{,}616 \text{ gal}}{6{,}944 \text{ gpm}} = 68.5 \text{ minutes}$$

0.4 mg/L x 68.5 minutes = 27.4 mg/L · min (this is the CT through the pipeline)

CT for the plant is

1.2 mg/L x 30 minutes = 36 mg/L · min (this is the CT through the plant)

Now finish populating the table

Location and Type of Disinfection	**Actual CT**	**Required CT**	**CT Ratio**
Pipeline (free chlorine)	27.4 mg/L · min	21 mg/L · min	1.3
Plant (chloramines)	36 mg/L · min	310 mg/L · min	0.12

The sum of the CT ratios equals 1.42 mg/L · min. Therefore, CT is met. You may have noticed that CT was achieved through the pipeline only and the chloramination through the plant is not needed. This is true. So, when solving one of these problems, once you meet the ratio of 1.0 or greater, CT is met and you can stop solving the problem.

Exercise 7

1. What is the required CT inactivation in a conventional filtration plant for Giardia by free chlorine at 20°C with a pH of 9.0 and a chlorine concentration of 1.0 mg/L?

2. What is the required CT inactivation for viruses with chlorine dioxide, a pH of 8.5, and a temperature of 7°C?

3. What is the required CT inactivation in a direct filtration plant for Giardia by free chlorine at 5°C with a pH of 8.0 and a chlorine concentration of 1.6 mg/L?

4. A conventional water treatment plant is fed from a reservoir 3 miles away through a 5 foot diameter pipe. Disinfection is provided from the supply reservoir to the plant influent at a free chlorine residual of 0.3 mg/L. The daily flow is a constant 50 MGD. And the water is 10°C and has a pH of 8.0. The treatment plant maintains a chloramines residual of 1.0 mg/L. Tracer studies have shown the contact time (T_{10}) for the treatment plant at the rated capacity of 50 MGD to be 30 minutes. Does this plant meet compliance for CT inactivation for *Giardia*?

5. A conventional water treatment plant is fed from a reservoir 2 miles away through a 6 foot diameter pipe. Disinfection is provided from the supply reservoir to the plant influent at a free chlorine residual of 0.2 mg/L. The daily flow is a constant 55 MGD. And the water is 10°C and has a pH of 7.5. The treatment plant maintains a chloramines residual of 1.0 mg/L. Tracer studies have shown the contact time (T_{10}) for the treatment plant at the rated capacity of 55 MGD to be 40 minutes. Does this plant meet compliance for CT inactivation for viruses?

6. A direct filtration water treatment plant is fed from a reservoir 2.5 miles away through a 4 foot diameter pipe. Disinfection is provided from the supply reservoir to the plant influent at a free chlorine residual of 0.4 mg/L. The daily flow is a constant 30 MGD. And the water is 15°C and has a pH of 8.5. The treatment plant maintains a chloramines residual of 0.75 mg/L. Tracer studies have shown the contact time (T_{10}) for the treatment plant at the rated capacity of 30 MGD to be 20 minutes. Does this plant meet compliance for CT inactivation for *Giardia*?

7. A direct filtration plant is operated at a designed flow of 10 MGD with a contact time of 15 minutes. A free chlorine dose of 0.5 mg/L is maintained through the plant. Upon leaving the plant the effluent is chloraminated (and maintained to the distribution system) to a dose of 1.0 mg/L through a pipeline with a contact time of 10 minutes into a 500,000 gallon reservoir. The pH of the water is 8.0 and has a temperature of 20°C. Does this treatment process meet compliance for CT inactivation for viruses?

8. Does a water utility meet CT for viruses by disinfection if only the free chlorine concentration through 150 ft of 48" diameter pipe at a flow rate of 1,200 gpm is 2.60 ppm? Assume the water is 15°C and has a pH of 7.0.

SECTION 8
PRESSURE, HEAD LOSS, AND FLOW
Are You At a Loss?

Pressure

Pressure is the amount of force that is "pushing" on a specific unit area. Well, what does this mean? When you turn on your water faucet or shower you feel the water flowing out, but why is it flowing out? Water flows through pipes and out of faucets because it is under pressure. It could be that a pump is turned on in which case the pump and motor are providing the pressure. More commonly, the pressure is being provided by water being stored at a higher elevation. Pressures are usually expressed as pounds per square inch (psi), but they can be expressed as pounds per square foot or pounds per square yard as well. The key is that the force is expressed per unit area.

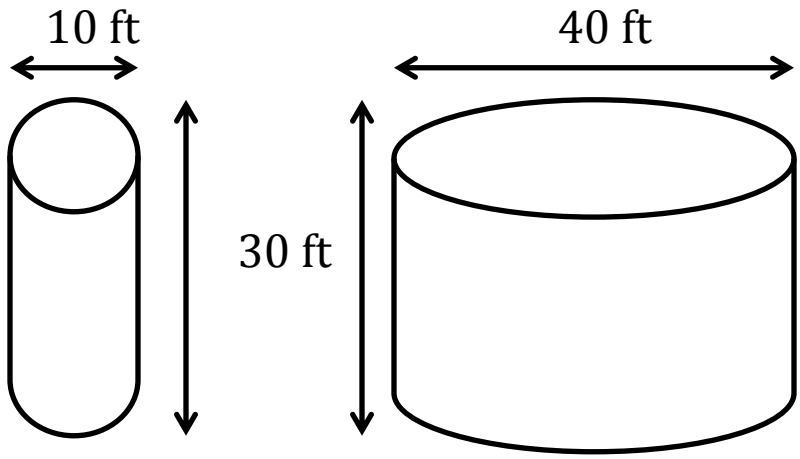
Typically, water operators will measure pressures with gauges and express the unit answer as psig. The "g" is this case represents gauge. However, it is also common to express pressure in feet. Feet represent the height of the water in relation to the location that the pressure is being measured.

There are two commonly used factors to convert from feet to psi and vice versa. For every foot in elevation change there is a 0.433 change in psi. Conversely, for every one psi change there is a 2.31 foot in elevation change.

1 foot = 0.433 psi
2.31 feet = 1 psi

As previously discussed in Section 3, the density or weight of water is approximately 8.34 pounds per gallon. Using this conversion factor, the actual force exerted by the water can be calculated.

Example



The pressure at the bottom of both tanks in this example is the same. This is due to the fact that the heights are equivalent and pressures are based solely on elevation. However, the force exerted on the bottom of the tanks is dramatically different. The "force" is based on the actual weight of the water.

Pressure = 30 ft x 0.433 psi/ft = 13 psi or 30 ft ÷ 2.31 ft/psi = 13 psi

Force = the volume of water (in gallons) in each tank multiplied by 8.34 lb/gal

Left Tank = 0.785 x 10 ft x 10 ft x 30 ft x 7.48 = 17,615 gallons

17,615 gallons x 8.34 lb/gal = 146,912 pounds of force

Right Tank = 0.785 x 40 ft x 40 ft x 30 ft x 7.48 = 281,846 gallons

281,846 gallons x 8.34 lb/gal = 2,350,599 pounds of force

<u>Exercise 8</u>

Solve the following pressure and force related problems.

1. What is the pressure at the bottom of a 30 ft tank if the tank is half full?

2. A 28 foot tall tank sits on a 75 foot tall hill. Assuming the tank is full, what is the pressure at the bottom of the hill?

3. The opening of a 2 1/2" fire hydrant nozzle has a pressure of 135 psi. What is the corresponding force in pounds?

4. A home sits at an elevation of 1,301 ft above sea level. The base of a water tank that serves the home sits at an elevation of 1,475 ft above sea level. The tank is 35 feet tall and ¾ full. What is the pressure in psi at the home?

5. Two houses are served by a nearby water storage tank. House A is 55 ft above House B which sits at 725 ft above sea level. The base of the tank sits at 855 ft above sea level. The low water level in the tank is at 7.5 ft. At the low level, will House A meet the minimum pressure requirements of 35 psi?

6. House A sits at an elevation of 975 ft. Another house (B) needs to be built 75 ft below House A. At what elevation should the tank be built in order to give House B the maximum pressure of 130 psi?

7. A flowing pipeline has a pressure of 98 psi and a corresponding force of 4,924 pounds. What is the diameter of the pipe?

SECTION 8.1 HEAD LOSS

As water travels through objects including pipes, valves, and angle points, or goes up hill, there are losses due to the friction. These losses are called "friction" or head loss. There are published tables listing head loss factors (also termed C factor) for pipes of differing age and material, different types of valves and angle points, etc. However, in this text we will focus on the theory more than the actual values.

Example

If water is traveling through 10,000 feet of pipe that has head loss of 3 feet, passes through 4 valves that have head loss of 1 foot for each valve, and passes through 2 angle points that have head loss of 0.5 feet each, calculate the total head loss.

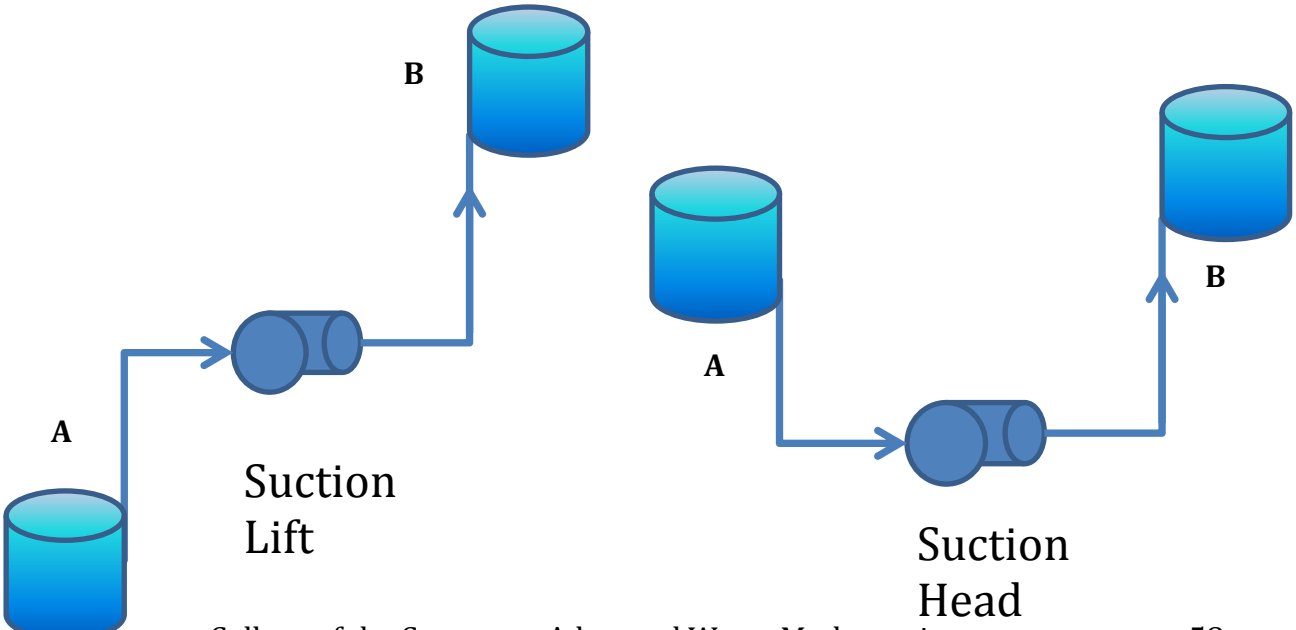
Answer – 3 feet + 1 foot + 1 foot + 1 foot + 1 foot + 0.5 feet + 0.5 feet = 8 feet

Summing all of the head loss values yields the answer.

In distribution systems water is pumped from lower elevations to higher elevations in order to supply customers with water in different areas termed zones. Water is also pumped out of the ground through groundwater wells and from treatment plants throughout the distribution system. As water makes its way through the distribution system head loss is realized (as mentioned in the previous paragraph) and pumps must also overcome the head loss from the elevation changes.

The diagrams below help illustrate the differences between suction lift and suction head. Suction lift requires more work by the pump to move the water from point A to point B. Suction head provides some help (head pressure) to get water from point A to point B.

Suction Lift and Suction Head



Exercise 8.1

Solve the following problems.

1. A well pumps directly to a 25 foot tall water tank that sits 200 feet above the elevation of the well. If the total head loss in the piping up to the tank is 5 feet, what is the total pressure in psi on the discharge side of the well?

2. A booster pump receives water from a tank that is 40 feet above the pump and discharges to a tank that is 275 feet above the pump. What is the total head (TH)?

3. A well located at 750 feet above sea level has a below ground surface water depth of 38 ft and pumps to a water tank at an elevation of 1,030 ft above sea level. The water main from the well to the tank has a total head loss of 11 psi. What is the TH in feet?

4. A housing tract is located at an approximate average elevation of 2,225 ft above sea level and is served from a storage tank that is at 2,330 ft. The average head loss from the tank to the housing tract is 15.5 psi. What is the minimum water level in the tank to maintain a minimum pressure 40 psi?

5. A water utility has two different pressure zones (1 and 2.) The zone 1 Tank is 30 ft tall and sits at an elevation of 850 ft and the zone 2 Tank is 40 feet tall and sits at 1,061 ft. The booster pump from zone 1 to 2 sits at an elevation of 925 ft. The head loss is 19 psi. Tank 1 is half full and Tank 2 needs to be ¾ full. What is the TH?

SECTION 8.2 FLOW RATE

Flow rate is the measurement of a volume of liquid (i.e., water) which passes through a given cross sectional area (i.e., pipe) per unit in time. In the waterworks industry, flow rates are expressed in several different units. The most common ones are shown below.

Flow Rates $\quad \text{cfs} = \dfrac{\text{cubic feet}}{\text{second}} \qquad \text{gpm} = \dfrac{\text{gallons}}{\text{minute}} \qquad \text{MGD} = \dfrac{\text{million gallons}}{\text{day}}$

Depending on the application, flow rates are expressed in these or potentially other units. For example, the flow rate from a well or booster pump is commonly expressed as gpm, whereas annual production might be expressed as acre-feet per year (AFY). However, when solving a problem for flow rate the common unit of expression is cfs. The reason for this is in part due to the measurement of unit area of the structure that the water is passing through (i.e., pipe, culvert, aqueduct, etc.) The areas for these structures are typically expressed as square feet (ft^2.) In addition, the speed (distance over time) at which the water is flowing is commonly expressed as feet per second. The flow rate formula and how the units are expressed are shown in the example below.

Flow Rate = Area x Velocity

Flow Rate (Q) = Area (A) x Velocity (V)

Q = A x V

$$Q\left(\frac{\text{cubic feet}}{\text{sec}}\right) = \text{Area } (ft^2) \times \text{Velocity } \left(\frac{\text{feet}}{\text{sec}}\right)$$

Understanding flow rates and velocities can help with the design on pipe sizes for wells, pump stations, and treatment plants. With the understanding that velocities are typically in the range of 2 – 7 feet per second and the known flow rate, pipe diameters can be calculated. For example, if a new well is being drilled and the pump test data determines that the well can produce a specific flow, let's say 1,500 gpm, and you do not want the velocity to exceed 6.5 fps, the required diameter of the pipe can be determined (see below.)

Example

Q = A x V or for this example $A = \frac{Q}{V}$ since the flow rate (Q = 1,500 gpm) and velocity (V = 6.5 fps) are known.

The first step is to make sure the "known" values are in the correct units.

Velocity given at 6.5 fps is in the correct unit. However, the flow rate given in gpm needs to be converted to cfs.

1,500 gpm ÷ 448.8 = 3.34 cfs

Now that both values are in their correct unit, divide the two to get the unknown value, in this case the Area (A).

$$\frac{3.34 \text{ cfs}}{6.5 \text{ fps}} = 0.51 \text{ ft}^2$$

Knowing that the Area is 0.51 ft^2 and that the formula for Area is 0.785 x D^2, the diameter of the pipe can be calculated.

$0.51 \text{ ft}^2 = 0.785 \times D^2$

$$D^2 = \frac{0.51\, ft^2}{0.785}$$

$D^2 = 0.66 \text{ ft}^2$

In order to find the value of the diameter (D), you must take the square root $(\sqrt{})$ of D^2.

$$\sqrt{D^2} = \sqrt{0.66\, ft^2}$$

D = 0.81 ft

Since pipe diameters are typically expressed in inches, multiply the answer by 12.

0.81 ft x 12 in = 9.7 or **10 inches**

Exercise 8.2

Solve the following problems.

1. What is the flow rate in MGD of a 24" diameter pipe with a velocity of 3 fps?

2. What is the velocity through a box culvert that is 3 feet wide and 2 feet deep if the daily flow is 27 AF?

3. What is the area of a pipe that flows 1.5 MGD and has a velocity of 5 fps?

4. What is the diameter of a pipe that flows 2,500 gpm with a velocity of approximately 7 fps?

5. A 15 mile aqueduct flows 30,000 AFY at an average velocity of 0.45 fps. If the distance across the top is 13 feet and the depth is 8 feet, what is the distance across the bottom?

SECTION 9
WELL YIELD, SPECIFIC CAPACITY, AND DRAWDOWN
It's All Under Ground

Well Yield

Well Yield is the amount of water a certain well can produce over a specific period of time. Typically well yield is expressed as gallons per minute (gpm). During the drilling of a well, pump tests are performed to determine if the underlying aquifer has the ability to supply enough water. A well yield test involves a comparison of the maximum amount of water that can be pumped and the amount of water that recharges back into the well from the surrounding aquifer. Continuous pumping for an extended period of time is usually performed and the yield is calculated based on the amount of water extracted. Well yields are typically measured in the field with a flow meter. Water levels in the well are then measured to determine the **Specific Capacity** and **Drawdown** of the well.

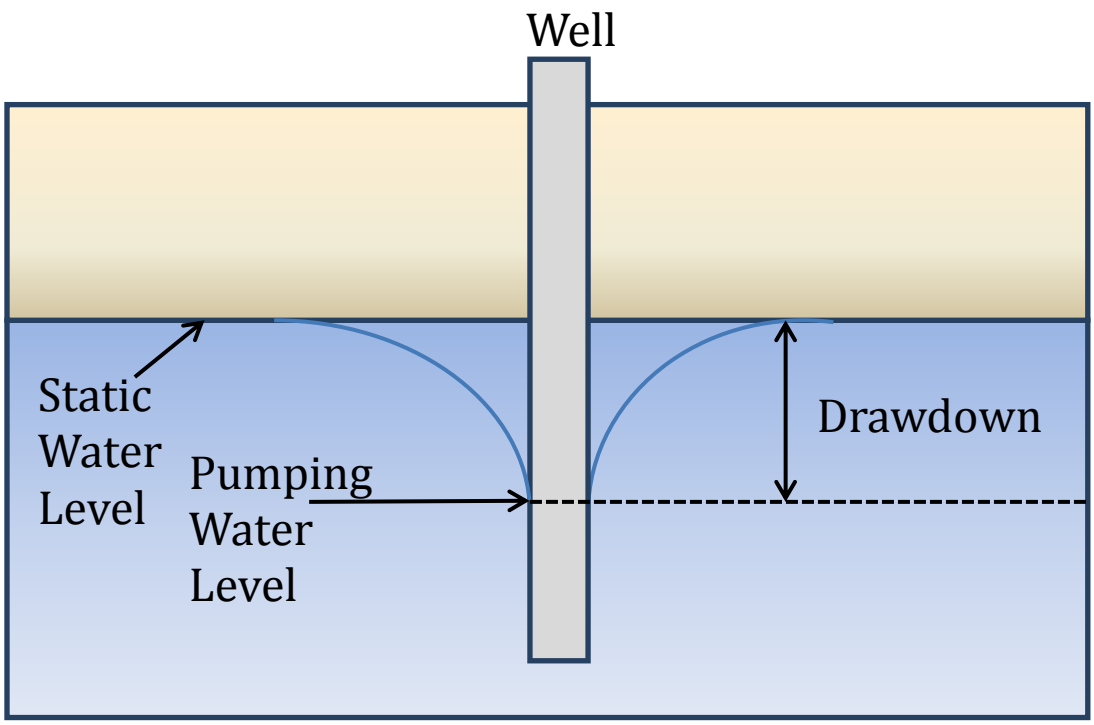
Specific Capacity

Specific Capacity is helpful in assessing the overall performance of a well and the transmissivity (horizontal flow ability) of the aquifer. The specific capacity is used in determining the pump design in order to get the maximum yield from a well. It is also helpful in identifying problems with a well, pump, or aquifer. The specific capacity is defined as the well yield divided by the **Drawdown**, expressed as gallons per minute per foot of drawdown.

$$\text{Specific Capacity} = \frac{\text{gpm}}{\text{ft}}$$

Drawdown

In order to understand the term drawdown, you must also understand static water level and pumping water level as these measurements provide valuable information regarding the well and underlying aquifer. The static water level is defined as the distance between the ground surface and the water level when the well is not operating. The pumping level is defined as the distance between the ground surface and the water level when a well is pumping. Therefore, the pumping water level is always deeper than the static water level. The difference between these two levels is the *drawdown*. Depending on the aquifer, static water levels can be 20 feet below ground surface (bgs) or several hundred feet bgs.



The diagram above shows a well casing penetrating into the ground, the relationship between static and pumping water levels, and the drawdown.

Examples

Calculating Drawdown

Pumping Water Level – Static Water Level = Drawdown
50 ft – 20 ft = 30 ft

Drawdown + Static Water Level = Pumping Water Level
30 ft + 20 ft = 50 ft

Pumping Water Level – Drawdown = Static Water Level
50 ft – 30 ft = 20 ft

Since static and pumping water levels are field measurements, drawdown is typically the calculated value.

Calculating Specific Capacity

Once you have the drawdown, the specific capacity of the well can be calculated, as long as you know the well yield.

Flow Rate = 1,000 gpm
Drawdown = 30 ft

$$\text{Specific Capacity} = \frac{1{,}000\ \text{gpm}}{30\ \text{ft}} = \frac{33.3\ \text{gpm}}{\text{ft}}$$

<u>Exercise 9</u>

Solve the following problems.

1. A well has a static water level of 23 ft bgs and a pumping level of 58 ft bgs. What is the drawdown?

2. A groundwater well has a base elevation of 1,125 ft above sea level. If the drawdown on this well is 44 ft and the pumping level is 80 ft bgs, what is the static water elevation above sea level?

3. A deep well has a static water level of 122 ft bgs. A drawdown has been calculated out to be 65 ft. What is the pumping level of the well?

4. A well has an hour meter attached to a water meter totalizer. After 3 hours of operation, the well produced 279,000 gallons. Water is the well yield in gpm?

5. When a well was first constructed it was pumping 1,750 gpm. The efficiency of the well has dropped 35%. In addition, the drawdown has decreased by 15%. If the original drawdown was 42 ft what is the current specific capacity?

6. A well pumped 538 AF over a one year period averaging 10 hours of operation per day. For half the year the static water level was 25 ft bgs and half the year 42 ft bgs. The pumping level averaged 55 ft bgs for half the year and 68 ft bgs the other half. What was the average specific capacity for the year?

7. A well has a specific capacity of 42 gpm per foot. The well operates at a constant 1,500 gpm. What is the drawdown?

8. A well has a calculated specific capacity of 30 gpm per foot and operates at a flow rate of 1.08 MGD. If the static water level is 28 ft bgs, what is the pumping level?

SECTION 10
HORSEPOWER AND EFFICIENCY
The Power of Water

Previously in this text, we discussed the theory of pressure in both feet (head pressure) and psi (pounds per square inch.) In this chapter we will look at the "power" requirements to move water with pumps and motors. How does water get to the customer's home? Water pressure is typically provided to customers from elevation (above ground tanks, reservoirs, elevated storage tanks, etc.) But, how does the water get to these storage structures? This is where the concept of horsepower comes in. Historically, the definition of horsepower was the ability of a horse to perform heavy tasks such as turning a mill wheel or drawing a load. It wasn't until James Watt (1736-1819) invented the first efficient steam engine that horsepower was used as a standard to which the power of an engine could be meaningfully compared. Watt's standard of comparing "work" to horsepower (hp) is commonly used for rating engines, turbines, electric motors, and water-power devices.

In the water industry there are three commonly used terms to define the amount of hp needed to move water: Water Horsepower, Brake Horsepower, and Motor Horsepower.

Water Horsepower is a measure of water power. The falling of 33,000 pounds of water over a distance of one foot in one minute produces one horsepower. It is the actual power of moving water.

$$\textbf{Water hp} = \frac{(\textbf{flow rate in gallons per minute})(\textbf{total head in feet})}{\mathbf{3,960}}$$

The above equation is used to calculate the power needed to move a certain flow of water a certain height. The constant 3,960 is the result of converting the 33,000 ft-lb/min with the weight of water flow. For example, instead of using gallons per minute, pounds per minute would be needed because 33,000 is in foot-pounds.

Water horsepower is the theoretical power needed to move water. In order to actually perform the work a pump and motor are needed. However, neither the pump nor the motor are 100% efficient. There are friction losses with each. The horsepower required by the pump (brake horsepower) can be calculated, but the actual horsepower needed looks at the efficiencies of both the pump and the motor. This efficiency is termed the *wire-to-water efficiency*. The formula below shows brake horsepower and motor horsepower which includes the combined pump and motor inefficiencies.

$$\textbf{Brake hp} = \frac{(\textbf{flow rate in gallons per minute})(\textbf{total head in feet})}{(\mathbf{3,960})(\textbf{pump efficiency}\ \%)}$$

$$\textbf{Motor hp} = \frac{(\textbf{flow rate in gallons per minute})(\textbf{total head in feet})}{(3,960)(\textbf{pump efficiency}\ \%)(\textbf{motor efficiency}\ \%)}$$

If the pump and the motor were both 100% efficient, then the resulting answer would be 100% x 100% or 1. Hence, the actual horsepower would be the water horsepower and the equation is not affected. However, this is never the case. Typically there are inefficiencies with both components.

Pump Efficiency = 60%
Motor Efficiency = 80% **0.6 x 0.8 = 0.48 or 48% efficient**

As with all water related math problems, it is important for the numbers being used to be in the correct units. For example, the flow needs to be in gallons per minute (gpm) and the total head in feet (ft). These will not always be the units provided in the questions. The example below demonstrates this concept.

Example

What is the horsepower of a well that pumps 2.16 million gallons per day (MGD) against a head pressure of 100 pounds per square inch (psi)? Assume that the pump has an efficiency of 65% and the motor 85%.

In this example, the flow is given in MGD and the pressure in psi. The appropriate conversions need to take place before the horsepower (hp) is calculated.

2.16 MGD ÷ 1440 min/day = 1,500 gpm
100 psi x 2.31 ft/psi = 231 ft

Now, these numbers can be plugged into the hp formula.

$$\textbf{hp} = \frac{(1,500\ \textbf{gpm})(231\ \textbf{ft})}{(3,960)(65\%)(85\%)}$$

Make sure to convert the efficiency percentages to decimals before solving.

$$\textbf{hp} = \frac{(1,500\ \textbf{gpm})(231\ \textbf{ft})}{(3,960)(0.65)(0.85)}$$

$$= 158\ \textbf{hp}$$

Exercise 10

Calculate the required horsepower related questions.

1. What is the required water horsepower for 100 gpm and a total head pressure of 50 ft?

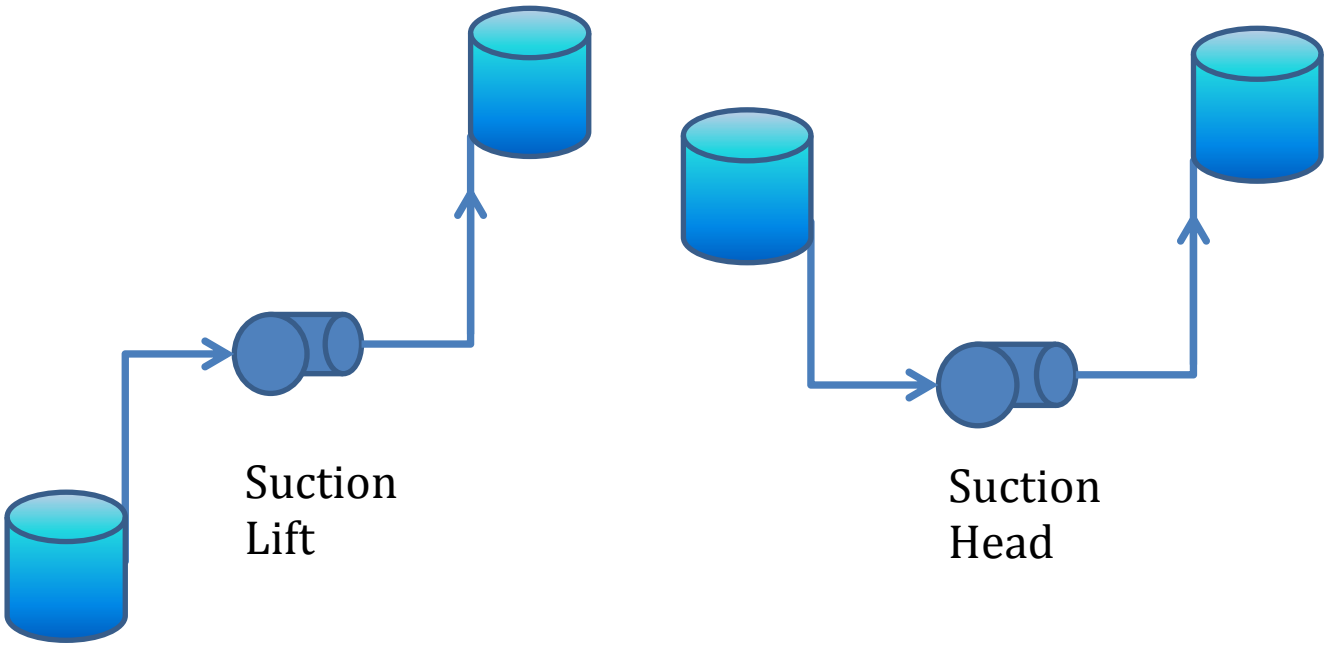
2. What is the water horsepower needed for a well that pumps 2,050 gpm against a pressure of 150 psi?

3. It has been determined that the wire-to-water efficiency at a pump station is 58%. If the pump station lifts 650 gpm to a tank 150 feet above, what is the motor horsepower needed?

4. What is the motor horsepower needed to pump 2,420 AF of water over a year with an average daily pumping operation of 12 hours? Assume the pump is pumping against 95 psi and has a pump efficiency of 70% and a motor efficiency of 80%.

SECTION 10.1 HEAD LOSS AND HORSEPOWER

As discussed in Section 8, suction pressure can either be expressed as "lift" or "head." In other words, the location of the water on the suction side of the pump can either help or hinder the pump. Recall the example diagrams from Section 8.



The diagram on the left (suction lift) requires work from the pump to bring the water up to the pump and then additional work to bring the water to the reservoir above the pump. The diagram on the right (suction head) receives "help" from the tank on the suction side and the pump only has to lift water the height difference between the two tanks. When calculating horsepower, the total head pressure (suction lift + discharge head) or (discharge head – suction head) needs to be calculated.

Exercise 10.1

Calculate the following horsepower related questions.

1. A well is pumping water from an aquifer with a water table 30 feet below ground surface (bgs) to a tank 150 feet above the well. If the well flows 1,000 gpm, what is the required horsepower? (Assume the wire-to-water efficiency is 68%.)

2. A booster pump station is pumping water from Zone 1 at an elevation of 1,225 ft above sea level to Zone 2 which is at 1,445 ft above sea level. The pump station is located at an elevation of 1,175 ft above sea level. The pump was recently tested and the efficiencies for the pump and motor were 62% and 78% respectively. The losses through the piping and appurtenances equate to a total of 11 ft. If the pump flows 1,200 gpm, what is the required motor horsepower?

3. A well with pumps located 75 ft bgs pumps against a discharge head pressure of 125 psi to a tank located at an elevation 253 ft above the well. The well pumps at a rate of 1,050 gpm. What is the level of water in the tank and what is the required water horsepower? (Assume the wire-to-water efficiency is 55%.)

4. A 200 hp booster pump is pulling water from a 32 foot tall tank that is 50 feet below the pump line. It is then pumping against a discharge head pressure of 112 psi. What is the flow rate in gpm? (Assume the wire-to-water efficiency is 65% and the tank is full.)

SECTION 10.2 CALCULATING POWER COSTS

It is important for water managers to determine the potential costs in electricity for pumping water. Units used for measuring electrical usage are typically in kilowatt hours (kW-Hr). In order to convert horsepower to kilowatts of power, the following conversion factor is used.

1 horsepower = 0.746 kilowatts of power

Once you know the hp that is needed you can then determine the amount of kW-Hr needed. Then, costs can be determined depending on what the local electric company charges per kW-Hr. Water utilities will calculate estimated budgets for pumping costs since these are typically the largest operating costs.

Exercise 10.2

Solve the following problems.

1. A well flows an estimated 3,200 gpm against a discharge head pressure of 95 psi. What is the corresponding hp and kW-Hr if the pump has an efficiency of 70% and the motor 88%?

2. Based on the above question, how much would the electrical costs be if the rate is $0.12 per kW-Hr and the pump runs for 10 hours a day?

3. A utility has 3 pumps that run at different flow rates and supply water to a 500,000 gallon storage tank. The TDH for the pumps is 210 ft. The utility needs to fill the tank daily and power costs are to be calculated at a rate of $0.135 per kW-Hr. Complete the table below.

Pump	**Flow Rate**	**Hp**	**Efficiency**	**Run Time**	**Total Cost**
1	500 gpm	50			
2	1,000 gpm	75			
4	2,000 gpm	250			

4. A well draws water from an aquifer that has an average water level of 150 ft bgs and pumps to a tank 225 ft above it. Friction loss to the tank is approximately 22 psi. If the well pumps at a rate of 2,300 gpm and has a wire-to-water efficiency of 62% how much will it cost to run this well 14 hours per day. Assume the electrical rate is $0.13 per kW-Hr.

5. A utility manager is trying to determine which hp motor to purchase for a pump station. A 400 hp motor with a wire-to-water efficiency of 65% can pump 3,000 gpm. Similarly, a 250 hp motor with a wire-to-water efficiency of 75% can pump 2,050 gpm. With an electrical rate of $0.155 per kW-Hr, how much would it cost to run each motor to achieve a daily flow of 2 MG? Which one is less expensive to run?

6. Approximately 224 kW of power are needed to run a certain booster pump. If the booster has a wire-to-water efficiency of 67.5% and is pumping against 135 psi of head pressure, what is the corresponding flow in gpm?

7. Complete the table below based on the information provided.

Well	Flow (gpm)	Run Time (Hr/Day)	Wire-to-Water Eff	Head Pressure (psi)	hp	Cost/Year ($) @ $0.135/kW-Hr
A	750	18	68%	110		
B	1,800	13	61%	85		
C	2,750	12	57%	95		

8. It costs $88.77 in electricity to run a well for 7 hours a day. The well has a TDH of 100 psi and an overall efficiency of 58.3%. The cost per kW-Hr is $0.17. What is the cost of the water per gallon?

SECTION 11
PER CAPITA WATER USAGE
How Much Water Do We Really Use?

Community water use is often expressed as gallons per capita per day (gpcd). The term "per capita" is the same as per person. How much does one person use each day? In general, an average person uses water daily to take a shower, use the restroom, cook, drink, wash dishes and clothes, brush teeth, wash hands, etc. The amount of water consumed/used can be estimated if certain assumptions are made. For example, it can be assumed that a typical shower head has a flow rate of 5 gallons per minute and each individual takes one shower per day. A toilet might use 2 gallons per flush and each person is assumed to use the restroom three times per day. An efficient dish and clothes washer might use 7 gallons and 20 gallons respectively. Brushing teeth, washing hands, drinking, and cooking might add up to 2 gallons. You can see that the typical amount of water usage can then be calculated rather quickly. These values are typical for efficient usage. Older toilets and appliances can use several times the amount of water use. The table below gives some examples of efficient and non-efficient indoor water usage by appliance or device. The units are in gallons.

Toilet		
Conventional	**Low-Flow**	**Ultra Low-Flow**
5.0	3.5	1.6
Washing Machine		
Conventional	**Efficient**	**Front Load**
37.0	26.0	21.0
Dishwasher		
Conventional	**Efficient**	
18.0	6.0	
Shower Heads		
Conventional	**Low-Flow**	
5.0	2.5	
Faucets		
Conventional	**Low-Flow**	
3.0	2.5	

Although these values can add up to significant daily usage, the primary household water use can be attributed to landscape irrigation. Due to a combination of climate and life style, Californians can use up to 70% of their household water consumption on landscape irrigation. Depending on the size of the actual landscaped area the water usage will vary dramatically and the gpcd will closely follow. Conversely, the national average water use for landscape irrigation is much lower at approximately 30%.

Utilities don't usually go into this much detail in calculating gpcd. Some utilities look at the entire water used in one year and compare it to the total population served. This can provide an adequate answer, but if the utility provides water to large commercial or industrial customers the gpcd can be skewed. Usually a utility will only look at residential water usage and estimate the total population. Regardless of the process, the per capita water use is expressed as the amount of water used per person per day as indicated in the following formula:

$$\text{gpcd} = \frac{\text{water used (gpd)}}{\text{total number of people}}$$

Remember, the total number of people represents the population you are observing. For example if it is a house of 5 people then the total number of people would equal five. In addition, if you are looking at the total amount of water used in one year, it is probably represented as acre-feet per year (AFY), in which case it would need to be converted to gallons per day.

In 2009 Senate Bill SBx7-7 was signed into law. It requires California water utilities to reduce water consumption in urban water use by 20% by the year 2020. This has prompted utilities to implement water conservation strategies such as high efficiency appliance rebate programs, various other incentives, tiered water rates, and water budget based water rates. All of these programs are designed to help reduce water use. Calculating gpcd is extremely important for water utilities, especially in California, or any other area where water conservation is needed or more importantly mandated.

Exercise 11

Solve the following problems.

1. What is the average gpcd of a small community of 3,200 people that use approximately 500,000 gallons per day?

2. A water utility produced 15,000 AF of water last year that supplied a population of 50,000. What was the averaged gpcd for this community?

3. A water utility in northern California has an average gpcd of 155. If the total population of this community is 42,300, how much AF of water must this utility supply in one year?

4. A large water utility has 10 wells that can produce a combined flow of 15,500 gpm. The average gpcd for this community of 175,000 residents is 235. How many AF of water must this utility purchase per year to make up the supply needed for this community?

5. A small water system has one well that pumps 250 gpm. This well serves a population of 1,575 with an average gpcd of 195. How many hours per day must this well run to meet the demand?

6. What is the gpcd of a community with 1,250,000 people if the annual water used is 245,000 AF?

7. A Water District has a goal of 145 gpcd and an annual water projection of 21,250 AF. What is the population that can be served?

8. A house of 4 people used 36 CCF of water in 31 days. What is their gpcd?

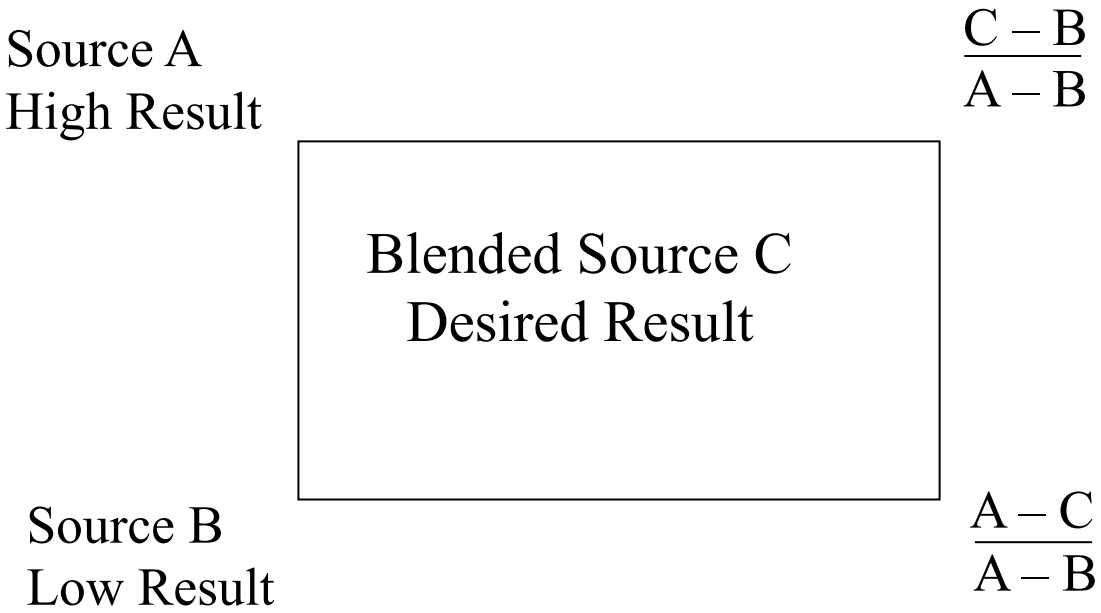
9. In question 8, what would the gpcd be if you took out 65% of the usage and classified it as outdoor usage?

SECTION 12
BLENDING AND DILUTING
Is Dilution the Solution to Pollution?

Dilution is not the solution to pollution, but dilution can be used to reduce the level of a contaminant in drinking water supplies. Blending water sources of different water quality is common practice. However, when a water utility wants to blend sources of supply to lower a certain contaminant to acceptable levels they must receive approval from the governing Health Department. A Blending Plan must be created that specifies what volumes of water from each source will be used and what the expected resulting water quality will be. In addition, a sampling strategy must be included in the plan. The Health Department may not allow blending for all contaminants. For example, the local health agency may not approve a blending plan for a contaminant that poses an acute health effect or is deemed to be too high of a risk to public health.

An acceptable blending plan may be for reducing manganese in a source that has exceeded the California Secondary Maximum Contaminant Level (MCL) of 0.05 mg/L. Manganese causes black water problems for customers at levels over the secondary MCL. Additionally, an approved blending plan may involve a Primary MCL for nitrate. Nitrates above the MCL of 45 mg/L as NO_3 can cause methemoglobinimia in infants under 6 months old. These are just two examples of blending plans.

How are blended water quality results calculated? The blending of water supplies is nothing more than comparing ratios. For example, if 100 gallons of one source was mixed with 100 gallons of another source, the resulting water quality would be the average between the two sources. However, when you mix varying flows with varying water quality, the calculations become a little more complex. Using the diagram below will assist you in solving blending problems.



If two sources are to be blended, the water quality data for both sources is known. One of the sources with a poor or high water quality result for a certain constituent will need to be blended with a source that has good or low water quality data. Source A will be the high out of compliance data point and Source B will be the low in compliance data point. Source C is the desired blended result. Typically this value is an acceptable level below an MCL. Once these values are established the ratios of the differences between these numbers can be calculated. For example the ratio of C - B to A - B yields the quantity of Source A that is needed. Therefore in the example below, the quantity of A needed is 37.5%. The same thing holds true for Source B. Simply take the ratio of the difference between the high (A) and desired (C) values and divide it by the difference between the high (A) and low (B) values. However, once you solve for the quantity of one source, simply subtract it from 100% to get the value for the other source. See the example below.

It is expected that water quality results can and will fluctuate. It is always a good idea to take the highest result from recent sampling when calculating needed blend volumes to reduce the impacted water to acceptable levels. For example, if a well is being sampled for trichloroethylene (TCE) quarterly and the results are 6 ug/L, 7.8 ug/L, 5.9 ug/L, and 8.5 ug/L from a recent year of sampling, it would be prudent to use the 8.5 mg/L result when calculating blending requirements. It is also important to note that the local health authority should be consulted with respect to any blending plan.

Source A
10 ppm

$$\frac{5-2}{10-2} = 0.375$$

Blended Source C
5 ppm

Source B
2 ppm

$$\frac{10-5}{10-2} = 0.625$$

This says that 37.5% of Source A is needed and 62.5% of Source B is needed to achieve the desired blended value. Once the percentage of each source has been calculated the actual flows can be determined. Sometimes the total flow from both sources is known. In this case you would take that known flow rate and multiply it by the respected percentages of each source. In the example below 5,000 gpm is needed.

Source A
10 ppm

$$\frac{5-2}{10-2} = 0.375 \text{ x } 5{,}000 \text{ gpm} = 1{,}875 \text{ gpm}$$

Blended
Source C
5 ppm

Source B
2 ppm

$$\frac{10-5}{10-2} = 0.625 \text{ x } 5{,}000 \text{ gpm} = 3{,}125 \text{ gpm}$$

This example demonstrates that Source A can provide 1,875 gpm of a supply that has a water quality constituent result of 10 ppm and Source B can provide 3,125 gpm of a supply that has a water quality constituent result of 2 ppm to achieve a total flow of 5,000 gpm with a resulting water quality result of 5 ppm.

This is just one example of how this equation can be used to calculate the answer. Another example is where the flows and the existing water quality results are known and the utility must calculate what the desired result will be. In any of these examples if the process above is followed, the resulting answers can be calculated.

<u>Exercise 12</u>

Solve the following blending problems.

1. A well has a nitrate level that exceeds the MCL of 45 mg/L. Over the last 3 sample results it has averaged 52 mg/L. A nearby well has a nitrate level of 32 mg/L. If both wells pump up to 2,275 gpm, how much flow is required from each well to achieve a nitrate level of 40 mg/L?

2. A well (A) has shown quarterly arsenic levels above the MCL over the last year, of 14 ug/L, 20 ug/L, 18 ug/L and 16 ug/L. A utility wants to blend this well to a level of 8.0 ug/L with a well (B) that has a level of 4.5 ug/L. The total production needed from both of these wells is 3,575 gpm. How much can each well produce?

3. A well with a PCE level of 7.5 ug/L is supplying approximately 35% of total water demand. It is being blended with a well that has a PCE level of 3.25 ug/L. Will this blended supply meet the MCL for PCE of 5.0 ug/L?

4. Well A has a total dissolved solids (TDS) level of 850 mg/L. It is pumping 1,500 gpm which is 40% of the total production from two wells. The other well (B) blends with well A to achieve a TDS level of 375 mg/L. What is the TDS level for Well B?

5. Two wells need to achieve a daily flow of 3.24 MG and a total hardness level of 90 mg/L as calcium carbonate ($CaCO_3$.) Well #1 has a total hardness level of 315 mg/L as $CaCO_3$ and Well #2 has a level of 58 mg/L as $CaCO_3$. What is the gpm that each well must pump?

6. The State Health Department has requested a blending plan to lower levels of sulfate from a small water utility well. The well has a constant sulfate level of 525 mg/L. The utility needs to purchase the water to blend with the well. The purchased water has a sulfate level of 135 mg/L. They need to bring the sulfate levels down to 265 mg/L and supply a demand of 1.15 MGD. The purchased water costs $550/AF. How much will the purchased water cost for the entire year?

SECTION 12.1 MIXING AND DILUTING SOLUTIONS

Another common process with chemicals is the mixing of solutions with different strengths, or diluting a certain chemical concentration strength with water. Let's look at a dilution based example first.

If 700 mL of water is added to 250 mL of a 65% concentration strength solution, what is the resulting concentration strength?

In the above example the resulting volume is 950 mL. This is calculated by adding 700 mL to 250 mL. The formula used to calculate the new concentration strength is the following:

$C_1V_1 = C_2V_2$

$0.65 \times 250 \text{ mL} = C_1 \times 950 \text{ mL}$

The left side of the equation becomes 162.5 and this is divided by 950 mL to get the diluted concentration strength.

$\frac{162.5}{950} = 0.17$ or 17% This says if 250 mL of a 65% solution is diluted with 750 mL of water, the resulting concentration will be 17%.

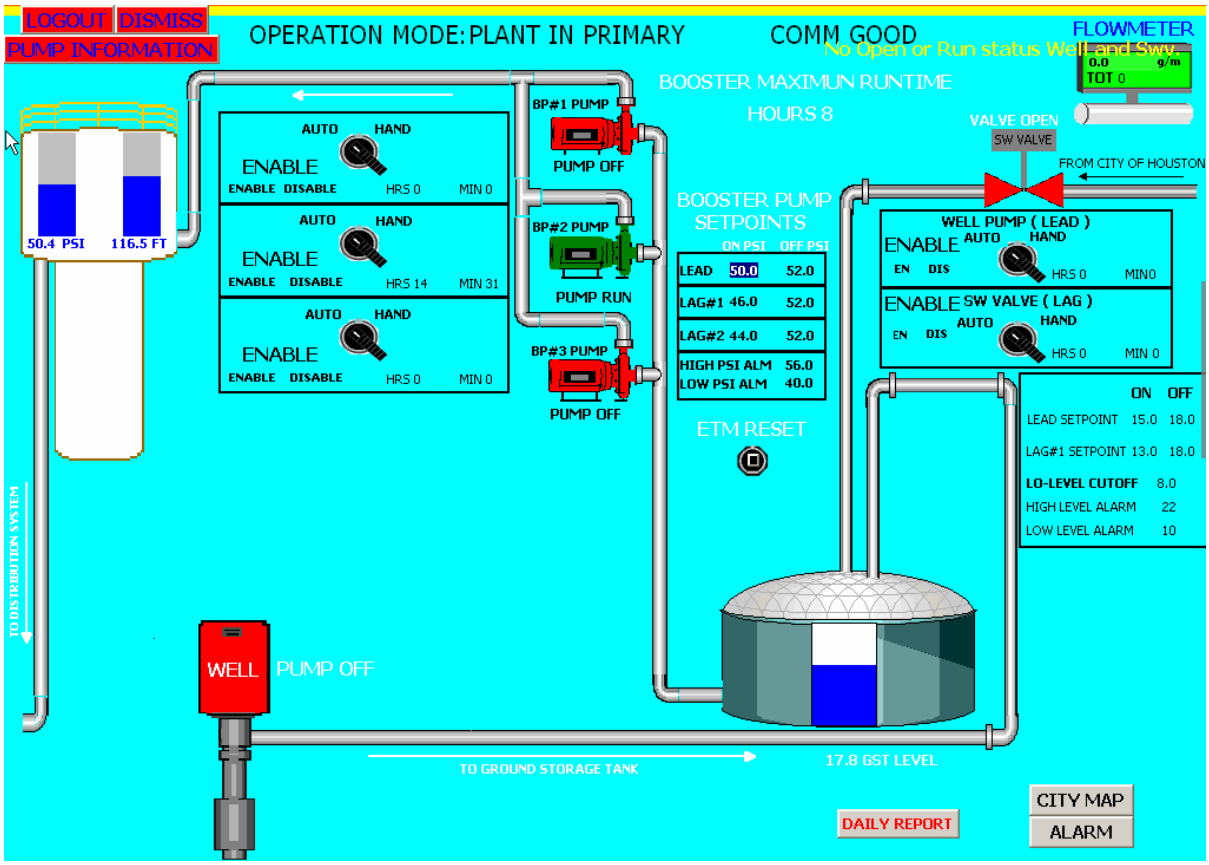
By mixing two solutions of different strengths and known volumes the resulting strength can be calculated. Let's look at the following example.

700 mL of a chemical with a concentration strength of 25% is mixed with 250 mL of 65% concentration strength. What is the resulting concentration strength?

In the example above, the resulting volume is 950 mL. This is calculated by adding 700 mL and 250 mL.

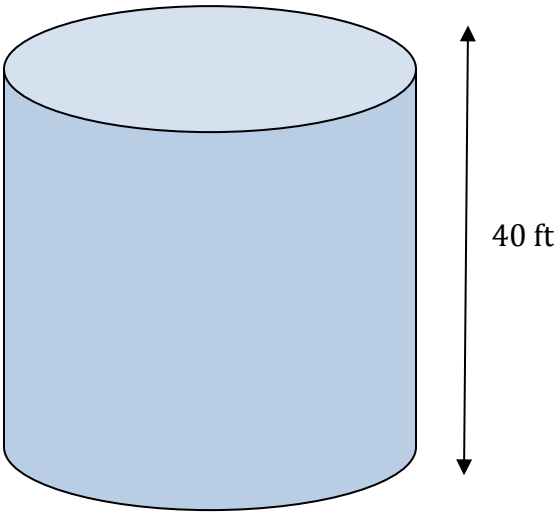
SECTION 13
SCADA AND THE USE OF mA
SCADA?

SCADA is the acronym for Supervisory Control and Data Acquisition. It is a computerized system allowing a water system to operate automatically. A SCADA system usually consists of three (3) basic components: field instrumentation, communications (telemetry), and some type of central control equipment. The field instrumentation will measure various parameters such as, flow, chemical feed rates, chemical dosage levels, tank levels, etc. These instruments will then gather a series of signals and transmit them through some type of communication device(s) known as telemetry. The telemetry communication can be radio signals, telephone lines, fiber optics, etc. This information is sent to a central control computer typically located at an office or operations control center. This computer will have software interpreting the signals and displaying the actual values of the parameters being measured. Below is an example of a typical SCADA computer screen.



A common measurement used to analyze the various field parameters of a water system is the 4-20 milliamp (mA). A 4-20 mA signal is a point-to-point circuit and used to transmit signals from instruments and sensors in the field to a controller. The 4 to 20 mA analog signal represents 0 to 100% of some process variable. For example, this 0 to 100% process variable can be a chlorine residual from 0.2 to 4.0 mg/L or a tank level of 0 to 40 feet. The 0% would represent the lowest allowed value of the process and 100% the highest. These mA signals are then sent through the SCADA system and processed into understandable values such as mg/L or feet, depending on the parameter being measured.

This first example is using the 4-20 mA signal to measure the level of water in a storage tank. The tank is 40 ft tall and has a diameter of 30 ft (mot to scale).



There are a couple things to point out with storage tanks. First, although the height of the tank is 40 ft, the water is never filled to that height. Why? Because the inside roof of the tank would be damaged. Therefore, all storage tanks have an "overflow" connected at the top of the tank off to the side. The second thing to point out is that the "bottom" or zero level of the tank is never at the actual bottom of the tank. Why? Because you never want to run a tank empty. There is always a several foot distance from the actual bottom to what is referred to as the "zero" level. In many questions the "overflow" (actual top level) and the "bottom" (actual location of the zero level) will be mentioned.

Therefore, in this example above since there is no reference to an overflow or where the zero level is located, the 4 mA signal would represent 0 ft and the 20 mA signal 40 ft. What this is saying is if your meter sends out a signal of 20 mA, then the corresponding level in feet would be 40. Likewise, if the signal was 4 mA the corresponding level would be 0 ft.

What do you expect the mA reading to be if the tank was half full (20 ft)?

If you initially thought 10 mA that would be a logical guess. However, let's think about this for a minute. Since the bottom or 0 ft is at 4 mA and the top or 40 ft is at 20 mA, the span or difference between 4 and 20 is only 16…not 20. This "span" is an important number when solving these problems.

Now, if your second guess was 8 mA that would be a logical answer too, but it is also an incorrect response. Yes, 8 is half of 16, but we are not dealing with a span of 0 - 16, we are dealing with a span of 4 - 20. Therefore, half of 16 is 8, but the halfway distance between 4 and 20 is 12! Anyone who guessed 12 mA, give yourself a hand. Whatever read you have on your meter, you must subtract out the 4 mA offset.

Once you understand this the equation is quite simple. The meter read minus the offset divided by the span equals the percent of the value being measured.

$$\frac{\text{mA (reading)} - \text{4mA (offset)}}{\text{16 mA (span)} \ (20 - 4)} = \text{percent of the parameter being measured}$$

Let's use the 40 ft tank example to illustrate the solution.

In a 40 ft tall tank a 10 mA reading was collected for the height of the water level in the tank.

$$\frac{\text{10mA (reading)} - \text{4mA (offset)}}{\text{16 mA (span)}} = \frac{\text{6 mA}}{\text{16 mA}} = \text{0.375 or 37.5\% full}$$

If the tank is 37.5% full then multiply this percent by the total height.

0.375 X 40 ft = 15 ft

Exercise 13

1. A 4-20 mA signal is being used to measure the water level in a water storage tank. The tank is 32 feet tall and the low level signal is set at 0 feet and the high level at 32 feet. What is the level in the tank with a 15 mA reading?

2. A 75 ft tall water tank uses a 4-20 mA signal for calculating the water level. If the 4 mA level is set at 4 feet from the bottom and the 20 mA is set at 4 feet from the top, what is the level in the tank with a 10 mA reading?

3. A chlorine analyzer uses a 4-20 mA signal to monitor the chlorine residual. The 4-20 mA range is 0.5 mg/l – 3.5 mg/L respectively. If the reading is 6 mA, what is the corresponding residual in mg/L?

4. A water tank is 45 ft tall and has 32 ft of water in it. If the 4-20 mA set points are at 2 ft and 42 ft respectively, what is the mA reading?

5. A water tank with a 120 ft diameter is 32 ft tall. The 4-20 mA set points are 3 ft and 29 ft respectively. If the current level reading is 17 mA, how many gallons of water are in the tank?

6. A utility uses a 4-20 mA signal to determine the level in a well based on pressures. The set points are based on pressures in psi below ground surface (bgs). The 20 mA signal is set at 182 psi bgs and the 4 mA signal at 10 psi bgs. If the reading is 9 mA, what is the water level in feet?

7. A water utility uses a 4-20 mA signal to determine groundwater elevations in a well. The set points are based on actually elevations above the mean sea level (MSL). The ground surface elevation at this well is 1,180 ft and this is where the 4 mA signal is set. The 20 mA signal is set at 930 ft. What is the elevation and the feet bgs with a18 mA reading?

8. A chemical injection system is monitored with a 4-20 mA signal. The reading is 14 mA at 2.45 mg/L and the 4 mA set point is at 0.4 mg/L. What is the 20 mA set point?

SECTION 14
WATER UTILITY MANAGEMENT
Managing With Numbers

Every water utility has a management staff that directs, plans, organizes, coordinates, and communicates the direction of the organization. But, what does this mean? It means that managers do a variety of functions that sometimes go unnoticed and at times can be difficult to measure. However, one important function of utility managers is financial planning. Managers are responsible for preparing budgets, working on water rate structures, and calculating efficiencies within the organization.

Budgets

How much money does a utility need to perform the routine, preventative, and corrective action maintenance items? How much money is needed to operate the utility? How much needs to be spent on Capital Improvement Projects? Does the utility have any debt to pay off? How much are salaries, benefits, etc., etc., etc.? These are some of the main items that managers look at when determining budgets. Many times budgets are not only prepared for the upcoming year. Frequently utilities will look 5, 10, even 20 years into the future for budgetary analysis. Let's define some of these budget items.

Operations and Maintenance (O&M)

These two items typically go hand and hand. There are certain costs that the utility must cover and must properly budget for in order to keep the water flowing. Chemical costs for treating water, repairs on vehicles and mechanical equipment, power costs to pump water, leak repairs, and labor are just a few of the items that fall under this budgetary classification. Some are known, such as labor (salaries), as long as overtime isn't too large. Others are predictable, such as power and chemicals. Based on historical water production, power and chemicals can be predicted within a reasonable amount of accuracy. Others, like water main breaks can be estimated based on history, but other factors come into play such as age, material, location, pressures, etc. Regardless of the predictability of O&M costs, managers must come up with an accurate budget number and then make sure that number is covered with revenue.

Capital Improvement Projects (CIP)

In addition to the reoccurring O&M costs, utilities need to plan and budget for future growth and the replacement of old infrastructure such as, pipelines and storage structures. Depending on the age of the utility and the expected future growth, CIP investment can be quite extensive. Typically, utilities can recover the costs of new infrastructure from the developers that are planning to build within the utilities service area. However, as infrastructure ages, it eventually

needs to be replaced. The timing and funding of these replacements is an important part of a manager's responsibility.

Debt

More times than not, utilities will take on large amounts of debt to cover major capital improvement projects. Debt is used by utilities as a way to keep water rates lower. If a utility were to cover the cost of replacing major infrastructure projects through rates, the water rate could be too high for many people to pay. With a proper debt structure, the utility can spread out the costs over many years to help keep rates lower.

Revenues and Rates

In order for water utilities to pay for all their expenses (i.e., pumping, chemicals, material, salaries, benefits, etc.) they need to collect enough money. This is known as Revenue Requirements. A utility must identify all revenue requirements and then identify the means for collecting this revenue. Utilities can have different revenue sources such as property taxes, rents, leases, etc. However, most water utility revenues are collected through the sale of water. The cost of water is determined through a Rate Study. A rate study is a report that lists the revenue requirements and then calculates how much the rate of water needs to be to collect these requirements. Water rates can be set in a variety of different structures (flat rate, single quantity rate, tiered rate, etc.), but regardless of the structure, the utility must sell water at the calculated rate to recover the needed revenue.

Efficiencies

As part of the budgetary process, managers need to identify if and when certain piece of equipment will fail. Calculating the return on investment and identifying when the cost of maintenance exceeds the cost to replace the asset is crucial. An example of this is looking at the efficiencies of pumps and motors. Over time the efficiency decreases and the cost to operate and maintain the pump and motor increases. Another example is with pipelines. As pipes age more and more leaks occur. At some point in time the cost to repair leaks becomes greater than the cost to replace the pipe.

Now that these topics have been loosely defined, let's take a look at how it all works mathematically. The table below demonstrates some O&M numbers for a typical small utility.

Example Exercise

O&M Item	Monthly Averages	Cost per Unit or Number	Monthly Cost	Annual Cost
Water Production				
Groundwater	440 MG	$230	$101,200	$1,214,400
Purchased Water	190 MG	$1,200	$228,000	$2,736,000
Staffing				
Hourly Employees	$3,500	15	$52,500	$630,000
Salary Employees	$6,200	10	$62,000	$744,000
Benefits	40% of Pay		$45,800	$549,600
Chemicals				
Chlorine (1.5 ppm)	5,504 lbs	$2.70	$14,860	$178,330
Vehicle Maintenance	$250	17	$4,250	$51,000
Leaks and Repairs (Materials Only)	$2,500	3	$7,500	$90,000
Pumps and Motors (Materials Only)	$1,000	6	$6,000	$72,000
Treatment Equipment	$75	8	$600	$7,200
Miscellaneous	$1,125	NA	$1,125	$13,500
TOTAL			**$523,836**	**$6,286,030**

Using the information provided in the table above, fill in the information in the table below.

O&M Item	Percentage of Annual Budget
Water Production GW & Purchased	
Staffing Salary & Benefits	
Chemicals	
Vehicle Maintenance	
Leaks and Repairs (Materials Only)	
Pumps and Motors (Materials Only)	
Treatment Equipment	
Miscellaneous	

Think about which items are controllable and which would be considered fixed costs. List the fixed costs versus variable costs and give an explanation justifying your response. Some might seem fixed, but there are ways to look at them as a variable cost. Others might seem like a variable cost, but in reality there is limited control of the cost and would be considered fixed.

Fixed Costs	**Reason**
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

Variable Costs	**Reason**
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

<u>Discussion</u>

Although the cost of water is "fixed" sometimes water utilities can control the amount that is purchased versus the amount that is pumped from wells. Buying water from another entity can be quite costly. However, more information would be needed about the utility to understand their production flexibilities. Staffing and benefits would also be considered a "fixed" cost, but staffing reductions or adjustments in benefits could also occur. There are certain fixed vehicle expenses, such as oil changes, tune ups, tires, etc. There are also some unknown maintenance issues such as a bad battery, a faulty water pump, etc. All of these examples can be looked at as fixed or variable costs. The idea is not to "pigeon hole" these expenses as fixed or variable. The idea is to be able to accurately estimate these and other expenses in a budget.

It is extremely important that utility managers have a general understanding of the concepts associated with utility management as well as the mathematical computations

necessary to support the budgetary decisions being made. Exercise13 provides some basic examples in utility budgeting practices.

Exercise 14

1. A utility vehicle costs on average $1,250 per year for maintenance. A replacement vehicle would cost $35,000. The utility has a vehicle policy that states all vehicles with 150,000 miles or more shall be replaced. The policy also states that once maintenance costs exceed 60% of the cost of a replacement vehicle the vehicle shall be replaced. This particular vehicle averages 18,500 miles per year.

    a. Will the vehicle cost more than 60% of a new vehicle cost before reaching 150,000 miles?

    b. What is the total maintenance cost if the vehicle reaches 150,000 miles?

2. A pump that has been in operation for 25 years pumps a constant 600 gpm through 47 feet of dynamic head. The pump uses 6,071 kW-Hr of electricity per month at a cost of $0.085 per kW-Hr. The old pump efficiency has dropped to 63%. Assuming a new pump that operates at 86% efficiency is available for $9,370, how long would it take to pay for replacing the old pump?

3. A utility has annual operating expenses of $3.4 million and a need for $1.2 million in capital improvements. The current water rate is $1.55 per CCF. Last year the utility sold 6550 AF of water and did not meet their capital budget need. How much does the utility need to raise rates in order to cover both the operational and capital requirements. (Round your answer to the nearest cent.)

4. In the question above, how much would the utility need to raise their rates in order to meet their operational and capital requirements and add approximately $100K to a reserve account?

5. A 250 hp well operates 9 hours a day and flows 2,050 gpm. The electricity cost is $0.135 per kW-Hr. The well is also dosed with a 65% calcium hypochlorite tablet chlorinator to a dosage of 1.25 ppm. The tablets cost $1.85 per pound. The labor burden associated with the well maintenance is $75 per day. What is the total operating expense for this well in one year?

6. In the question above, what is the cost of water per acre-foot?

7. A small water company has a total operating budget of $400,000. Salaries and benefits account for approximately 68% of this budget. The company has 8 employees. What is the average annual salary?

8. A water treatment manager has been asked to prepare a cost comparison between gas chlorine and a chlorine generation system using salt. Gas chlorine is $2.35 per pound and salt is $0.38 per pound. It takes approximately 5 pounds of salt to create 1 gallon of 0.8% chlorine with a specific gravity of 1.15. Assuming that the plant is dosing 15 MGD to a dosage of 2.25, what would be the annual cost of each? Which one is more cost effective?