Advanced Waterworks Mathematics

ZERO TEXTBOOK COST

WATER-131

ADVANCED WATERWORKS MATHEMATICS

Learning and Understanding Mathematical Concepts in Water Distribution and Water Treatment

An Open Educational Resources Publication by College of the Canyons

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UNIT 1: UNIT DIMENSIONAL ANALYSIS (UDA)

1.1 CONVERTING UNITS

Converting units is the most important concept in waterworks mathematics. You may work with million gallons, cubic feet, acre feet, feet per second, gallons per minute, milligrams per liter, pounds per gallon, yards, ounces, and parts per billion. Units are the "driver" for problem solving in many waterworks math questions because operators measure processes and need units to describe these processes. 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. So, a conversion is necessary to report out this water usage. Many times, flow rates are measured as gallons per minute, but dosage computations require million gallons per day. An operator must convert correctly to administer the right dose.

In an introductory water mathematics course, unit conversion is typically explained in a "unit by unit" breakdown. **Unit dimensional analysis** or UDA is the process through which we convert units by writing all units out and looking for opportunities to convert and cancel units.

Example: Convert seconds to days using UDA.

$$\frac{\text{sec}}{1} \times \frac{\text{min}}{\text{sec}} \times \frac{\text{hour}}{\text{min}} \times \frac{\text{day}}{\text{hour}}$$

If we break the problem up into parts, you can see how the canceling of units occurs.

$$\frac{\cancel{\text{sec}}}{1} \times \frac{\text{min}}{\cancel{\text{sec}}} = \text{min}$$

In the above example, if we just do the first part you can see that canceling seconds will yield minutes as the result. By continuing the same process, you can convert to the appropriate units.

$$\frac{\cancel{\text{sec}}}{1} \times \frac{\cancel{\text{min}}}{\cancel{\text{sec}}} \times \frac{\cancel{\text{hour}}}{\cancel{\text{min}}} \times \frac{\text{day}}{\cancel{\text{hour}}} = \text{day}$$

The reason seconds is set up over a "1" is because it is the units you begin with. Remember anything over 1 is that same value.

Multiple units may need to be converted. In the text for Water 130, you were instructed to convert one unit at a time. In this text, we will look at common unit conversions that include multiple units, which is the preferred method to minimize mistakes and avoid costly errors. As you become more familiar with water-related math problems, you will notice these recurring numbers and conversions.

A common waterworks mathematics conversion is from cubic feet per second (cfs) to gallons per minute (gpm). 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.

Example: Convert from cubic feet per second (cfs) to gallons per minute (gpm).

$$\frac{1\ \cancel{cf}}{\cancel{sec}} \times \frac{60\ \cancel{sec}}{1\ \text{min}} \times \frac{7.48\ \text{gal}}{1\ \cancel{cf}} = \frac{448.8\ \text{gal}}{\text{min}}$$

Units in the numerators and denominators cancel out.

Cubic feet are converted to gallons and seconds are converted to minutes. This results in a single, very useful, conversion factor that can be used any time you need to convert from cfs to gpm or from gpm to cfs.

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

Example: Convert 5 cubic feet per second (cfs) to gallons per minute (gpm) using the combined conversion factor.

$$\frac{5\ \text{cfs}}{1} \times \frac{448.8\ \text{gpm}}{1\ \text{cfs}} = 2{,}244\ \text{gpm}$$

Instead of breaking up cubic feet per second into cubic feet and seconds, cubic feet per seconds are kept together as cfs.

There are additional combined conversion factors. Let's look at converting millions of gallons per day (MGD) to cfs.

Example: Show how 1 MGD is equivalent to 1.55 cfs.

$$\frac{1{,}000{,}000\ \cancel{gal}}{\cancel{day}} \times \frac{1\ \cancel{day}}{24\ \cancel{hr}} \times \frac{1\ \cancel{hr}}{60\ \cancel{min}} \times \frac{1\ \cancel{min}}{60\ sec} \times \frac{1\ cf}{7.48\ \cancel{gal}} = 1.55\ cfs$$

In converting MGD to cfs, there are multiple units to convert including gallons to cubic feet, days to hours, hours to minutes, and minutes to seconds. Now, you can use the combined conversion factor when you need to convert from MGD to cfs.

$$\frac{1\ MGD}{1.55\ cfs} \quad \text{or} \quad \frac{1.55\ cfs}{1\ MGD}$$

Practice Problems 1.1a

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

1. 1 MGD = 694 gpm

2. 86,400 seconds = 1 day

3. 1 MGD = 3.069 AF/day

Exercise 1.1a

Show how each of the following combined conversion factors are calculated.

1. 1 day = 1,440 minutes

2. 1 cfs = 0.646 MGD

3. 1 cf = 62.4 lbs

Word problems may involve unit conversion. When solving word problems, there is always a specific question that must be answered. Identifying that question or problem is critical in solving the problem. Then you need to be able to identify which information provided is necessary to solve for the answer and which is not necessary. Most students skip checking their answer to make sure it makes sense. This is a critical step.

Use these steps to solve word problems.

Step 1: Read and understand the problem to determine what is being asked. Know what you are trying to solve for.

Step 2: Identify the information you need. You may want to underline key parts or circle units.

Step 3: Make a sketch to clarify the information. This step works well in geometric problems when you are trying to solve for missing dimensions, but you may find other times when it is helpful to make a quick sketch.

Step 4: Put the information into an equation or formula. Using a reference sheet for formulas is often key in this step. Make sure you copied the formula correctly!

Step 5: Solve and double check your answer. Does the solution make sense? If your solution does not make sense, read the problem again.

Practice Problems 1.1b

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

1. Convert 3,837,000 lbs to AF

2. Convert 12.75 cfs to MGD

3. A well is pumping water at a rate of 8.25 gpm. If the pump runs 12 hours per day, how many acre feet are pumped out of the well in one year?

4. A rectangular basin contains 4.45 AF of water. How many gallons are in the basin?

5. A fire hydrant is leaking at a rate of 10 ounces per minute. How many gallons will be lost in one week? (There are 128 ounces in one gallon.)

6. A pipe flows at a rate of 6.3 cfs. How many MG will flow through the pipe in 3 days?

7. A water utility operator needs to report the total water drained from two separate basins. The 18” pipe in Basin A drained water at a rate of 12.4 cfs for four hours each day. The 12” pipe in Basin B drained water at a rate of 3.1 cfs for 16 hours each day. What is the total amount of water drained in million gallons in 30 days?

8. A water utility operator while on duty drove a total of 22,841 miles in one year. What were the average miles driven per day? Assume that the vehicle operated 6 days per week.

9. Water travels 52 miles per day through an aqueduct. What is the velocity of the water in feet per second?

10. How many days will it take to fill an Olympic size swimming pool with 660,000 gallons of water if the flow rate is 150 gpm?

Exercise 1.1b

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 last 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?

1.2 APPLYING THE MATH OF THE UDA

Converting units is an everyday task in the water industry. Flow rates, hours of operation, and water sources are only part of the big picture in terms of water supply. To plan sustainable, long term groundwater and surface water supplies, it is better to have different or diverse sources of water. Pumping the lowest cost source, but typically groundwater, isn't always a sustainable solution over the long term.

Example: A water utility manager has been asked to prepare an end of year report for the utility's board of directors. The utility has two groundwater wells and one connection 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		
SW Pump	1,750	7		

In order to solve this problem, you will need to work with each well and the pump separately to calculate the total flow and then the annual flow. Let's start with Well 1.

Well 1: Total Flow in MGD

$$\frac{800\text{ gal}}{\text{min}} \times \frac{60\text{ min}}{1\text{ hr}} \times \frac{10\text{ hrs}}{1\text{ day}} = 480{,}000\frac{\text{gal}}{\text{day}} \times \frac{1\text{ MG}}{1{,}000{,}000\text{ gal}} = 0.48\text{ MGD}$$

Well 1: Annual Flow in AFY

$$\frac{480{,}000\text{ gal}}{\text{day}} \times \frac{1\text{ AF}}{325{,}851\text{ gal}} \times \frac{365\text{ day}}{1\text{ year}} = 537.7\text{ AFY}$$

These calculations are repeated for the remaining wells and pumps.

Well 2: Total Flow in MGD

$$\frac{1{,}000 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{8 \text{ hrs}}{1 \text{ day}} = 480{,}000\frac{\text{gal}}{\text{day}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 0.48 \text{ MGD}$$

Well 2: Annual Flow in AFY

$$\frac{480{,}000 \text{ gal}}{\text{day}} \times \frac{1 \text{ AF}}{325{,}851 \text{ gal}} \times \frac{365 \text{ day}}{1 \text{ year}} = 537.7 \text{ AFY}$$

SW Pump: Total Flow in MGD

$$\frac{1{,}750 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{7 \text{ hrs}}{1 \text{ day}} = 735{,}000\frac{\text{gal}}{\text{day}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 0.735 \text{ MGD}$$

Well 1: Annual Flow in AFY

$$\frac{735{,}000 \text{ gal}}{\text{day}} \times \frac{1 \text{ AF}}{325{,}851 \text{ gal}} \times \frac{365 \text{ day}}{1 \text{ year}} = 823.3 \text{ AFY}$$

Example: Using the information from the above example problem, fill in the table below.

Source of Supply	Annual Production (AFY)	Cost per AF ($/AF)	Total Annual Cost ($)
Well 1	537.7	60	$32,262
Well 2	537.7	60	$32,262
SW Pump	823.3	450	$370,485
Total Annual Cost			$435,009

To calculate the total annual cost for Well 1, multiply the AFY times the cost per acre foot.

$$\frac{537.7\ \text{AF}}{1\ \text{year}} \times \frac{\$\ 60}{1\ \text{AF}} = \$\ 32{,}262\ \text{per year}$$

Repeat this calculation for the remaining wells and pump.

$$\frac{537.7\ \text{AF}}{1\ \text{year}} \times \frac{\$\ 60}{1\ \text{AF}} = \$\ 32{,}262\ \text{per year}$$

$$\frac{823.3\ \text{AF}}{1\ \text{year}} \times \frac{\$\ 450}{1\ \text{AF}} = \$\ 370{,}485\ \text{per year}$$

The total annual cost for the water utility is determined by adding the annual cost of each well and pump.

$\$32,262 + \$32,262 + \$370,485 = \$\ 435,009$ per year

Key Terms

- **unit dimensional analysis (UDA)** – the process through which we convert units by writing all units out and looking for opportunities to convert and cancel units

Practice Problems 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 four groundwater wells and two connections to a surface water treatment plant. Complete the table below.

Source of Supply	Flow Rate (cfs)	Daily Operation (Hr)	Total Flow (MGD)	Annual Flow (AFY)
Well 1	3.2	5		
Well 2	5	10		
Well 3	1.4	12		
Well 4	2.7	18		
SW Pump 1	4.2	4		
SW Pump 2	0.5	20		

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		55	
Well 2		64	
Well 3		35	
Well 4		70	
SW Pump 1		325	
SW Pump 2		275	
Total Annual Cost			$

Exercise 1.2

1. A utility manager has been asked to prepare an end of year report for the utility's board of directors. The utility has four 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	625	7.5		
Well 2	1,122	9		
Well 3	495	15		
Well 4	2,325	8		
SW Pump 1	1,347	6		
SW Pump 2	1,400	10		

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?

UNIT 2: GEOMETRIC SHAPES

2.1 AREA

In order to transport water from the source to treatment, to the distribution system, and eventually to the customer, water flows through geometric shapes. In cross section, the aqueduct is a trapezoid. Canals are also trapezoids in cross section. The canal below transports irrigation water from the Central Valley Project to farmers within Madera County.

Figure 2.1[1]

Reservoirs and tanks store water before it enters the treatment process. The surface of a reservoir could approximate a rectangle.

[1] Photo used with permission of Stephanie Anagnoson

The shape of a tank is often a cylinder. The tank below is in Santa Clarita and placed on top of a hill in order to use elevation to create pressure.

Figure 2.2[2]

Simple residential tanks are also cylinders and sometimes have a partial sphere on the top for extra storage.

Figure 2.3[3]

[2] Photo used with permission of [SCV Water]
[3] Photo used with permission of Stephanie Anagnoson

Water flows through pipes in the treatment plant and through the distribution system. Pipes are cylindrical and used throughout water distribution systems.

Figure 2.4[4]

You can see why geometric shapes are important in the water industry both in terms of area and in terms of volume.

To solve these problems correctly, you will need to apply what you already know about the Order of Operations:

Step 1: Complete anything in parentheses.

Step 2: Complete all exponents.

Step 3: Complete all multiplication and division from left to right.

Step 4: Complete all addition and subtraction from left to right.

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.

[4] Photo used with permission of SCV Water

Circles

A **circle** is a round figure whose boundary is an equal distance from the center. The distance around the circle is the **circumference.** The **diameter** is the distance across the circle through the center. The **radius** is the distance from the center to the edge of the circle.

To calculate the area of a circle, square the diameter and then multiply by 0.785. This means multiply the diameter times the diameter and then multiply the product by 0.785. This follows the Order of Operations in which exponents are worked out before multiplication and division. If you recall from the Water 130 course, we use 0.785 in the "area" formula rather than the more typical formula you probably learned in high school.

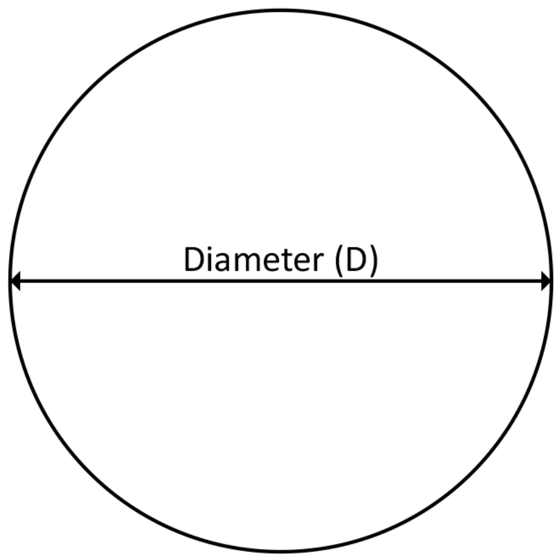


Figure 2.5[5]

$\text{Area} = \pi r^2$ or $\text{Area} = 0.785 \times D^2$

If we compare the two formulas, you can see that 0.785 replaces Pi and the diameter replaces radius. The diameter squared is four times greater than radius squared and 0.785 is one fourth of Pi.

Let's look at why these formulas and equations are both correct.

$\text{Area} = \pi r^2$ and $r = \dfrac{D}{2}$ where r is the radius and D is the diameter.

Now substitute D/2 into the Area formula for r.

[5] Image by Marilyn Hightower is licensed under CC BY 4.0

$$\text{Area} = \pi\left(\frac{D}{2}\right)^2 = \frac{\pi D^2}{4}$$

To simplify the equation, divide the number pi by 4.

$$\text{Area} = \frac{\pi D^2}{4} = \frac{\pi}{4} \times D^2 = 0.785 \times D^2$$

Pin It! Misconception Alert
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.

Example: What is the area of a 24" diameter pipe?

When the diameter is provided in inches, it is easiest to convert the inches to feet first and then solve for area.

$$\frac{24\ \cancel{\text{in}}}{1} \times \frac{1\text{ ft}}{12\ \cancel{\text{in}}} = 2\text{ ft}$$

Now calculate the area.

$$\text{Area} = 0.785 \times D^2 = 0.785 \times (2\text{ ft})^2 = 0.785 \times 4\text{ ft}^2 = 3.14\text{ ft}^2$$

Example: What is the area of a 130" diameter pipe?

When the diameter is provided in inches, it is easiest to convert the inches to feet first and then solve for area.

$$\frac{130\text{ in}}{1} \times \frac{1\text{ ft}}{12\text{ in}} = 10.8\text{ ft}$$

Now calculate the area.

$$0.785 \times (10.8\text{ ft})^2 = 0.785 \times 116.64\text{ ft}^2 = 91.56\text{ ft}^2$$

Example: What is the area of an 813 mm diameter pipe?

Measurements may be provided in either standard or metric units. In either case, convert to feet and then solve for area. Note that there are 304.8 mm in 1 foot.

$$\frac{813 \text{ mm}}{1} \times \frac{1 \text{ ft}}{304.8 \text{ mm}} = 2.67 \text{ ft}$$

Now calculate the area.

$$0.785 \times (2.67 \text{ ft})^2 = 0.785 \times 7.1289 \text{ ft}^2 = 5.60 \text{ ft}^2$$

Rectangles

A **rectangle** is a four-sided shape with four right (90 degree) angles. A **square** is a type of rectangle with four sides that are the same length. 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.

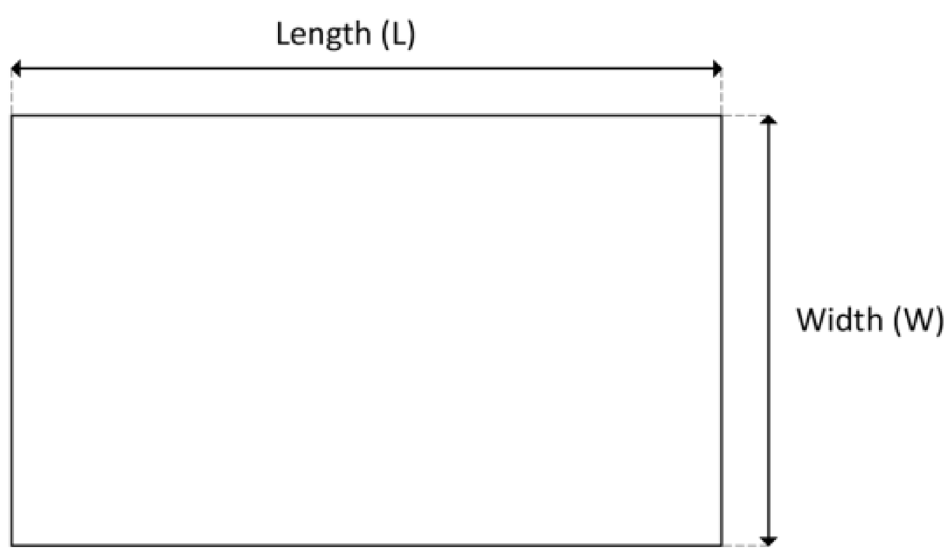


Figure 2.6[6]

$$\text{Area of a Rectangle} = \text{L} \times \text{W}$$

[6] Image by Marilyn Hightower is licensed under CC BY 4.0

Example: What is the area of a rectangle that is 30’ long and 10’ wide?

Since both measurements are provided in units of feet, you can calculate the area directly.

$$30 \text{ ft} \times 10 \text{ ft} = 300 \text{ ft}^2$$

Example: What is the area of a rectangle that has a height of 15’ and a width of 7”?

Since the height is provided in feet and the width is provided in inches, you need to convert inches to feet before you calculate the area.

$$\frac{7\ \cancel{\text{in}}}{1} \times \frac{1 \text{ ft}}{12\ \cancel{\text{in}}} = 0.5833 \text{ ft}$$

$$15 \text{ ft} \times 0.5833 \text{ ft} = 8.75 \text{ ft}^2$$

Trapezoids

Trapezoids are four-sided shapes with one set of parallel sides. Aqueducts are commonly a trapezoid in cross section with a parallel top and bottom called bases. Aqueducts have narrow flat bottoms and wider flat tops at the water level. 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.

Figure 2.7: Public Domain from U.S.G.S. of California Aqueduct through the Central Valley transporting water from Northern California to Southern California[7]

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.

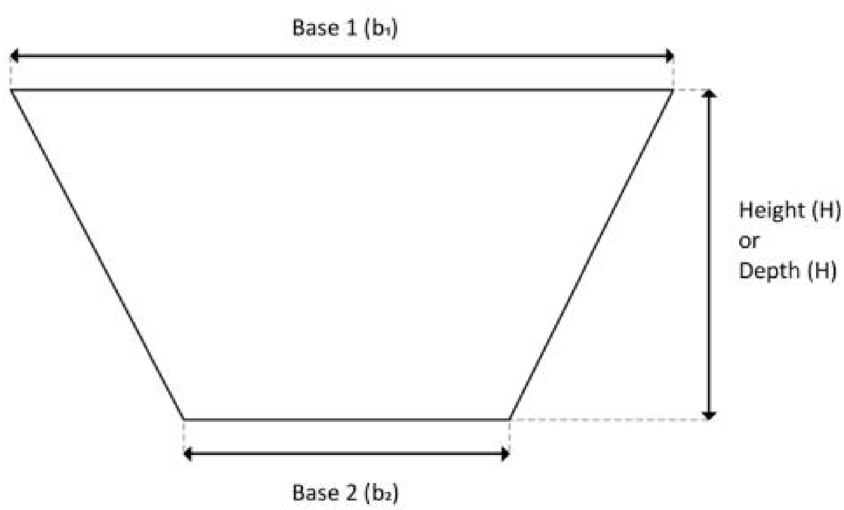


Figure 2.8[8]

$$\text{Area of a Trapezoid} = \frac{b_1 + b_2}{2} \times H$$

[7] Image by the USGS is in the public domain
[8] Image by Marilyn Hightower is licensed under CC BY 4.0

Example: What is the area of a cross section of an aqueduct that is 5 feet across the bottom, 7 feet across the top and 6 feet deep?

$$\text{Area of a Trapezoid} = \frac{b_1 + b_2}{2} \times H$$

$$\text{Area of a Trapezoid} = \frac{5\text{ ft} + 7\text{ ft}}{2} \times 6\text{ ft} =$$

$$\left(\frac{12\text{ ft}}{2}\right)(6\text{ ft}) = (6\text{ ft})(6\text{ ft}) = 36\text{ ft}^2$$

Example: What is the area of a cross section of an aqueduct that is 8 feet across the bottom, 12 feet across the top and 10 feet deep?

$$\text{Area of a Trapezoid} = \frac{b_1 + b_2}{2} \times H$$

$$\text{Area of a Trapezoid} = \frac{8\text{ ft} + 12\text{ ft}}{2} \times 10\text{ ft} =$$

$$\left(\frac{20\text{ ft}}{2}\right)(10\text{ ft}) = (10\text{ ft})(10\text{ ft}) = 100\text{ ft}^2$$

Surface Area

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 flat areas. 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.

Cylinder

The circumference is the distance around a circle. The circumference is importance in waterworks mathematics as it is used to calculate the surface area of the side of a cylinder or tank. This is especially helpful when painting or coating a tank. The picture below shows a cylinder and the surface area of a cylinder.

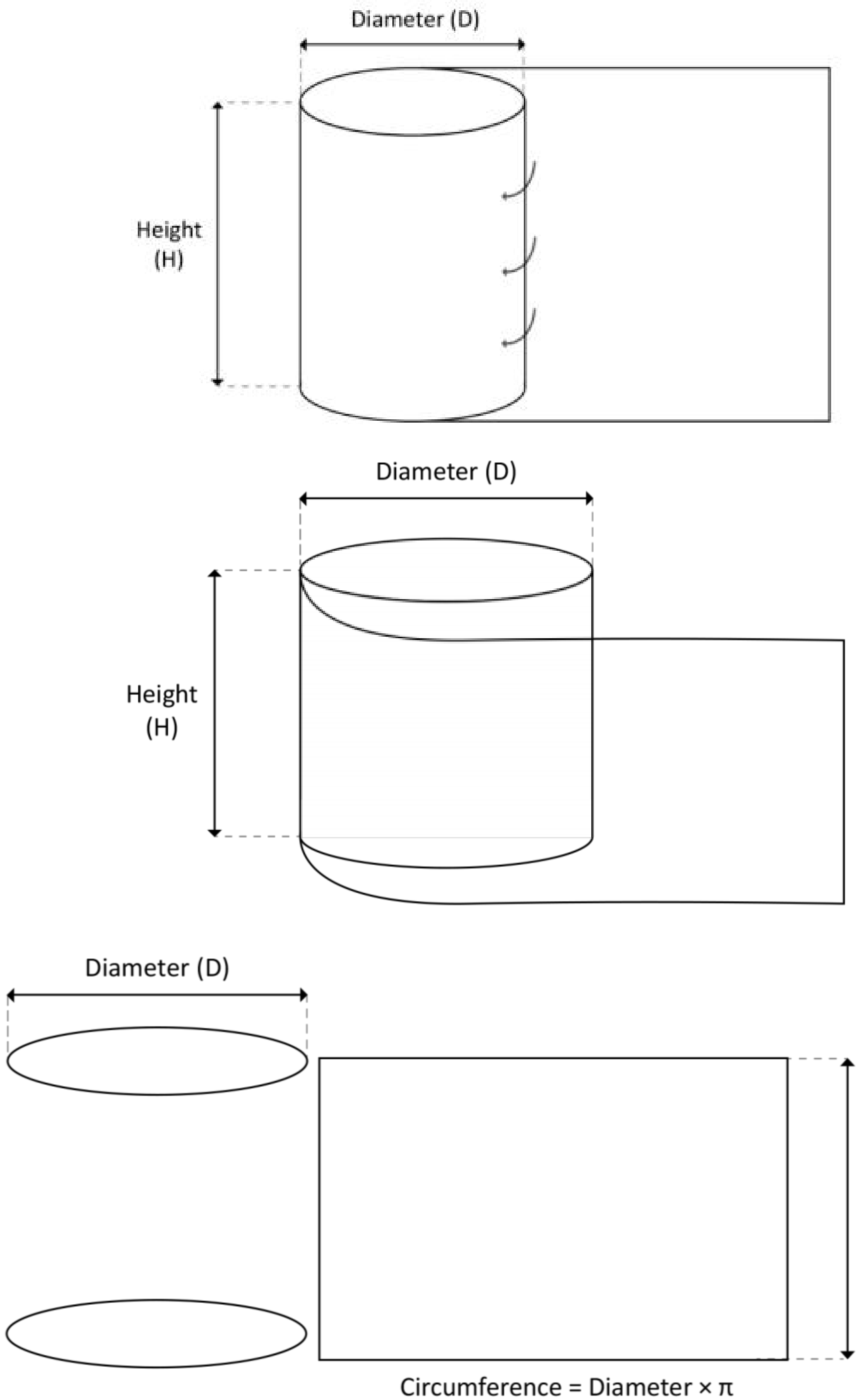


Figure 2.9[9]

Circumference of a Circle = π × D

[9] Image by Marilyn Hightower is licensed under [CC BY 4.0]

The circumference can also be looked at as the "length" around a cylinder. To calculate the circumference requires the unitless constant, Pi, which is typically represented as the number 3.14.

If you "slice" open a cylinder and unwrap it, it becomes a rectangle as shown in the above image. The length of this rectangle is the circumference of the cylinder. In order to calculate the surface area of a cylinder, multiply the height or depth of the cylinder by the circumference.

$$\text{Surface Area of a Cylinder} = H \times \pi \times D$$

Height or depth may be used interchangeably in the surface area calculation and are dependent on your perspective.

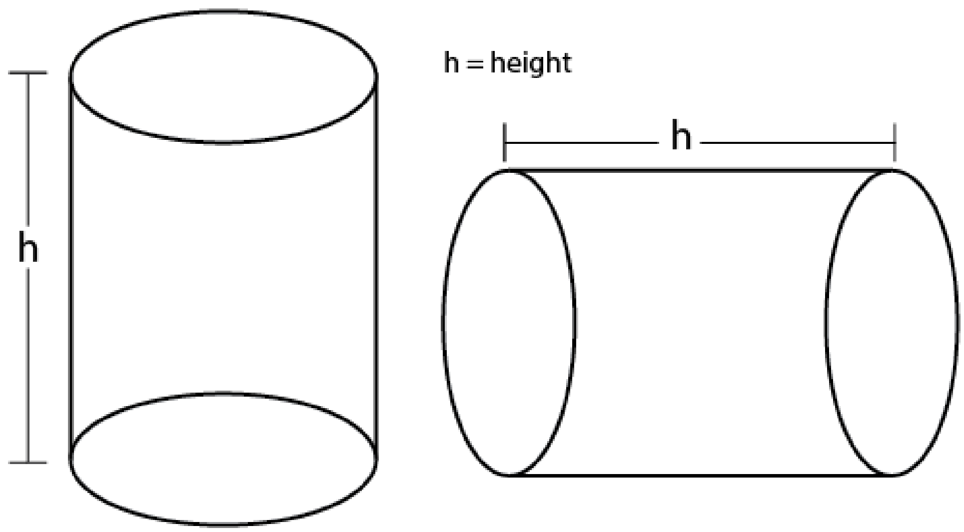


Figure 2.10[10]

Example: What is the surface area of the wall of a 20 ft tall tank with a 100 ft diameter?

$$\text{Circumference of a Circle} = \pi \times D =$$
$$3.14 \times 20\text{ ft} = 62.8\text{ ft}$$
$$\text{Surface Area} = 62.8\text{ ft} \times 100\text{ ft} = 6{,}280\text{ ft}^2$$

Sphere

A **sphere** is a three-dimensional solid whose surface is made up of points all the same distance from a center. It is commonly thought to be shaped like a tennis ball. The surface area of a sphere is the entire surface area of a "ball." Spheres can be commonplace in flat areas, such as California's Central Valley, as elevated storage structures.

[10] Image by Marilyn Hightower is licensed under CC BY 4.0

The formula for the area of a sphere is:

$$\text{Surface Area of a Sphere} = 4 \times 0.785 \times D^2$$ Where D is the diameter of the sphere.

Example: What is the surface area of a sphere with a 50 ft diameter?

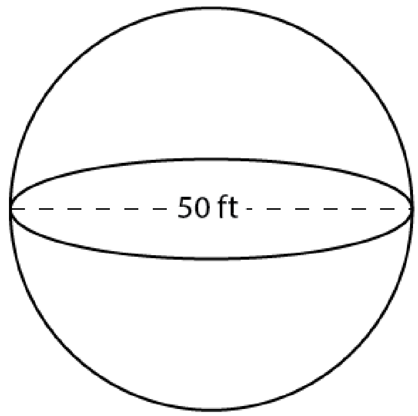


Figure 2.11[11]

$$\text{Surface Area of a Sphere} = 4 \times 0.785 \times D^2$$

$$\text{Surface Area of a Sphere} = 4 \times 0.785 \times (50\text{ ft})^2 = 7{,}850\text{ ft}^2$$

Example: What is the surface area of a sphere with a diameter of 35 ft?

$$\text{Surface Area of a Sphere} = 4 \times 0.785 \times D^2$$

$$4 \times 0.785 \times (35\text{ ft})^2 = 3{,}846.5\text{ ft}^2 = 3{,}847\text{ ft}^2$$

Some of these shapes may be combined in practical applications. You may see a cylinder with a sphere on top for example or a myriad of other combinations.

[11] Image by Marilyn Hightower is licensed under CC BY 4.0

Figure 2.12[12]

Figure 2.13[13]

[12] Image by the USGS is in the public domain
[13] Image by the USGS is in the public domain

Example: What is the entire interior surface area of a 350-foot-long, 20-inch diameter pipe that is capped with half of a sphere. The sphere is not included in the length of the pipe.

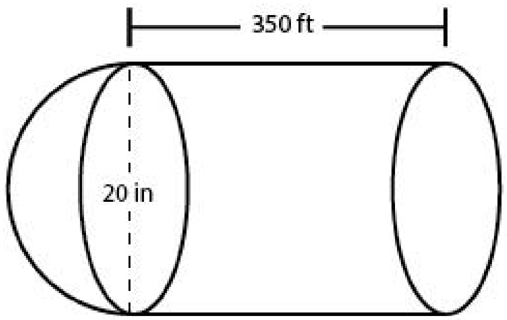


Figure 2.14[14]

First convert inches to feet:

$$\frac{20\ \cancel{in}}{1} \times \frac{1\ ft}{12\ \cancel{in}} = 1.67\ ft$$

Now we can calculate the surface area of the interior of the pipe. Remember that when you unroll a cylinder, you end up with a rectangle. The length of one side of the rectangle is the circumference of the pipe or cylinder.

$$\text{Circumference} = \pi \times D$$

$$\text{Circumference} = 3.14 \times 1.67\ ft = 5.2438\ ft$$

Using the circumference, you can calculate the surface area of the interior of the pipe.

$$\text{Surface Area} = L \times W$$

$$\text{Surface Area} = 350\ ft \times 5.2438\ ft = 1{,}835.33\ ft^2$$

Now we will calculate the surface area of the interior of half of the sphere.

$$\text{Surface Area of a Sphere} = 4 \times 0.785 \times D^2$$

$$\text{Surface Area of a Sphere} = 4 \times 0.785 \times (1.67\ ft)^2$$

$$\text{Surface Area of a Sphere} = 4 \times 0.785 \times 2.7889\ ft^2 = 8.757146\ ft^2$$

[14] Image by Marilyn Hightower is licensed under CC BY 4.0

Since only half a sphere is capping the pipe, we need to divide the total surface area by two to get the actual area for this problem.

$$\text{Half the Surface Area} = \frac{8.757146\ \text{ft}^2}{2} = 4.378573\ \text{ft}^2 = 4.38\ \text{ft}^2$$

The entire interior surface area is the sum of the pipe surface area and the surface area of the half sphere.

$$\text{Total Area} = 1{,}835.33\ \text{ft}^2 + 4.38\ \text{ft}^2 = 1{,}839.71\ \text{ft}^2$$

Practice Problems 2.1

1. What is the area of the opening of a 21” diameter pipe?

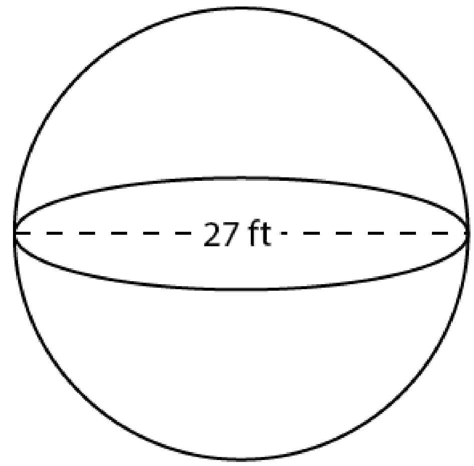
2. What is the cross-sectional area of a rectangular channel that has a width of 5 feet 8 inches and a height of 8 feet 5 inches?

3. A trapezoidal channel is 12 feet wide at the bottom and 22 feet wide at the water line when the water is 7 feet deep. What is the cross-sectional area of the channel?

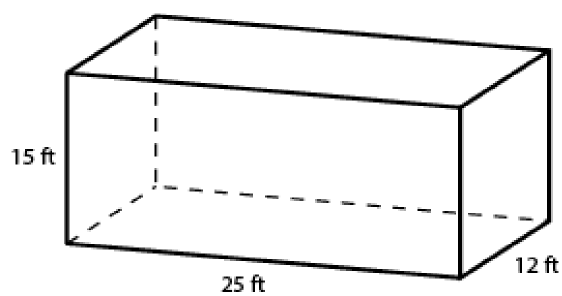
4. A 35-foot diameter spherical tank needs to be painted. If one gallon of paint will cover 400 sf, how many gallons of paint will be required to put two coats of paint on the exterior of the tank?

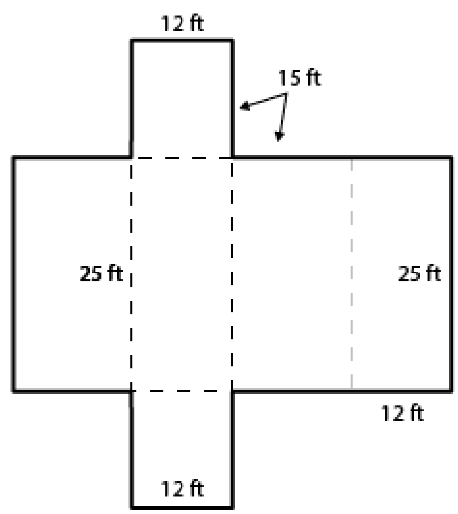
5. What is the surface area of a 45-foot tall standpipe with a diameter of 20 feet?

6. What is the surface area of a 27-foot diameter sphere?

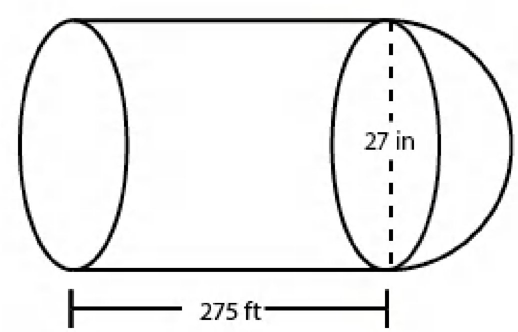


7. The inside of a rectangular structure measuring 15 feet tall by 25 feet long by 12 feet wide needs painting. What is the total surface area? Include all six interior surfaces.





8. What is the entire interior surface area of a 275 foot long, 27 inch diameter pipe that is capped with half of a sphere? The sphere is not included in the length of the pipe.



Exercise 2.1

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 trapezoidal-shaped 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 a cross section of the channel?

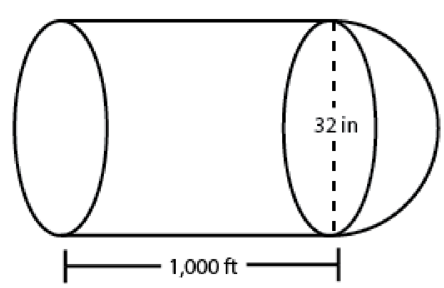
4. An elevated storage tank is shaped like a sphere and needs to be recoated. If the diameter of the tank is 65 feet, what is the surface area?

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

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)



2.2 VOLUMES

To calculate the volume inside a structure, a third dimension needs to be included in the "area" formula. For example, if a circle (a two-dimensional object) becomes part of a cylinder (a three-dimensional object), a volume can be calculated using the height.

Cylinder

A **cylinder** is a three-dimensional solid with circular bases and parallel sides. The formula for volume of a cylinder uses the area formula for a circle with the addition of a third dimension. Notice that a cylinder can have either a length or a height depending on your perspective. In fact, all three-dimensional structures can have a depth or a height.

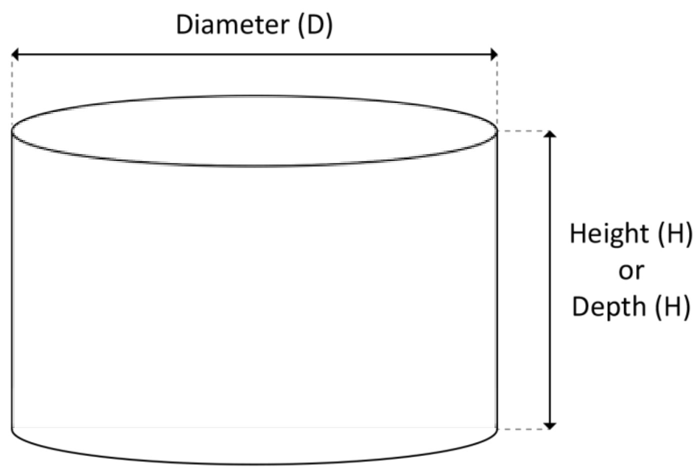


Figure 2.15

$$\text{Volume of a Cylinder} = 0.785 \times D^2 \times H$$

Example: What is the volume of a cylindrical tank that has an 80" diameter and is 30 feet tall?

$$\text{Volume of a Cylinder} = 0.785 \times D^2 \times H$$

Notice that the diameter of the tank is in inches. First, we need to convert the units for the diameter from inches to feet.

$$\frac{80\ \cancel{\text{in}}}{1} \times \frac{1\ \text{ft}}{12\ \cancel{\text{in}}} = 6.67\ \text{ft}$$

Then, calculate the volume of the tank.

$$\text{Volume of a Cylinder} = 0.785 \times (6.67\text{ ft})^2 \times 30\text{ ft} = 1{,}047.713595\text{ ft}^3 = 1{,}047.7\text{ ft}^3$$

Rectangular Prism

A **prism** is a three-dimensional solid with two bases that are the same size and shape polygons. A **rectangular prism** has bases that are rectangles.

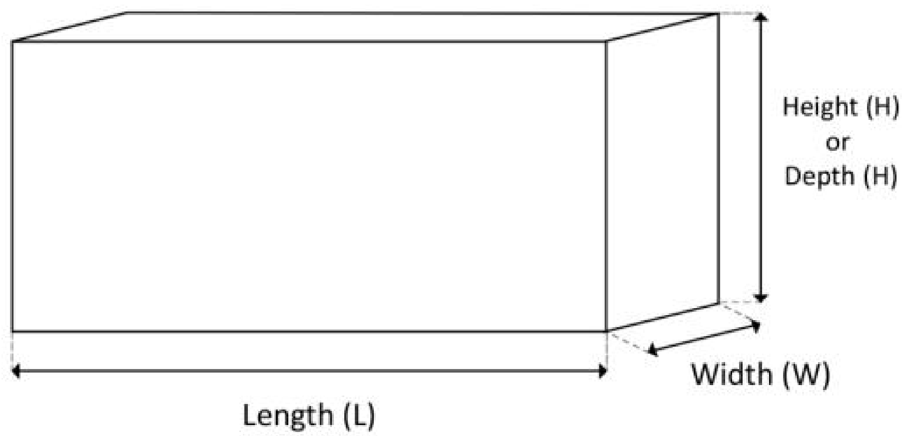


Figure 2.16[15]

$$\text{Volume of a Rectangular Prism} = L \times W \times H$$

Example: A rectangular basin is 225 feet long, 37 feet wide, and has a depth of 45 feet. How much water can the basin hold?

$$\text{Volume of a Rectangular Prism} = L \times W \times H$$

$$\text{Volume of a Rectangular Prism} = 225\text{ ft} \times 37\text{ ft} \times 45\text{ ft} = 374{,}625\text{ ft}^3$$

Note that the question is asking how much water will fit in the basin. You need to convert cubic feet to gallons in order to answer the question.

$$\frac{374{,}625\text{ ft}^3}{1} \times \frac{7.48\text{ gal}}{\text{ft}^3} = 2{,}802{,}195\text{ gal}$$

$$2{,}802{,}195\text{ gal} \times \frac{1\text{ MG}}{1{,}000{,}000\text{ gal}} = 2.8\text{ MG}$$

Note that 2.802195 MG rounds to 2.8 MG.

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Trapezoidal Prism

A **trapezoidal prism** is a prism with bases that are trapezoids.

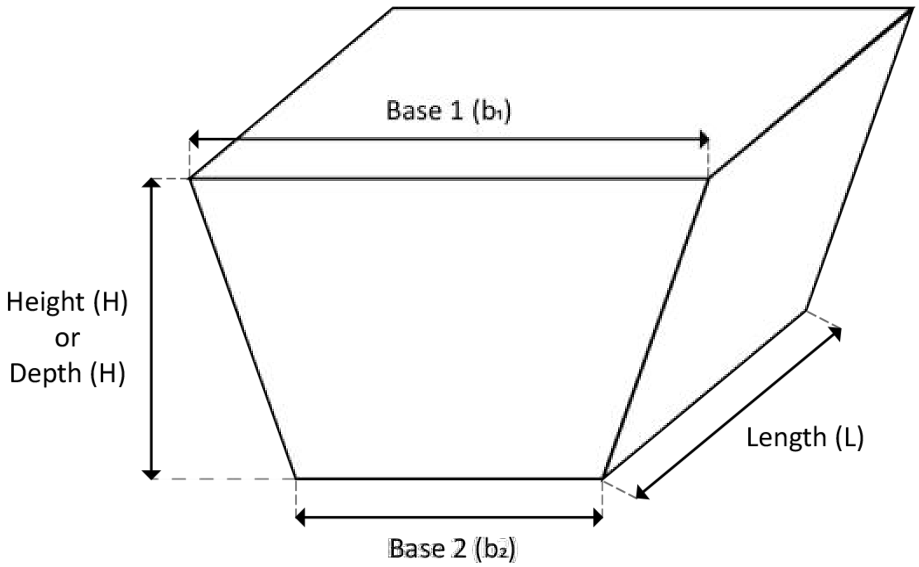


Figure 2.17[16]

$$\text{Volume of a Trapezoidal Prism} = \frac{b_1 + b_2}{2} \times H \times L$$

Example: The width across the bottom of an aqueduct measures 8 feet 6 inches. The width across the water level measures 14 feet 8 inches and the water is 10 feet deep. The aqueduct extends for 8,475 feet. How much water is in the aqueduct?

$$\text{Volume of a Trapezoidal Prism} = \frac{b_1 + b_2}{2} \times H \times L$$

First, we need to convert all of the measurements to feet.

$$8\text{ ft }6\text{ in} = 8\text{ ft} + \left(6\text{ in} \times \frac{1\text{ ft}}{12\text{ in}}\right) = 8\text{ ft} + 0.5\text{ ft} = 8.5\text{ ft}$$

$$14\text{ ft }8\text{ in} = 14\text{ ft} + \left(8\text{ in} \times \frac{1\text{ ft}}{12\text{ in}}\right) = 14\text{ ft} + 0.667\text{ ft} = 14.667\text{ ft}$$

Now we can calculate the volume of the aqueduct.

[16] Image by Marilyn Hightower is licensed under CC BY 4.0

$$\text{Trapezoidal Prism} = \frac{b_1 + b_2}{2} \times H \times L$$

$$\text{Trapezoidal Prism} = \frac{8.5\text{ ft} + 14.67\text{ ft}}{2} \times 10\text{ ft} \times 8{,}475\text{ ft} = 981{,}828.75\text{ ft}^3$$

Note that the question is asking how much water is in the aqueduct. You need to convert cubic feet to gallons in order to answer the question.

$$\frac{981{,}828.75\text{ ft}^3}{1} \times \frac{7.48\text{ gal}}{\text{ft}^3} = 7{,}344{,}079.05\text{ gal} = 7.3\text{ MG}$$

Sphere

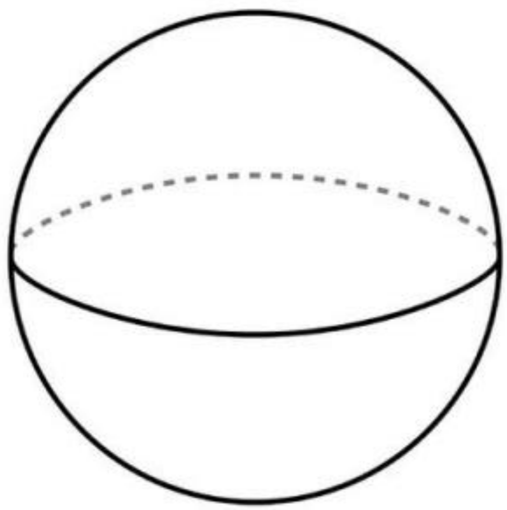


Figure 2.18[17]

$$\text{Volume of a Sphere} = \frac{\pi D^3}{6}$$ Where D is the diameter of the sphere.

Example: How many gallons of water can a 20-foot diameter spherical tank hold?

$$\text{Volume of a Sphere} = \frac{\pi D^3}{6}$$

$$\text{Volume} = \frac{\pi(20\text{ ft})^3}{6} = \frac{3.14(8{,}000\text{ ft}^3)}{6} =$$

[17] Image by Marilyn Hightower is licensed under CC BY 4.0

$$\text{Volume} = \frac{25{,}120 \text{ ft}^3}{6} = 4{,}187 \text{ ft}^3$$

You have found the volume of the sphere. However, the question is asking how many gallons of water can the sphere hold? To calculate the volume in gallons, convert cubic feet to gallons. Both units are units of volume.

$$\text{Volume} = 4{,}187 \text{ ft}^3 \times \frac{7.48 \text{ gal}}{1 \text{ cf}} = 31{,}319 \text{ gal}$$

Practice Problems 2.2

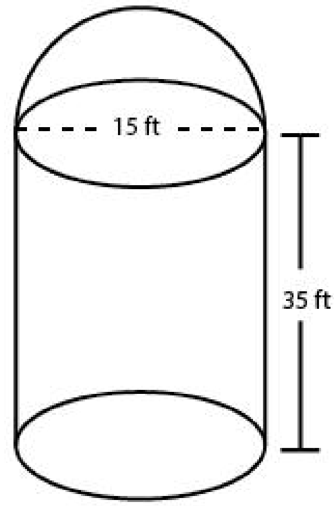
1. What is the volume of a 52-foot diameter sphere?

2. What is the volume of a 36" diameter pipe that is 1,500 feet long?

3. A half-full aqueduct is 10 miles long. It is 15 feet wide at the bottom, 24 feet wide at the top, and 25 feet tall. How many acre feet of water are in the aqueduct?

4. A sedimentation basin is 110 feet long, 40 feet wide, and 30 feet deep. How much water can it hold in million gallons?

5. A 35-foot tall cylinder with a 15-foot diameter is topped with a half sphere. How many gallons will it hold?



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 cylinder is 80 feet tall and has a 25-foot diameter. The cylinder is topped with a half sphere. How many gallons will it hold?

2.3 AREA AND VOLUME WORD PROBLEMS

Water structures and components are often made up of multiple geometric shapes. An operator may need to determine the volume of water within a tank that sits on top of a tall pipe. 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. You might be asked to paint the interior walls of a room.

When solving word problems, there is always a specific question that must be answered. Identifying that question or problem is critical in solving the problem. Then you need to be able to pull out the information in the question needed to solve for the answer. Remember that the question may have extra information that is not needed to solve for what is being asked.

Use these steps to solve word problems.

> **Step 1:** Read and understand the problem to determine what is being asked. Know what you are trying to solve for.
>
> **Step 2:** Identify the information you need. You may want to underline key parts or circle units.
>
> **Step 3:** Make a sketch to clarify the information. This step works well in geometric problems when you are trying to solve for missing dimensions, but you may find other times when it is helpful to make a quick sketch.
>
> **Step 4:** Put the information into an equation or formula. Using a reference sheet for formulas is often key in this step. Make sure you copied the formula correctly!
>
> **Step 5:** Solve and double check your answer. Does the solution make sense? If your solution does not make sense, read the problem again.

Figure 2.19[18]

Example: 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 (as seen above)? (Assume the trench will be backfilled up to 6 inches from the ground surface.)

Step 1: What is being asked in this problem?
How many cubic yards of dirt are needed to backfill the trench?

Step 2: Identify the information you need.
You need to know the size/volume of the trench and the size/volume of the pipe being placed in the trench in order to compute the total amount of dirt required to backfill the trench once the pipe has been installed.

Step 3: Make a sketch to clarify the information.

[18] Photo used with permission of SCV Water

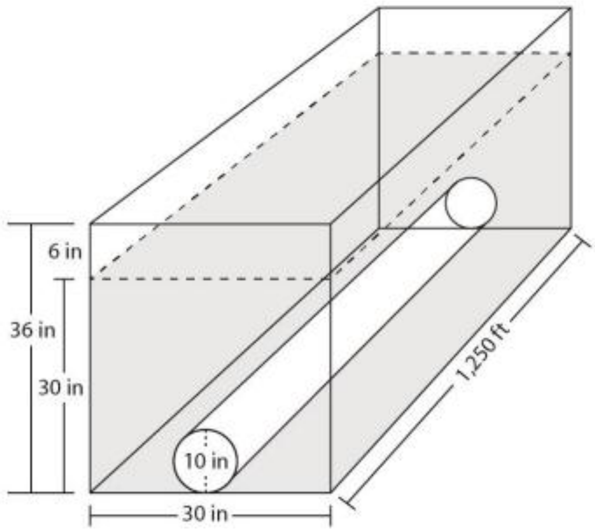


Figure 2.20[19]

Step 4: Put the information into an equation or formula. Solve.

Calculate the volume of the trench to the backfill height in cubic feet.

The height of the trench is 36 inches and the backfill is required up to 6 inches from the top of the trench. Therefore, the backfill will be at 30 inches (36" – 6" = 30"). Note that the width of the trench is also 30 inches.

$$\frac{30\ \cancel{in}}{1} \times \frac{1\ ft}{12\ \cancel{in}} = 2.5\ ft$$

$$\text{Volume of the trench at backfill height} = 2.5\ ft \times 2.5\ ft \times 1{,}250\ ft = 7{,}812.5\ ft^3$$

Calculate the volume of the pipe in cubic feet.

$$\frac{10\ \cancel{in}}{1} \times \frac{1\ ft}{12\ \cancel{in}} = 0.8333\ ft$$

$$\text{Volume of the pipe} = 0.785 \times (0.8333\ ft)^2 \times 1{,}250\ ft = 681.42\ ft^3$$

The total volume of back fill required in cubic feet is the difference between the backfill trench volume and the pipe volume.

$$7{,}812.5\ ft^3 - 681.42\ ft^3 = 7{,}131.08\ ft^3$$

[19] Image by Marilyn Hightower is licensed under CC BY 4.0

Now convert the cubic feet to cubic yards to determine how many cubic yards of dirt are required to backfill the trench.

$$7{,}131.08\ \text{ft}^3 \times \frac{1\ \text{yd}^3}{27\ \text{ft}^3} = 264.1\ \text{yd}^3$$

Step 5: Solve and double check your answer. Does the solution make sense?

You can make sure that the answer is in cubic yards as the question was asking for an answer in cubic yards.

Note that when converting from cubic feet to cubic yards, there should be fewer cubic yards than cubic feet. This is because a cubic yard is larger than a cubic foot.

Currently, you may not have any idea if approximately 264 cubic yards makes sense as a solution to this problem or not. However, as you gain experience as an operator, you can work on developing a better sense of scale related to the various units frequently used.

Example: In the above example, 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?

Step 1: What is being asked in this problem?
The problem is asking how many cubic feet of aggregate base are needed to fill the trench on top of the dirt backfill.

Step 2: Identify the information you need.
You need to know the size/volume of the trench that still needs to be filled with aggregate base.

Step 3: Make a sketch to clarify the information.

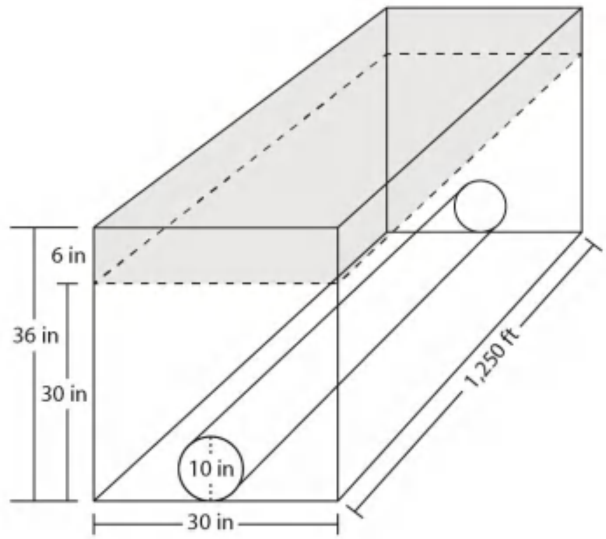


Figure 2.21[20]

Step 4/5: Put the information into an equation or formula. Solve.

Option #1: One way to solve this problem is to determine the difference between the entire volume of the trench and the volume of the trench at the dirt backfill height since the original problem stated that the backfill height is 6 in from the top of the trench.

The volume of the trench to the backfill height in cubic feet was previously calculated.

$$\text{Volume of the trench at backfill height } = 2.5 \text{ ft} \times 2.5 \text{ ft} \times 1{,}250 \text{ ft} = 7{,}812.5 \text{ ft}^3$$

Calculate the volume of the entire trench in cubic feet.

$$\frac{36 \cancel{\text{in}}}{1} \times \frac{1 \text{ ft}}{12 \cancel{\text{in}}} = 3 \text{ ft}$$

$$\text{Volume of the trench at backfill height } = 2.5 \text{ ft} \times 3 \text{ ft} \times 1{,}250 \text{ ft} = 9{,}375 \text{ ft}^3$$

The difference between these is the total cubic feet of aggregate base required to fill the trench in cubic feet.

$$9{,}375 \text{ ft}^3 - 7{,}812.5 \text{ ft}^3 = 1{,}562.5 \text{ ft}^3$$

[20] Image by Marilyn Hightower is licensed under CC BY 4.0

Option #2: The other way to approach the solution to this problem is to directly calculate the amount of aggregate base. The problem statement indicates that 6 inches of aggregate base are needed.

The volume of aggregate base is then calculated as follows.

$$\frac{6\ \cancel{in}}{1} \times \frac{1\ ft}{12\ \cancel{in}} = 0.5\ ft$$

$$\text{Volume of the aggregate base} = 0.5\ ft \times 2.5\ ft \times 1{,}250\ ft = 1{,}562.5\ ft^3$$

Step 5: Solve and double check your answer. Does the solution make sense?

First check to make sure your solution is in the correct units, which are the units being requested in the problem. In this case, our answer is in cubic feet and the problem statement is asking for cubic feet.

Both ways of approaching the problem provide the correct answer. Choose the approach that seems most logical to you.

Sometimes you many need to solve multiple smaller problems to find what is being asked. Multiple shapes may be combined to create other system fixtures. In this image, you can see a large tank built on top of a pipe.

Figure 2.22[21]

When looking at a problem that contains an unfamiliar shape, the best approach is to divide the shape into smaller, more common shapes like rectangles, circles, or semi-circles. You can compute areas, volumes, etc. for these more common shapes and then add it all together to get the solution for the entire shape.

Example: A water storage tank is shaped like a "pill" with a cylinder and half of a sphere on each end. Each end has a 22-foot diameter and the center section is 15 feet long. How much water in gallons, can be stored in this tank?

Step 1: What is being asked in this problem?
The volume of water in gallons that can be stored in the tank.

Step 2: Identify the information you need.
You need to know the volume of the tank.

[21] Image by J. Nguyen~commonswiki is licensed under CC BY-SA 3.0

Step 3: Make a sketch to clarify the information.

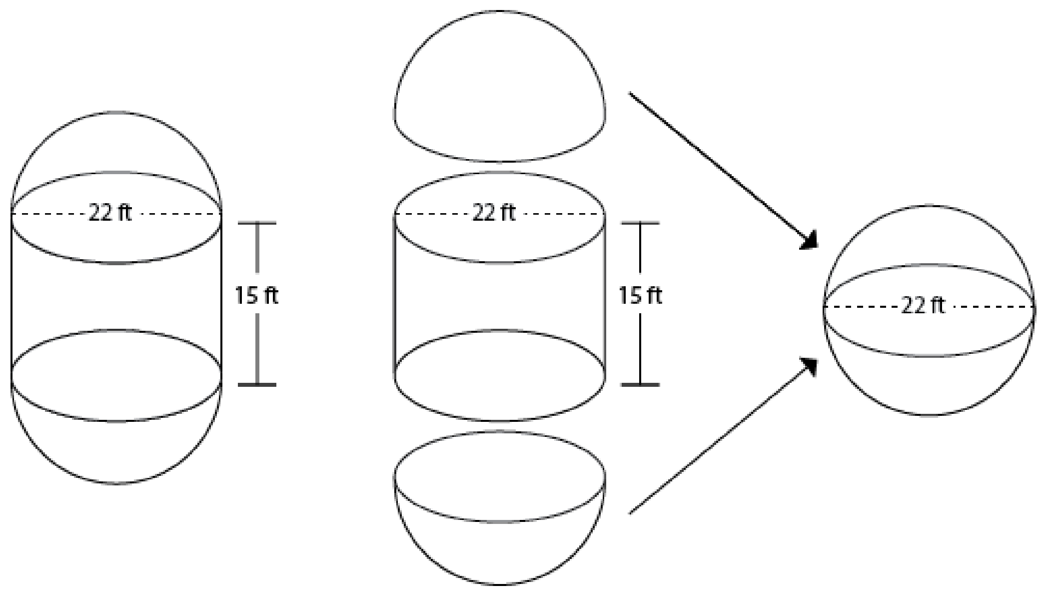


Figure 2.23[22]

Step 4: Put the information into an equation or formula. Solve.

To calculate the volume of the tank, you need to break the tank down into more common shapes. Each end of the tank is an identical half sphere with a 22-foot diameter. Put together, they combine to form a whole sphere with a 22-foot diameter. The center part of the tank is a cylinder with a diameter of 22 feet and a height or length of 15 feet.

Let's calculate the volume of the sphere first. (You can calculate either volume first).

$$\text{Volume of a Sphere} = \frac{\pi D^3}{6}$$

$$\text{Volume} = \frac{\pi(22\text{ ft})^3}{6} = \frac{3.14(10{,}648\text{ ft}^3)}{6} =$$

$$\text{Volume} = \frac{33{,}434.72\text{ ft}^3}{6} = 5{,}572.45\text{ ft}^3$$

[22] Image by Marilyn Hightower is licensed under CC BY 4.0

Calculate the volume of the cylinder in cubic feet.

$$\text{Volume of the cylinder} = 0.785 \times (22\text{ ft})^2 \times 15\text{ ft} = 5{,}699.1\text{ ft}^3$$

To calculate the total volume in the tank in cubic feet add the volume of the sphere to the volume of the cylinder.

$$5{,}572.45\text{ ft}^3 + 5{,}699.1\text{ ft}^3 = 11{,}271.55\text{ ft}^3$$

Now convert the cubic feet to gallons to determine how many gallons of water the tank can hold.

$$11{,}271.55\text{ ft}^3 \times \frac{7.48\text{ gal}}{1\text{ ft}^3} = 84{,}311.2\text{ gal}$$

Step 5: Solve and double check your answer. Does the solution make sense?

You can make sure that the answer is in gallons as the question was asking for an answer in gallons.

Note that when converting from cubic feet to gallons, there should be significantly more gallons than cubic feet. This is because there are more than 7 gallons in every cubic foot.

Practice Problems 2.3

1. A water utility operator needs to determine the cost of painting an above ground storage tank. The tank is 50 feet tall and has a diameter of 28 feet. One gallon of paint can cover 200 sf and costs $36.27 per gallon. What is the total cost to paint the storage tank?

2. A local amusement park requires a 0.5 MG storage tank. If the diameter of the tank is 55 feet, how tall will the tank need to be in order to store the 4.2 MG?

3. How many gallons of water are in a 32-foot diameter storage tank that sits on a 15-foot diameter, 45 foot tall pipe?

4. A water tank truck delivered 30 loads of water to a construction site. The water tank on the truck is shaped like a pill. Each end has a 10-foot diameter and the center section is 15 feet long. If the water costs $352 an AF, how much did the construction site pay for the water?

5. A maintenance crew is replacing an 18" meter at a pump. The specifications state that there needs to be 6.5 times the pipe diameter in feet of straight pipe before the meter and 4 times the pipe diameter in feet of straight pipe after the meter. How many feet of 18" pipe are needed?

6. A 1,200-foot section of a trapezoidal shaped aqueduct needs to be drained for maintenance. The aqueduct contains 5 AF of water, is 8 feet wide at the bottom, and is 14 feet wide at the water line. What is the water depth?

7. A water utility has installed 900 feet of 28" diameter pipe. They want to wrap a corrosion resistant sleeve around the pipe and fill the pipe to pressure test it. How many gallons of water will the pipe hold and how many square feet of corrosion resistant sleeve are required to cover the whole pipe?

8. Which of the following tanks will provide storage for 50,000 gallons of water?
    a. A spherical tank with a 20-foot diameter.
    b. A rectangular tank that is 20 feet by 30 feet by 12 feet

Exercise 2.3

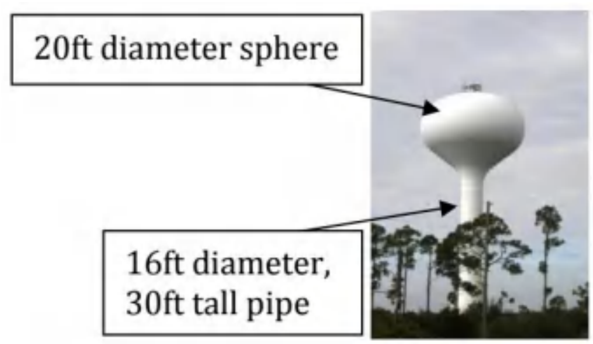
1. A water utility operator needs to determine how many gallons of paint are needed to paint the outside of an above ground storage tank and the cost of the paint. The tank has a 120-foot diameter and is 32 feet tall. (Assume that one gallon of paint can cover 125 ft^2 and costs $25.75 per gallon.)

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?

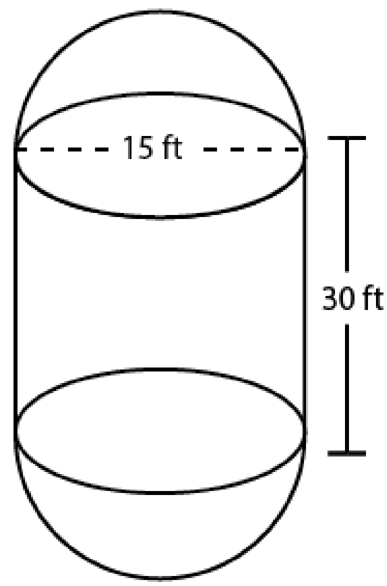
3. A construction crew will be installing 2,500 feet of 18-inch diameter pipe. The width of the trench will be 40 inches and the depth 45 inches. After the pipe has been installed, how many cubic yards of dirt will be needed to backfill the trench? (Assume the trench will be backfilled up to 8 inches from the ground surface.)

4. In the above problem, the construction crew also needs to place an aggregate base on top of the dirt fill in order to completely fill the trench. 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. 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. They want to wrap a corrosion resistant sleeve around the pipe and fill the pipe to pressure test it. How many gallons of water will the pipe hold and how many square feet of corrosion resistant sleeve are required to cover the whole pipe?

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?

2.4 FLOW RATE

Flow rate is the measurement of a volume of liquid that passes through a given cross-sectional area (i.e., pipe) per unit in time.

$$\text{Flow Rate} = \frac{\text{Volume}}{\text{Time}}$$

In the waterworks industry, flow rates are expressed in several different units. The most common ones are shown below.

$$\text{cfs} = \frac{\text{cubic feet}}{\text{sec}} \qquad \text{gpm} = \frac{\text{gallons}}{\text{min}} \qquad \text{MGD} = \frac{\text{million gallons}}{\text{day}}$$

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.) 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.

$$\text{Flow Rate (cfs)} = \text{Area }(\text{ft}^2) \times \text{Velocity (ft/sec)}$$

The letters Q, A, and V are used to represent Flow Rate, Area, and Velocity respectively in the equation.

$$Q\ (\text{cfs}) = A\ (\text{ft}^2) \times V\ (\text{ft/sec})$$

Understanding flow rates and velocities can help with the design of pipe sizes for wells, pump stations, and treatment plants. Typically, velocities are in the range of 2 – 7 feet per second and can be used with a known flow rate to calculate the pipe diameter. For example, if a new well is being drilled and the pump test data determines that the well can produce a specific flow of 1,500 gpm, and you do not want the velocity to exceed 6.5 fps, then you can calculate the required pipe diameter.

Example: Given a flow rate of 1,500 gpm and a velocity of 6.5 fps, what is the required pipe diameter?

The problem statement is asking for a pipe diameter which means that you need to solve for Area in the flow rate equation.

$$Q\ (cfs) = A\ (ft^2) \times V\ (ft/sec)$$

$$A\ (ft^2) = \frac{Q\ (cfs)}{V\ (ft/sec)}$$

Before you can substitute the values provided in the problem statement into the formula, you must make sure that all of the units align. The flow rate is provided in gpm and the velocity is provided as fps. Convert gpm to cfs.

$$\frac{1{,}500\ gpm}{1} \times \frac{1\ cfs}{448.8\ gpm} = 3.3422\ cfs = 3.34\ cfs$$

Now you can substitute the values into the equation and solve for Area.

$$A\ (ft^2) = \frac{Q\ (cfs)}{V\ (ft/sec)} = \frac{3.34\ cfs}{6.5\ fps} = 0.513846\ ft^2 = 0.51\ ft^2$$

To determine the diameter of the pipe, use the formula for the area of a circle and solve for diameter.

$$Area = 0.785 \times D^2$$

$$D^2 = \frac{Area}{0.785} = \frac{0.51\ ft^2}{0.785} = 0.6496815\ ft^2$$

Note that this is what D squared equals, not D. In order to solve for D, you need to take the square root of both sides of the equation.

$$\sqrt{D^2} = \sqrt{0.6496815\ ft^2}$$

$$D = 0.806028\ ft \times \frac{12\ in}{1\ ft} = 9.6723\ in = 9.7\ in$$

Length in small diameter pipes is expressed in inches, so you would need a 10-inch pipe.

Key Terms

- **circumference** – the distance around the circle
- **circle** – a round figure whose boundary is an equal distance from the center
- **cylinder** – a three-dimensional solid with two bases that are circles (or ovals)
- **diameter –** the distance across the circle through the diameter
- **flow rate** – the measurement of a volume of liquid that flows over a cross-sectional area over time
- **prism** – a three-dimensional solid with two bases that are the same size and shape polygon
- **radius** – the distance from the center to the edge of the circle
- **rectangle** – a four-sided figure with four right (90 degree) angles
- **rectangular prism** – a prism with bases that are trapezoids
- **sphere** – a three-dimensional solid is entirely made of points an equal distance from the center; a ball
- **square** – a type of rectangle with four sides that are the same length
- **trapezoid** – four-sided shape with one set of parallel sides called bases; aqueducts are commonly trapezoids in cross-section
- **trapezoidal prism** – a prism with bases that are trapezoids

Practice Problems 2.4

1. What is the flow rate in MGD of a 30" diameter pipe with a velocity of 5.5 fps?

2. What is the velocity through a box culvert that is 8 feet wide and 5 feet deep if the daily flow is 44 AF?

3. What is the area of a pipe that flows 3.1 MGD and has a velocity of 9 fps?

4. What is the diameter of a pipe that flows 1,425 gpm with a velocity of approximately 2.7 fps?

5. A 20-mile aqueduct flows 22,200 AFY at an average velocity of 0.32 fps. If the distance across the top is 20 feet and the depth is 6 feet, what is the distance across the bottom?

Exercise 2.4

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?

UNIT 3

3.1 DENSITY AND SPECIFIC GRAVITY

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** or mass per unit volume of water is 1 gram per cubic centimeter. The ratio of a solution's density compared to the density of water is known as **specific gravity.** Water has a specific gravity of 1.00.

$$\frac{\text{Density of a Solution}}{\text{Density of Water}} = \text{Specific Gravity} = \frac{\text{lbs/gal of a Solution}}{\text{lbs/gal of Water}}$$

Tip: The weight ratio of a solution compared to that of water can also be used to calculate specific gravity.

In order to understand specific gravity, we need to have a better understanding of density and its relationship to mass. Mass is the amount of matter (atoms) in a given substance. Take saltwater for example. We know that one gallon of water weighs 8.34 gallons. However, if one pound (453 grams) of salt is added to create a saltwater solution, then that same gallon of water would weigh 9.34 pounds per gallon instead. It is the same volume (one gallon) but has a different weight due to the additional mass that was added from the salt. Hence the definition of density, mass per unit volume. The amount of “stuff” in a given volume.

As discussed, the specific gravity of water is used as the reference point for comparisons. 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 and weights of substances used in the waterworks industry. 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
8% Sodium Hypochlorite	1.12	9.34 lbs/gal
12.5% Sodium Hypochlorite	1.20	10.0 lbs/gal
Alum	1.16 – 1.40	9.67 – 11.68 lbs/gal
Ferric chloride	1.43	11.93 lbs/gal

Substance	Specific Gravity	Weight
Calcium hypochlorite	2.35	19.60 lbs/gal
Chlorine (g)	2.49	20.77 lbs/gal

The specific gravities in the table are approximate. Professionally, you will consult the Safety Data Sheets for the value.

Note that everything listed in the table after water is heavier, and before water is lighter. Also, it's important to consider that sodium hypochlorite has a different specific gravity depending on the concentration of the solution. This is true of all chemical solutions.

Since water is the reference, then a specific gravity (SG) of 1 and a weight of 8.34 lbs/gal are the reference numbers needed to calculate the SG and weight of other substances. We can use this information as a conversion factor to determine the SG or weight of other substances. The conversion can be expressed as follows:

$$\frac{8.34 \text{ lbs/gal}}{1 \text{ SG}} \quad \text{or} \quad \frac{1 \text{ SG}}{8.34 \text{ lbs/gal}}$$

Let's take a look at how to apply this information.

Example: What is the weight of ferric chloride in lbs/gal if it has a SG of 1.43?

The problem statement indicates a SG of 1.43 for ferric chloride. Based on the SG of water being 1 and weighing 8.34 lbs/gal, we can determine the weight of the ferric chloride.

$$\frac{8.34 \text{ lbs/gal}}{1 \text{ SG}} \times \frac{1.43 \text{ SG}}{1} = 11.9262 = 11.93 \ \frac{\text{lbs}}{\text{gal}}$$

Remember, anything that has a SG >1 will weigh more than 8.34 lbs/gal.

Example: What is the SG of ferric chloride that weighs 11.93 lbs/gal?

In this problem, the weight of ferric chloride is provided, and you are asked to calculate the specific gravity (SG). Using the conversion above, you can calculate the SG for ferric chloride.

$$\frac{1 \text{ SG}}{8.34 \text{ lbs/gal}} \times \frac{11.93 \text{ lbs/gal}}{1} = 1.43 \text{ SG}$$

Remember, anything with a weight <8.34 lbs/gal will have a SG <1.

Practice Problems 3.1

1. Liquid sodium hypochlorite has a specific gravity of 1.69. What is the corresponding weight in pounds per gallon?

2. Chlorine gas is cooled and pressurized into a liquid state. It weighs 17.31 lbs/gal. What is the specific gravity?

3. What is the weight difference between 111 gallons of water and 61 gallons of sodium hypochlorite with a specific gravity of 1.37?

4. A treatment operator has 75 gallons of 14.5% sodium hypochlorite. How many pounds of the 75 gallons are available chlorine?

5. The specific gravity of 25% Alum is 1.24. How much does 83 gallons of 25% Alum weigh?

6. Ferric chloride weighs 19.44 lbs/gal. What is the specific gravity?

7. How many pounds of ferric chloride are in 92 gallons of 33% strength? (Assume the specific gravity is 1.52.)

8. What is the weight in lbs/cf of a substance that has a specific gravity of 1.47?

9. A shipment of crude oil has a specific gravity of 0.674. What is the weight in lbs/cf?

Exercise 3.1

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

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

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

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

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

3.2 PARTS-PER NOTATION

Parts-per notation is used to describe very small quantities of chemical concentrations. Most of the time, chemical concentrations are expressed in percentages. However, it is important to understand the relationship between the concentration expressed as a percentage and the concentration expressed in parts-per notation.

Commonly used parts-per notation is below:

Parts-per Notation	Parts-per Acronym	Value	Value in Scientific Notation
Parts per Hundred	pph	0.01	10^{-2}
Parts per Million	ppm	0.000001	10^{-6}
Parts per Billion	ppb	0.000000001	10^{-9}
Parts per Trillion	ppt	0.000000000001	10^{-12}

Because the amounts are small, examples will help.

One part per million is the equivalent of a drop of ink in 55 gallons of water.

One part per billion is the equivalent of one drop of ink in 55 barrels of water.
One part per billion is the equivalent of the width of a human hair within 68 miles.

One part per trillion is the equivalent of one drop in 500,000 barrels of water.
One part per trillion is the equivalent to six inches in 93 million miles, the distance to the sun.[23]

In chemical dosage-related problems, concentrations are typically expressed in parts per million, ppm. Therefore, we are most interested in converting a percentage to ppm and ppm to a percentage. If you divide 1,000,000 (1 ppm) by 100 (100%), you get the following:

$$\frac{1\text{ ppm}}{100\%} = \frac{1{,}000{,}000}{100} = 10{,}000$$

Therefore, a solution with a 1% chemical concentration can also be expressed as a solution with a 10,000-ppm chemical concentration.

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

[23] https://www.watereducation.org/aquapedia-background/parts-notation and

https://www.secnav.navy.mil/eie/Pages/DrinkingWaterConcentrations.aspx

To convert between a percentage and ppm, multiply the percent solution by 10,000. Note that you do not convert the percentage to a decimal before multiplying. It has already been accounted for in the conversion.

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

Example: What is the ppm of a 25% solution?

$25 \times 10{,}000 = 25{,}000 \text{ ppm}$

Example: A water utility uses a 0.5% sodium hypochlorite solution to disinfect a well. What is the ppm concentration of the solution?

To solve this problem, you need to take the percent of the solution given in the problem and multiply by 10,000 in order to have an answer in parts per million.

$0.5 \times 10{,}000 = 5{,}000 \text{ ppm}$

Now let's look at the differences between parts per million (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 smaller and smaller concentrations. 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). Another way to express the amount of contaminant in water supplies is as follows.

$1{,}000{,}000 = 1 \text{ million}$

$1{,}000{,}000{,}000 = 1 \text{ billion}$

$1{,}000{,}000{,}000{,}000 = 1 \text{ trillion}$

Based on this, one billion is equal to one thousand million and one trillion is equal to one thousand billion.

$1 \text{ billion} = 1{,}000 \text{ million}$

$1 \text{ trillion} = 1{,}000 \text{ billion}$

So how does this relate to our very small concentrations of ppm, ppb, and ppt?

$1 \text{ ppm} = 1{,}000 \text{ ppb} = 1{,}000{,}000 \text{ ppt}$

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). You can further simplify the difference between ppb and ppt as follows.

$$1 \text{ ppb} = 1{,}000 \text{ ppt}$$

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

Constituent	ppm	ppb	ppt
Arsenic		14	
Chromium	0.19		
Nitrate (NO_3)	57		
Perchlorate			7,400
Vinyl chloride		0.8	

To complete the chart, we will start with the first constituent, Arsenic, and work our way down completing one row at a time.

To convert ppb to ppm, you divide ppb by 1,000.

$$\text{Arsenic: } 14 \text{ ppb} \times \frac{1 \text{ ppm}}{1{,}000 \text{ ppb}} = 0.014 \text{ ppm}$$

To convert ppb to ppt, you multiply ppb by 1,000.

$$\text{Arsenic: } 14 \text{ ppb} \times \frac{1{,}000{,}000 \text{ ppt}}{1{,}000 \text{ ppb}} = 14 \text{ ppb} \times \frac{1{,}000 \text{ ppt}}{1 \text{ ppb}} = 14{,}000 \text{ ppt}$$

Now, we are going to move to the row for Chromium. To convert ppm to ppb, you multiply ppm by 1,000.

$$\text{Chromium: } 0.19 \text{ ppm} \times \frac{1{,}000 \text{ ppb}}{1 \text{ ppm}} = 190 \text{ ppb}$$

To convert ppb to ppt, you multiply ppb by 1,000.

$$\text{Chromium: } 190 \text{ ppb} \times \frac{1{,}000{,}000 \text{ ppt}}{1{,}000 \text{ ppb}} = 190 \text{ ppb} \times \frac{1{,}000 \text{ ppt}}{1 \text{ ppb}} = 190{,}000 \text{ ppt}$$

And now we are moving to the row for Nitrate. To convert ppm to ppb, you multiply ppm by 1,000.

$$\text{Nitrate } \left(NO_3\right) : 57 \text{ ppm} \times \frac{1{,}000 \text{ ppb}}{1 \text{ ppm}} = 57{,}000 \text{ ppb}$$

To convert ppb to ppt, you multiply ppb by 1,000.

$$\text{Nitrate } \left(NO_3\right) : 57{,}000 \text{ ppb} \times \frac{1{,}000 \text{ ppt}}{1 \text{ ppb}} = 57{,}000{,}000 \text{ ppt}$$

Now, we are moving to the row for Perchlorate. To convert ppt to ppb, you divide ppt by 1,000.

$$\text{Perchlorate} : 7{,}400 \text{ ppt} \times \frac{1 \text{ ppb}}{1{,}000 \text{ ppt}} = 7.4 \text{ ppb}$$

To convert ppb to ppm, you divide ppb by 1,000.

$$\text{Perchlorate} : 7.4 \text{ ppb} \times \frac{1 \text{ ppm}}{1{,}000 \text{ ppb}} = 0.0074 \text{ ppm}$$

And finally, we are moving to the row for Vinyl Chloride. To convert ppb to ppm, you divide ppb by 1,000.

$$\text{Vinyl chloride: } 0.8 \text{ ppb} \times \frac{1 \text{ ppm}}{1{,}000 \text{ ppb}} = 0.0008 \text{ ppm}$$

To convert ppb to ppt, you multiply ppb by 1,000.

$$\text{Vinyl chloride: } 0.8 \text{ ppb} \times \frac{1{,}000 \text{ ppt}}{1 \text{ ppb}} = 800 \text{ ppt}$$

Here is the completed table with the numbers calculated in bold.

Constituent	ppm	ppb	ppt
Arsenic	**0.014**	14	**14,000**
Chromium	0.19	**190**	**190,000**
Nitrate (NO_3)	57	**57,000**	**57,000,000**
Perchlorate	**0.0074**	**7.4**	7,400
Vinyl chloride	**0.0008**	0.8	**800**

Practice Problems 3.2

1. An 87.5% chlorine solution has a ppm concentration of?

2. What is the percent concentration of a 471-ppm solution?

3. A water utility uses a 12.7% 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 390 ppm. What is the percent concentration of the solution?

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

Constituent	ppm	ppb	ppt
Arsenic		51	
Chromium	1.74		
Nitrate (NO3)	112		
Perchlorate			90,832
Vinyl chloride		0.75	

Exercise 3.2

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. 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	

3.3 MIXING AND DILUTING SOLUTIONS

The water industry uses a variety of different chemicals for various processes in water treatment. These chemicals can come in different forms including gas, solid, or liquid (typically a solution). A **solution** is a liquid often made up of water and one or more chemicals. The concentration of a solution is dependent on the amount of chemical that is diluted within the water and can be represented as a percentage.

The percentage strength of a disinfectant solution represents the amount of active chemical available to inactivate pathogenic bacteria. For example, if you were to separate the two components of a 10% bleach solution, you would see that it is made up of 90% water and 10% sodium hypochlorite (active chemical).

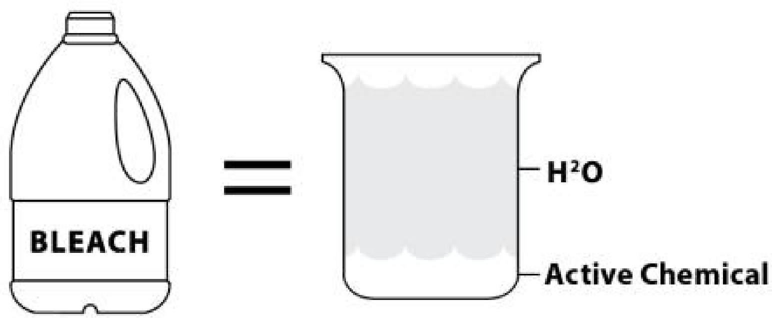


Figure3.1 [24]

Chemicals sometimes need to be diluted or mixed so that operators can safely work with them or to match the needs of a treatment process. The following formula can be used to calculate either the new concentration of a mixed solution, or the required volume needed to achieve a desired concentration.

$$C_1V_1 = C_2V_2$$

C = Concentration represented as a percentage

V = Volume of the solution in mL, gallons, etc.

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

First you need to identify which information is being provided and what is being asked. We know that one of the solutions is 250 mL at a 65% concentration.

[24] Image by Marilyn Hightower is licensed under CC BY 4.0

$C_1 = 65\%$

$V_1 = 250$ mL

Then you add 700 mL of water to the existing solution and want to know what the resulting concentration is of the new solution. Since we are adding water, the solution is being diluted.

Total Volume of the new solution is:

$$250 \text{ mL} + 700 \text{ mL} = 950 \text{ mL}$$

C_2 = ? %
V_2 = 950 mL

Now you can substitute all the information into the equation and solve for the unknown quantity.

$$C_1V_1 = C_2V_2$$

$$(65\%)(250 \text{ mL}) = C_2(950 \text{ mL})$$

Rearrange the terms to isolate the variable and convert the percent to a decimal in order to perform the calculation. To convert from a percent to a decimal, move the decimal two places to the left.

$$C_2 = \frac{(0.65)(250 \text{ mL})}{(950 \text{ mL})}$$

$$C_2 = \frac{162.5}{950} = 0.17105$$

Multiply the answer by 100 to convert from a decimal to a percent or move the decimal two places to the right.

$$C_2 = 0.17105 \times 100 = 17.1\%$$

This says if 250 mL of a 65% solution is diluted with 700 mL of water, the diluted solution's concentration will be 17%.

Key Terms

- **density** – mass per unit of volume
- **parts-per notation** – a way of describing small quantities of chemical concentrates, often expressed as percentages
- **solution** – a liquid often made up of water and one or more chemicals
- **specific gravity** – the ratio of a solution's density compared to the density of water

Practice Problems 3.3

1. How many gallons are needed to dilute 30-gallons of 18.75% sodium hypochlorite solution to a 10% solution?

2. If a 500-gallon container is 1/2 full of a 14% solution and is then completely filled with fresh water, what would the resulting ppm of the water be?

3. A chlorine storage tank that is 6 ft high with a 3ft diameter contains 227 gallons of 30% chlorine solution. If the tank is filled up with water, what will the new diluted concentration be?

4. 45 gallons of a 223,000ppm solution are mixed with 100 gallons of water. What is the concentration of the diluted solution? (Express the answer as a percentage.)

Exercise 3.3

1. How many gallons are needed to dilute 15-gallons of 12.5% sodium hypochlorite solution to a 6% solution?

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

3. A chlorine storage tank that is 10 ft high with a 5ft diameter contains 400 gallons of 20% chlorine solution. If the tank is filled up with water, what will the new diluted concentration be?

4. 10 gallons of a 50,000ppm solution are mixed with 15 gallons of water. What is the concentration of the diluted solution? (Express the answer as a percentage)

UNIT 4

4.1 CHEMICAL DOSAGE ANALYSIS

One of the most common and useful formulas in waterworks mathematics is used to calculate the amount of chemical needed to add to water. It is commonly known as the **Pound Formula** because it is a calculation for the weight of a chemical that is being added to water. Typically, this chemical is chlorine or a chlorine-related compound. However, it can be also used to calculate alum, ferric chloride, or any other type of chemical dosage.

Recall that the pound formula can be used in two forms.

The first is used when you are calculating chemical dosage in a volume of water, for example a tank, reservoir, or pipeline.

Pound Formula: $$\frac{\text{MG}}{1} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{\text{parts}}{\text{million parts}} = \frac{\text{lbs}}{1}$$

The second is used when you are calculating chemical dosage on a flow rate, for example through a pipeline, in a channel, or through a treatment facility.

Pound Formula: $$\frac{\text{MG}}{\text{D}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{\text{parts}}{\text{million parts}} = \frac{\text{lbs}}{\text{day}}$$

Note that the only difference between the two formulas is the unit for time. It is important to remember that MGD means Million Gallons per Day and this expression can be written as the following.

$$\text{MGD} \quad \text{or} \quad \frac{\text{MG}}{\text{D}}$$

Specific units for volume and flow must be used in the Pound Formulas. Volume must be in million gallons and flow must be in million gallons per day before you solve.

You may want to use the Pie Wheel to solve pound formula problems. In the pie wheel, the horizontal line across the middle of the pie wheel represents a division sign. Anything above the line should be divided by anything below the line. Everything below the line, which are variables next to one another, are multiplied together. Anything in the bottom half of the pie wheel is multiplied together to get the answer in the top half of the wheel.

The following charts or Pie Wheels are helpful in illustrating how to apply the Pound Formula.

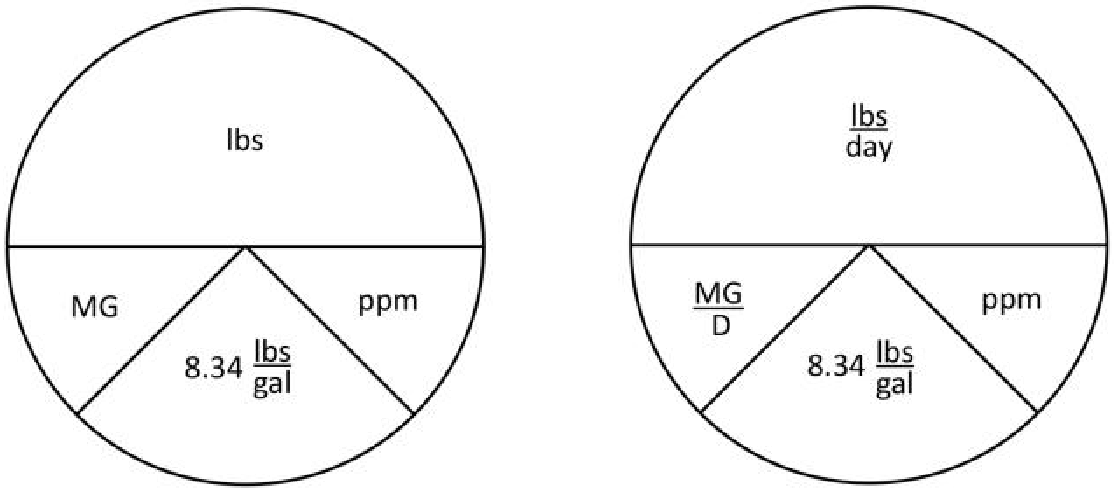


Figure 4.1[25]

Example: How many pounds of chlorine are needed to dose 2 MG of water to a dosage of 3.25 ppm?

Here is the Pound Formula.

$$\text{MG} \times \frac{8.34\text{ lbs}}{\text{gal}} \times \text{ppm} = \text{lbs}$$

To calculate the lbs of chlorine, plug the values into the formula and solve.

$$2\text{ MG} \times \frac{8.34\text{ lbs}}{\text{gal}} \times 3.25\text{ ppm} = 54.21\text{ lbs}$$

It's pretty easy to use the Pound Formula to calculate how many pounds of chlorine are needed to provide a certain dosage if we are using 100% concentration of any chemical.
However, most chemicals used are not in pure 100% form.

In many treatment plants and at treatment sites within distribution systems, the use of chlorine gas is in decline, unless the plant is of considerable size. In gas form, 100 lbs of gas chlorine is 100 lbs of available chlorine. The reduction in chlorine gas usage is primarily due to safety concerns and other forms of chlorine being less expensive. For example, groundwater wells are commonly disinfected with solid (calcium hypochlorite) or liquid (sodium hypochlorite) 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.

When solving dosage problems with chemicals of different concentrations, you will still use the Pound Formula, but you need to adjust for the concentration strength of the chemical in the calculation.

$$\text{Pound Formula:} \quad \frac{\text{MG} \times \frac{8.34\text{ lbs}}{\text{gal}} \times \text{ppm}}{\%\text{ concentration}} = \text{lbs}$$

$$\text{Pound Formula:} \quad \frac{\frac{\text{MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}} \times \text{ppm}}{\%\text{ concentration}} = \frac{\text{lbs}}{\text{day}}$$

If you are calculating the number of pounds needed, you divide by the decimal equivalent of the percent concentration. Since it is not at 100% concentration, you need more of the chemical. When you divide by a number less than one, you get a larger number, in this case, the lbs of chemical needed at the reduced concentration level.

Example: How many pounds of 10% Alum are needed to dose a treatment flow of 5 MGD to a dosage of 10 ppm?

$$\text{Pound Formula} \rightarrow \frac{\frac{\text{MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}} \times \text{ppm}}{\%\text{ concentration}} = \frac{\text{lbs}}{\text{day}}$$

First, solve the pound formula in the numerator by taking information from the problem and substituting it into the formula. In this case, you know 5 MGD and 10 ppm

$$\frac{5\text{ MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}} \times 10\text{ ppm} = \frac{417\text{ lbs}}{\text{day}}$$

It takes 417 lbs per day of 100% Alum to dose 5 MGD to 10 ppm. However, the Alum being used is only a 10% concentration. To adjust for the percent concentration, divide lbs per day by the percent concentration. Remember that to change a percent to a decimal, you need to move the decimal point over two places to the left.

$$\frac{\frac{417\text{ lbs}}{\text{day}}}{\%\text{ concentration}} = \frac{\frac{417\text{ lbs}}{\text{day}}}{10\%} = \frac{\frac{417\text{ lbs}}{\text{day}}}{0.10} = \frac{4{,}170\text{ lbs}}{\text{day}}$$

At only a 10% concentration, you will need 4,170 lbs of 10% Alum, significantly more, to get the equivalent of 417 lbs at full concentration. Therefore, to determine the amount of 10% Alum needed, you divide the total amount by 10% (or 0.1).

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

If the number of pounds is known, multiplying by the decimal equivalent of the percent concentration 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.

Example: An operator added 382 pounds of 15% ferric chloride to a treatment flow of 12.9 MGD. What was the corresponding dosage?

$$\text{Pound Formula} \rightarrow \frac{\frac{\text{MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}} \times \text{ppm}}{\%\text{ concentration}} = \frac{\text{lbs}}{\text{day}}$$

First, substitute all of the known information into the formula.

$$\text{Pound Formula} \rightarrow \frac{\frac{12.9\text{ MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}} \times \text{ppm}}{15\%} = \frac{382\text{ lbs}}{\text{day}}$$

To solve for the dosage, you need to rearrange the terms in the equation. In this step, you can see that you are multiplying the lbs per day by the decimal equivalent of the percent concentration (15% is equal to 0.15)

$$\frac{12.9\text{ MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}} \times \text{ppm} = \frac{382\text{ lbs}}{\text{day}} \times 0.15$$

Now, isolate the variable, ppm.

$$\text{ppm} = \frac{\frac{382\text{ lbs}}{\text{day}} \times 0.15}{\frac{12.9\text{ MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}}}$$

$$\text{ppm} = \frac{\frac{57.3\text{ lbs}}{\text{day}}}{\frac{107.586\text{ lbs}}{\text{day}}} = 0.533$$

The dosage applied is 0.533 ppm.

In problems where pounds are given, you multiply by the percent concentration.

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 75% ferric chloride. The same is true if you are using calcium hypochlorite as opposed to gas chlorine, because gas is at a greater strength (100%) than calcium hypochlorite.

Example: You have 100 pounds of 65% calcium hypochlorite solution. How many pounds are calcium hypochlorite?

$100 \text{ lbs} \times 65\% =$

$100 \text{ lbs} \times 0.65 = 65 \text{ lbs of calcium hypochlorite}$

Therefore, if you have 100 pounds of 65% calcium hypochlorite solution only 65 pounds of the substance is actually calcium hypochlorite, the portion actively working as the disinfectant.

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 measuring chemicals in pounds, the liquid chemical needs to be expressed as pounds. In Unit 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.

Example: The specific gravity of 12.5% sodium hypochlorite is 1.89. If 220 lbs per day are used, how many gallons of sodium hypochlorite are needed per hour?

From Unit 3, you can use the specific gravity to calculate the lbs per gallon.

$$\frac{8.34 \text{ lbs/gal}}{1 \text{ SG}} \times \frac{1.89 \text{ SG}}{1} = 15.7626 = 15.76 \frac{\text{lbs}}{\text{gal}}$$

You know that 220 lbs per day are being used and that it weighs 15.76 lbs per gallon. This allows you to calculate the gallons per day being used. Make sure to write your fractions in a way that allows for the lbs to cancel and the units in your answer to be gallons per day.

$$\frac{220 \text{ lbs}}{\text{day}} \times \frac{\text{gal}}{15.76 \text{ lbs}} = \frac{13.96 \text{ gal}}{\text{day}}$$

Now the question is asking how many gallons are needed per hour. Assuming a 24-hour day, you can calculate the gallons needed per hour.

$$\frac{13.96 \text{ gal}}{\text{day}} \times \frac{1 \text{ day}}{24 \text{ hours}} = \frac{0.58 \text{ gal}}{\text{hour}}$$

Therefore, slightly more than a half-gallon is required every hour.

Example: 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).

In order to use the Pound Formula equation, you first need to convert the flow rate from gpm to MGD.

$$\frac{1{,}500 \text{ gal}}{\text{min}} \times \frac{1{,}440 \text{ min}}{1 \text{ day}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 2.16 \text{ MGD}$$

Now you can substitute the information into the Pound Formula.

$$\text{Pound Formula} \rightarrow \frac{\frac{\text{MG}}{\text{D}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \text{ppm}}{\% \text{ concentration}} = \frac{\text{lbs}}{\text{day}}$$

First, solve the pound formula in the numerator.

$$\frac{2.16 \text{ MG}}{\text{D}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times 1.75 \text{ ppm} = \frac{31.5252 \text{ lbs}}{\text{day}}$$

To adjust for the percent concentration, divide lbs per day by the percent concentration. You know that 15% is equivalent to 0.15.

$$\frac{\frac{31.5252 \text{ lbs}}{\text{day}}}{\% \text{ concentration}} = \frac{\frac{31.5252 \text{ lbs}}{\text{day}}}{15\%} = \frac{\frac{31.5252 \text{ lbs}}{\text{day}}}{0.15} = \frac{210.17 \text{ lbs}}{\text{day}}$$

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.

$$\frac{8.34 \text{ lbs/gal}}{1 \text{ SG}} \times \frac{1.42 \text{ SG}}{1} = 11.8428 = \frac{11.84 \text{ lbs}}{\text{gal}}$$

$$\frac{210.17 \text{ lbs}}{\text{day}} \times \frac{\text{gal}}{11.84 \text{ lbs}} = \frac{17.75 \text{ gal}}{\text{day}}$$

17.75 gallons per day of 15% strength sodium hypochlorite are needed to dose a well flowing 1,500 gpm to a dosage of 1.75 ppm.

The reason drinking water is disinfected is to prevent pathogenic organisms from causing illness in the population drinking the water. These organisms are controlled by the amount of disinfectant, typically chlorine, added to the water. The amount of chlorine required to inactivate the various pathogens is called the **chlorine demand**.

Once the demand is satisfied, the remaining chlorine in the water supply is termed the **residual**. In order to keep the water supply safe for consumption, there must be a residual after the **dosage** has been applied. Water operators may be required to measure the original dosage or the residual in a water supply.

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

Example: An operator is disinfecting a line. He doses the line to 50 ppm. An hour later, the dosage is measured as 40 ppm. What is the chlorine demand in the line?

First identify the information provided. The line was dosed to 50 ppm and later it was measured as 40 ppm. Therefore, the dosage was 50 ppm and the residual was 40 ppm.

Substituting this into the equation will allow you to solve for the demand.

$$\text{dosage} = \text{residual} + \text{demand}$$
$$50 \text{ ppm} = 40 \text{ ppm} + \text{demand}$$

Now isolate the demand in the equation and solve.

$$\text{demand} = 50 \text{ ppm} - 40 \text{ ppm}$$
$$\text{demand} = 10 \text{ ppm}$$

Therefore, the chlorine demand in the line is 10 ppm.

Key Terms

- **chlorine demand** – the amount of chlorine required to inactivate the various pathogens
- **dosage** – the amount added to satisfy demand
- **Pound Formula** – a calculation for the weight of a chemical, such as chlorine or chlorine-related, that is added to water; can be used to calculate alum, ferric chloride or other chemical doses
- **residual** – remaining chlorine in the water supply once the demand is satisfied

Practice Problems 4.1

1. How many gallons of water can be treated with 325 pounds of 80% High Test Hypochlorite (HTH) to a dosage of 1.25 mg/L?

2. An operator added 85 pounds of 10% ferric chloride to a treatment flow of 4.1 MGD. What was the corresponding dosage?

3. How many pounds of 24.5% sodium hypochlorite are needed to dose a well with a flow rate of 2,150 gpm to a dosage of 3.45 ppm? (Assume the well runs 10 hours a day).

4. In the above problem, how many gallons of chemical are needed per hour? (Assume the SG is 1.9).

5. A treatment operator has set a chemical pump to dose 145 gallons of NaOH (sodium hydroxide) per day for a flow rate of 6.35 MGD. What is the corresponding dosage? (Assume the SG is 2.41).

6. 3 miles of 24" diameter main line needs to be dosed to 100 ppm. Answer the following questions.

    a. How many gallons of 15% (SG = 1.60) sodium hypochlorite are needed?

    b. How many pounds of 45% HTH are needed?

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

        i. Sodium hypochlorite = $2.75 per gallon

        ii. HTH = $1.35 per pound

7. A water treatment operator adjusted the amount of 15% Alum dosage from 90 mg/L to 65 mg/L. Based on a treatment flow of 8 MGD, what is the cost savings if 15% Alum costs $1.20 per pound?

8. A water utility produced 6,000 AF of water last year. The entire amount was dosed at an average rate of 0.6 ppm. If the chemical of choice was 35% HTH at a per pound cost of $2.43, what was the annual budget?

9. Ferric chloride is used as the coagulant of choice at a 10.1 MGD rated capacity treatment plant. If the plant operated at the rated capacity for 60% of the year and operated at 30% of rated capacity for 40% of the year, how many pounds of the coagulant was needed to maintain a dosage of 65 mg/L?

10. A water softening treatment process uses 30% NaOH during 40% of the year and 40% NaOH for 60% of the year. Assuming a constant flow rate of 500 gpm and a dosage of 55 mg/L, what is the annual budget if the 30% NaOH (SG = 1.55) costs $1.20 per gallon and the 40% NaOH (SG = 1.87) costs $2.10 per gallon?

11. An operator added 422 gallons of 15% sodium hypochlorite (SG=1.57) in to 5,340 ft of 3 feet diameter pipe. After 36 hours, the residual was measured at 122.65 ppm. What was the demand?

Exercise 4.1

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 20% 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% sodium hypochlorite (SG=1.32) into 2,550 ft of 12-foot diameter pipe. After 24 hours, the residual was measured at 10.25 ppm. What was the demand?

UNIT 5

5.1 WEIR OVERFLOW RATE

A **weir** is an overflow structure that is used to alter flow characteristics. Weirs are used in many different circumstances, including water treatment facilities and irrigation canals.

The weir raises the water level and causes the water to flow over the weir structure at a constant flow 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).

Figure 5.1[26]

[26] Image by Titico is in the public domain

Weirs can either be sharp-crested or broad-crested. Broad-crested weirs are flat-crested structures and are commonly used in dam 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. The same WOR formula can be used no matter which style of weir is used.

Figure 5.2: Sharp crested weir[27]

Figure 5.3: Broad crested weir[28]

Weir Overflow Rate (WOR) Formula:

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{\text{Flow (gpm)}}{\text{Weir Length (ft)}}$$

[27] Image by Regina Blasberg is used with permission

[28] Image by Ernesto Velazquez is used with permisison

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.

Example: What is the weir overflow rate through a 12.85 MGD treatment plant if the weir is 90 feet long? (Express your answer in MGD/ft and gpm/ft).

The values provided in the problem statement are in MGD and feet. Therefore, to calculate the weir overflow rate in MGD/ft, substitute the values for flow and weir length into the equation.

$$\text{Weir Overflow Rate (MGD/ft)} = \frac{12.85\text{ MGD}}{90\text{ ft}} = 0.142778\text{ MGD/ft}$$

You can approach calculating the solution in gpm/ft in two ways.

Option #1: One way is to convert the MGD/ft solution previously calculated to gpm/ft.

$$\frac{\frac{0.142778\text{ MG}}{\text{D}} \times \frac{1{,}000{,}000\text{ gal}}{1\text{ MG}} \times \frac{1\text{ day}}{24\text{ hour}} \times \frac{1\text{ hour}}{60\text{ min}}}{\text{ft}} = \frac{99.15\text{ gpm}}{\text{ft}}$$

Option #2: You can convert the treatment plant flow rate provided in the problem statement from MGD to gpm and then calculate the weir overflow rate.

$$\frac{12.85\text{ MG}}{\text{D}} \times \frac{1{,}000{,}000\text{ gal}}{1\text{ MG}} \times \frac{1\text{ day}}{24\text{ hour}} \times \frac{1\text{ hour}}{60\text{ min}} = 8{,}923.611\text{ gpm}$$

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{8{,}923.611\text{ gpm}}{90\text{ ft}} = \frac{99.15\text{ gpm}}{\text{ft}}$$

Note that the final answer is the same using either option.

Example: A drainage channel has a 32-foot weir and a weir overflow rate of 14.5 gpm/ft. What is the daily flow expressed in MGD?

Substitute the values provided in the question into the Weir Overflow Rate formula and solve for the unknown flow rate.

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{\text{? gpm}}{\text{32 ft}} = \text{14.5 gpm/ft}$$

Rearrange the terms and solve for the flow rate in gpm.

$$\text{? gpm} = \frac{\text{14.5 gpm}}{\text{ft}} \times \text{32 ft} = \text{464 gpm}$$

Now you can convert the gpm to MGD.

$$\frac{\text{464 gal}}{\text{min}} \times \frac{\text{1 MG}}{\text{1,000,000 gal}} \times \frac{\text{24 hour}}{\text{1 day}} \times \frac{\text{60 min}}{\text{1 hour}} = \text{0.66816 MGD} = \text{0.67 MGD}$$

Example: What is the length of a weir if the daily flow is 4.3 MG and the weir overflow rate is 52 gpm/ft?

The units of the values provided in the problem statement, do not match. You have MGD for the daily flow and gpm/ft for the weir overflow rate. Therefore, in order to solve for length, either MGD must be converted to gpm or gpm/ft must be converted to MGD/ft. Both will provide you with the same final answer.

Converting 4.3 MGD to gpm.

$$\frac{\text{4.3 MG}}{\text{D}} \times \frac{\text{1,000,000 gal}}{\text{1 MG}} \times \frac{\text{1 day}}{\text{24 hour}} \times \frac{\text{1 hour}}{\text{60 min}} = \text{2,986.1 gpm}$$

Now you can substitute the values into the Weir Overflow Rate formula and solve for the weir length.

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{\text{2,986.1 gpm}}{\text{? ft}} = \text{52 gpm/ft}$$

Rearrange the terms and solve for the weir length in feet.

$$\text{Weir Length (ft)} = \frac{\text{2,986.1 gpm}}{\text{52 gpm/ft}} = \text{57.425 ft} = \text{57.43 ft}$$

Converting 52 gpm/ft to MGD/ft.

$$\frac{\frac{\text{52 gal}}{\text{min}} \times \frac{\text{1 MG}}{\text{1,000,000 gal}} \times \frac{\text{24 hour}}{\text{1 day}} \times \frac{\text{60 min}}{\text{1 hour}}}{\text{ft}} = \frac{\text{0.07488 MGD}}{\text{ft}}$$

Now you can substitute the values into the Weir Overflow Rate formula and solve for the weir length.

$$\text{Weir Overflow Rate (MGD/ft)} = \frac{4.3\ \text{MGD}}{?\ \text{ft}} = 0.07488\ \text{MGD/ft}$$

Rearrange the terms and solve for the weir length in feet.

$$\text{Weir Length (ft)} = \frac{4.3\ \text{MGD}}{0.07488\ \text{MGD/ft}} = 57.425\ \text{ft} = 57.43\ \text{ft}$$

It doesn't matter whether you calculate the weir length using MGD or gpm. In either case, the weir length is 57.43 ft. However, it is important that all of the units in the problem are the same – MGD to MGD/ft or gpm to gpm/ft.

Example: A treatment plant processes 12.5 MGD. The weir overflow rate through a circular clarifier is 33.8 gpm/ft. What is the diameter of the clarifier?

Since the plant flow rate is provided in MGD and the WOR is provided in gpm per foot, you have the option of converting gpm to MGD or MGD to gpm in order to solve. Here is the conversion for gpm to MGD.

$$\frac{\dfrac{33.8\ \text{gal}}{\text{min}} \times \dfrac{1\ \text{MG}}{1{,}000{,}000\ \text{gal}} \times \dfrac{24\ \text{hour}}{1\ \text{day}} \times \dfrac{60\ \text{min}}{1\ \text{hour}}}{\text{ft}} = \frac{0.048672\ \text{MGD}}{\text{ft}}$$

$$\text{Weir Overflow Rate (MGD/ft)} = \frac{12.5\ \text{MGD}}{?\ \text{ft}} = 0.048672\ \text{MGD/ft}$$

$$\text{Weir Length (ft)} = \frac{12.5\ \text{MGD}}{0.048672\ \text{MGD/ft}} = 256.8212\ \text{ft}$$

It is a circular weir. Therefore, the length calculated is actually the circumference of a circle. To calculate the diameter, use the circumference formula and solve for D.

$$\text{Circumference} = \pi \times D = 256.8212\ \text{ft}$$

$$D = \frac{256.8212\ \text{ft}}{3.14} = 81.79\ \text{ft} = 81.8\ \text{ft}$$

Key Terms

- **weir** – an overflow structure that is used to alter flow characteristics
- **weir overflow rate (WOR)** – the rate at which water flows over the weir structure; the flow of water by the length of the weir

Practice Problems 5.1

1. What is the weir overflow rate through a 3.2 MGD treatment plant if the weir is 18 feet long? (Express your answer in MGD/ft and gpm/ft).

2. A drainage channel has a 210-foot weir and a weir overflow rate of 28 gpm/ft. What is the daily flow expressed in MGD?

3. What is the length of a weir if the daily flow is 6.9 MG and the weir overflow rate is 41 gpm/ft?

4. A 37 ft diameter circular clarifier has a weir overflow rate of 25 gpm/ft. What is the daily flow in MGD?

5. A treatment plant processes 8.4 MGD. The weir overflow rate through a circular clarifier is 17.6 gpm/ft. What is the diameter of the clarifier?

6. An aqueduct that flowed 44,500 acre-feet of water last year has a weir overflow structure to control the flow. If the weir is 315 feet long, what was the average weir overflow rate in gpm/ft?

7. An aqueduct is being reconstructed to widen the width across the top. The width across the bottom is 25 feet and the average water depth is 40 feet. The aqueduct must maintain a constant weir overflow rate of 15 gpm per foot with a daily flow of 0.88 MGD. What is the length of the weir?

8. An engineering report determined that a minimum weir overflow rate of 25 gpm per foot and a maximum weir overflow rate of 30 gpm per foot were needed to meet the water quality objectives of a certain treatment plant. The existing weir is 120 feet long. What is the daily treatment flow range of the plant?

Exercise 5.1

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 overflow 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. 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?

UNIT 6

6.1 DETENTION 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 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**. Note that this should not be confused with CT, Concentration Time which will be discussed in Unit 7. 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.) Since detention times and contact times are typically expressed in hours, it is important that the correct units are used. When solving D_t 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 pie wheel (below) shows a simple way of calculating the variables. If the variables are next to each other (D_t and Flow Rate) then multiply. If they are over each other (Volume and D_t or Volume and Flow Rate) then divide.

The following formula is used for calculating detention times.

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

You may also use the Pie Wheel to solve for Detention Time as shown below.

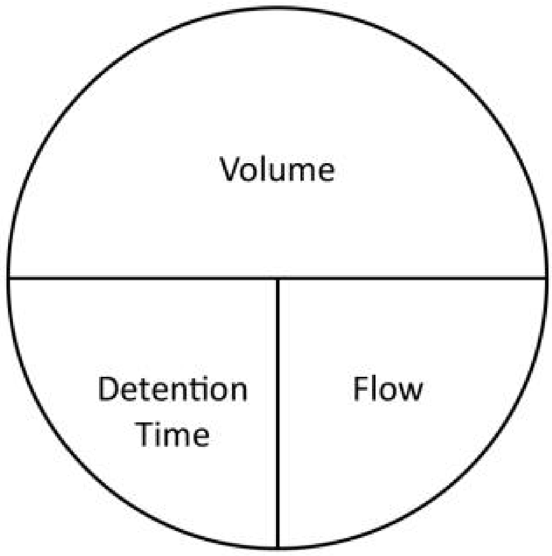


Figure 6.1[29]

Units are extremely important when using this formula. There are three variables in this formula: Detention Time, Flow, and Volume. Each variable can be provided using a variety of units. You cannot calculate the solution unless all of the units align. If the units are similar (matching), then dividing volume by flow will yield a time (Detention Time). However, simply dividing a volume by a flow will not result in a time. For example, if you divide gallons by cubic feet per second there is no resulting answer. This is because "gallons" and "cubic feet" will not cancel each other.

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

Example: Calculate the detention time.

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{\text{gallons}}{\text{gallons/minute}} = \text{minute}$$

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{\text{cubic feet}}{\text{cubic feet/second}} = \text{second}$$

[29] Image by Marilyn Hightower is licensed under CC BY 4.0

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{\text{gallons}}{\text{million gallons/day}}$$

In the first two examples, the terms can be divided. However, in the third example they cannot. D_t 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:

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{100{,}000 \text{ gallons}}{1 \text{ MGD}}$$

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.

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

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{0.1 \text{ MG}}{1 \text{ MGD}} = 0.1 \text{ day or } 2.4\text{hrs}$$

Converting the days to hours is easy since there are 24 hours in one day.

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

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.

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

Now solve for the Detention Time.

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

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

Example: What is the detention time in a circular clarifier with a depth of 50 ft and a 30 ft diameter if the daily flow is 2.2 MG. (Express your answer in hours:minutes.)

First you need to calculate the volume of the clarifier.

$$\text{Clarifier Volume} = 0.785 \times D^2 \times H = 0.785 \times (30\text{ ft})^2 \text{ x } 50\text{ ft} = 35{,}325\text{ ft}^3$$

In order to calculate the detention time, the units for Volume and the units for Flow must align. Since the flow rate is provided in MG, convert the cubic foot volume to MG.

$$35{,}325\text{ ft}^3 \times \frac{7.48\text{ gal}}{1\text{ cf}} \times \frac{1\text{ MG}}{1{,}000{,}000\text{ gal}} = 0.264231\text{ MG}$$

Now you can calculate the detention time by substituting the volume calculated and the daily flow provided into the detention time formula.

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{0.264231\text{ MG}}{2.2\text{ MGD}} = 0.120105\text{ days} \times \frac{24\text{ hour}}{1\text{ day}} = 2.88252\text{ hours}$$

The problem asks for the detention time to be expressed in hours and minutes. Based on the calculation above, you know that you have 2 full hours and a portion of a third hour. To calculate the exact number of minutes, take the decimal amount and multiply by 60 min per hour.

$$0.88252\text{ hours} \times \frac{60\text{ min}}{1\text{ hour}} = 52.95\text{ min} = 53\text{ min}$$

$$D_t = 2\text{ hours } 53\text{ minutes} = 2{:}53$$

Example: A water utility is designing a transmission pipeline collection system in order to achieve a chlorine contact time of 2 hours 10 mins once a 1,125 gpm well is chlorinated. How many feet of 30” diameter pipe are needed?

The problem statement provides both the detention time and the flow rate. However, in order to use the detention time provided, you need to convert it to minutes.

$$\left(2\text{ hours} \times \frac{60\text{ min}}{1\text{ hour}}\right) + 10\text{ min} = 130\text{ min}$$

Rearranging the terms in the detention time equation to solve for volume results in volume equals detention time times flow. Substitute the minutes calculated and the flow rate into this equation in order to solve for the total volume in gallons.

$$\text{Volume} = D_t \times \text{Flow} = 130 \text{ min} \times \frac{1{,}125 \text{ gal}}{\text{min}} = 146{,}250 \text{ gal}$$

Since the problem statement is asking for how many feet of pipe, convert the gallons to cubic feet.

$$\text{Volume} = 146{,}250 \text{ gal} \times \frac{1 \text{ cf}}{7.48 \text{ gal}} = 19{,}552.1390374 \text{ cf} = 19{,}552.1 \text{ cf}$$

Now that you know the total volume of the pipe in cubic feet, you can use the formula for volume of a pipe to determine the pipe length. Substitute the pipe diameter and the pipe volume into the equation and rearrange the terms to solve for length.

$$\text{Pipe Volume} = 0.785 \times D^2 \times H =$$

$$0.785 \times \left(30 \text{ in x } \frac{1 \text{ ft}}{12 \text{ in}}\right)^2 \text{ x Length} = 19{,}552.1 \text{ ft}^3$$

$$\text{Length} = \frac{19{,}552.1 \text{ ft}^3}{0.785 \times (2.5 \text{ ft})^2} = \frac{19{,}552.1 \text{ ft}^3}{4.90625 \text{ ft}^2} = 3{,}985.1414 \text{ ft} = 3{,}985 \text{ ft}$$

Practice Problems 6.1

1. What is the detention time in hours of a 300 ft by 50 ft by 25 ft sedimentation basin with a flow of 8.1 MGD?

2. What is the detention time in a circular clarifier with a depth of 65 ft and a 95 ft diameter if the daily flow is 7.3 MG. (Express your answer in hours:minutes.)

3. A water utility engineer is designing a sedimentation basin to treat 12 MGD and maintain a minimum detention time of 3 hours 30 minutes. The basin cannot be longer than 100 feet and wider than 65 feet. Under this scenario, how deep must the basin be?

4. A water utility is designing a transmission pipeline collection system in order to achieve a chlorine contact time of 75 minutes once a 3,400 gpm well is chlorinated. How many feet of 36” diameter pipe are needed?

5. The chlorine residual decay rate is 0.7 mg/L per 3/4 hour in a 4 MG water storage tank. If the storage tank needs to maintain a minimum chlorine residual of 6.5 mg/L what is the required dosage if the tank is filling at a rate of 900 gpm until the tank is full?

6. A 44-foot-tall water storage tank is disinfected with chloramines through an onsite disinfection system. The average constant effluent from the tank is 680 gpm through a 20-inch diameter pipe. If the first customer that receives water from the tank is 4,972 feet from the tank, would the required 30-minute contact time be achieved?

7. A 70-foot diameter, 35-foot-deep clarifier maintains a constant weir overflow rate of 22.6 gpm/ft. What is the detention time in hours:min?

8. A circular clarifier processes 9.5 MGD with a detention time of 3.7 hours. If the clarifier is 45 feet deep, what is the diameter?

Exercise 6.1

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. 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?

10. 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?

11. 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?

12. 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?

6.2 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.

Filtration Rate Formula:

$$\text{Filtration Rate (gpm/ft}^2\text{)} = \frac{\text{Flow (gpm)}}{\text{Surface Area (ft}^2\text{)}}$$

You may also use the Pie Wheel to solve Filtration Rate problems.

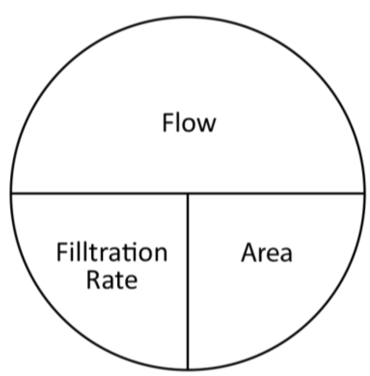


Figure 6.2[30]

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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). This “fall” references the fact that filtration rates are reduced over time as particles are lodged into the filtration media during operation. Backwashing, a process of cleaning the media by reversing the flow through the filter, is then employed in order to try and recover some of the filtering capacity and prolong the operational life of the filter. During backwashing, the formula is expressed with the same units as “fall” but is described as “rise” in the filter instead. This lets you know how much filtering capacity is recovered through your backwashing cycle. Use the formulas below.

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

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

The conversion from gallons per minute g per square foot to inches per min requires converting gallons to cubic feet, then feet to inches.

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

First, convert gpm to cfm. This is the first step toward converting the gallons to inches.

$$\frac{2.5\text{ gpm}}{\text{ft}^2} \times \frac{1\text{ ft}^3}{7.48\text{ gal}} = \frac{0.33\text{ cfm}}{\text{ft}^2}$$

In the above conversion, the gallons canceled, and you were left with cubic feet per min divided by square feet. This can cancel further.

$$\frac{0.33\text{ ft}^3/\text{m}}{\text{ft}^2} = 0.33\text{ ft/min} = \frac{0.33\text{ ft}}{\text{min}}$$

When you divide cubic feet by square feet, you are left with feet. The result in this example is feet per minute.

Feet per minute can easily be converted to inches per minute by multiplying by the conversion 12 inches equals 1 foot.

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

However, this can be simplified by using the following unit conversion.

$$\frac{1.6 \text{ in}}{\text{min}} = \frac{1 \text{ gpm}}{\text{sqft}}$$

$$\frac{1.6 \text{ in/min}}{1 \text{ gpm/sqft}} \quad \text{or} \quad \frac{1 \text{ gpm/sqft}}{1.6 \text{ in/min}}$$

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

Use the unit conversion to solve this problem.

$$2.5 \text{ gpm/ft}^2 \times \frac{1.6 \text{ in/min}}{1 \text{ gpm/sqft}} = 4 \text{ in/min}$$

Example: What is the filtration rate through a 20' by 20' filter if the average flow through the treatment process is 2.5 MG? Express the filtration rate as in/min.

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

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

Next, calculate the surface area of the filter in square feet.

$$20 \text{ ft} \times 20 \text{ ft} = 400 \text{ ft}^2$$

To calculate the filtration rate, substitute the values into the formula.

$$\text{Filtration Rate (gpm/ft}^2\text{)} = \frac{\text{Flow (gpm)}}{\text{Surface Area (ft}^2\text{)}}$$

$$\text{Filtration Rate (gpm/ft}^2\text{)} = \frac{1{,}736 \text{ gpm}}{400 \text{ ft}^2} = 4.32 \text{ gpm/ft}^2$$

Now use the unit conversion to calculate the filtration rate as inches per minute.

$$\text{Filtration Rate} = 4.32 \text{ gpm/ft}^2 \times \frac{1.6 \text{ in/min}}{1 \text{ gpm/sqft}} = 6.912 \text{ in/min}$$

Key Terms

- **contact time** – detention time; do not confuse contact time with concentration time
- **detention time** – time that allows large particles to settle out from the flow of water through gravity
- **filtration** –the last barrier between the treatment process and the customer; filters trap or remove particles from the water further reducing the cloudiness or turbidity; conventional filtrate plants require large areas of land to construct sedimentation basins and employ detention time process; the direct filtration process eliminates sedimentation to have a shorter run time, use less land, and requires more frequent backwashing to clean the filters.

Practice Problems 6.2

1. A water treatment plant processes 15.2 MGD. What is the required filter bed area needed to maintain a filtration rate of 2.80 gpm/ft^2?

2. A 30 ft by 35 ft filter needs to be back washed at a rate of 25 gpm/ft^2 for a minimum of 22 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 15 inches per minute rise is needed. If the filter is 40 ft by 30 ft, what is the backwash flow rate in gpm?

4. A water treatment plant processes a maximum of 7.50 MGD. The plant has 3 filters measuring 28 ft by 33 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 10.3 MGD through a 50 ft by 50 ft filter. What is the corresponding inches per minute through the filter?

6. A filter is backwashed at a rate of 27.0 inches per minute for 17 minutes. If the filter is 225 ft^2, how many gallons were used?

7. An Engineer is designing a circular filter to handle 2.14 MGD and maintain a filtration rate of 1.25 inches per minute. What will the diameter be?

8. A filter needs to be backwashed when the fall rate exceeds 6.3 inches per minute. It was determined that this rate is reached after 4.7 MG flows through a 27 ft by 28 ft filter. How often does the filter need backwashing? Give your answer in the most logical time unit.

Exercise 6.2

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 flows through a 17 ft by 17 ft filter. How often does the filter need backwashing? Give your answer in the most logical time unit.

UNIT 7

7.1 CT CALCULATIONS

Concentration and Time are critical variables in water treatment. **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 does it need to be in contact with the water? Well, it takes time to complete the disinfection process once chemical is added to water. 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 concentration of the disinfectant and the time the disinfectant has to do its "work" is very important in ensuring water is properly disinfected and safe for human consumption.

There are many different types of bacteria in natural water sources that can cause sickness if not properly treated. The disinfection process kills and/or inactivates pathogenic (disease causing) bacteria to make it safe for human consumption. In order to follow the Surface Water Treatment Rule (SWTR), drinking water treatment plants must meet the following inactivation requirements:

Cryptosporidium parvum – 2.0 Log or 99% Inactivation
Giardia lamblia – 3.0 Log or 99.9% Inactivation
Viruses – 4.0 Log or 99.99% 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
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

See Appendix for further information regarding Logs

Pin It! Misconception Alert
Sometimes logs (logarithms) can seem scary! Think of the Log as the power to which a number has to be raised to get another number.

Cryptosporidium will not be discussed in this class due to the complexities in the 2003 update to the SWTR known as the Long Term 2 Enhanced Surface Water Treatment Rule. Instead, we will focus on Giardia and viruses.

Table 7.2 (below) depicts the log requirements that are required for both Giardia and viruses. Notice in the second column that Giardia must be disinfected to 3 Log (99.9%) and viruses to 4 Log (99.99%). Various treatment processes (shown in the first column) account for some of the inactivation or removal of pathogens from the raw water. Therefore, the SWTR provides "credits" toward the inactivation of *Giardia* and viruses (shown in the third column). Credits are subtracted from the inactivation requirements to determine the level of disinfection still required after water goes through treatment.

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

Direct Filtration, DE, or Slow Sand	3	4	2	1	1	3

4 Log (Required) - 1 Log (Credit) = 3 Log (Remaining)

For example, the CT requirement for viruses is 4 Log. This requirement can be satisfied through disinfection, treatment, or a combination of the two.

If raw water is treated using direct filtration, it would receive 1 Log credit. After water leaves the treatment plant, the disinfection requirement remaining for viruses would be 3 Log, as shown in the fourth column of Table 7.2 (complete calculation illustrated below the table). The remaining 3 Logs will need to be inactivated by disinfecting the water using the appropriate concentration and time. Disinfectant can either be added before or after water goes through the treatment process to make sure the pathogens are thoroughly inactivated and meet the requirements.

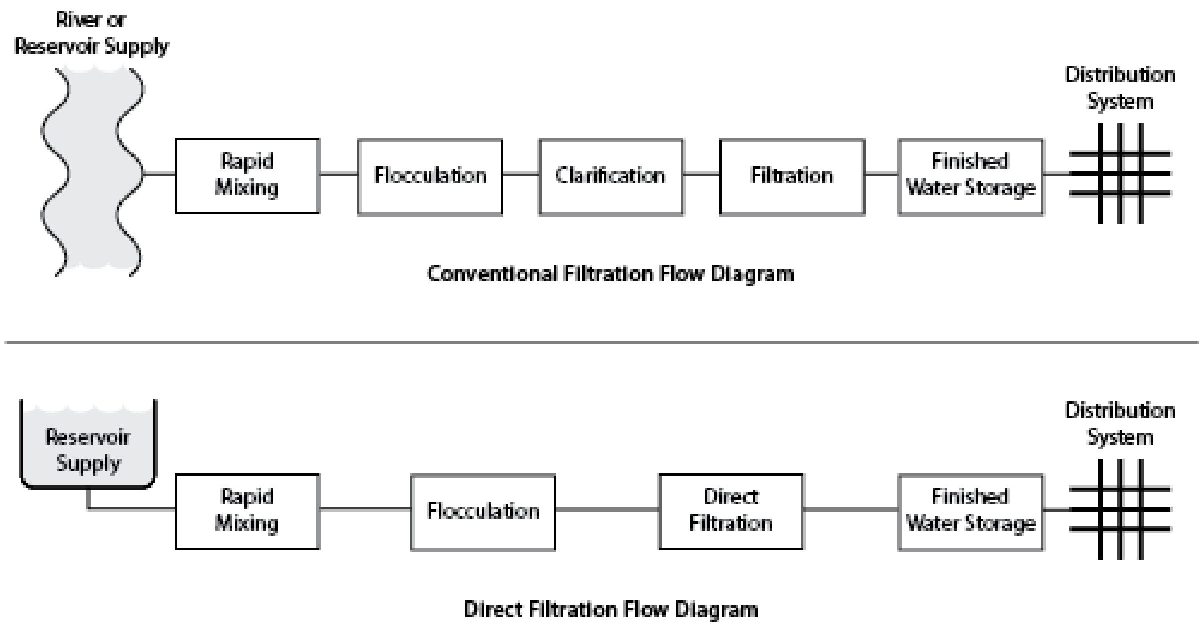

Figure 7.1[31]

Now let's discuss CT units. When dealing with CT calculations, concentration will be expressed in mg/L and Time will be expressed in minutes. Therefore, CT is expressed as mg/L · min (all one unit). When solving CT problems, the concentration of the disinfectant is typically provided in the question. However, there may be times when the "Pound Formula" is needed to calculate the chemical concentration. In order to calculate the contact time of an applied chemical, the detention time (D_t) formula from Unit 6 will be needed.

Time is defined as the moment 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 of known volumes but can be difficult to calculate through various treatment plant processes. To solve this issue, Tracer Studies (aka T_{10}) are sometimes conducted.

A tracer study can be accomplished by adding a unique tracer chemical to the raw water before it goes through the treatment plant and measuring how long before it is detected in the effluent of the plant. More specifically, 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 using the D_t formula while others will provide T_{10} values.

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Next, there are two crucial terms that are required in order to calculate whether water has been adequately disinfected, “actual CT” and “required CT.” Actual CT is the actual concentration of chemical through the treatment process and the actual time the disinfectant is in contact with the water. Required CT is found in the CT tables using the information provided in the problem. Once the concentration of chemical and the contact time are calculated, they can be multiplied together to determine the Actual CT.

Example: Determine the Actual CT given 2 mg/L concentration in a pipeline and 10 minutes of contact time (either calculated using D_t formula or provided as a T_{10})

Remember that the units for the Actual CT are mg/L · min.

$$2 \text{ mg/L} \times 10 \text{ min} = 20 \text{ mg/L min}$$

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. See the example below.

Example: What is the required 1.0 log inactivation from disinfection (value after credits are applied) for the Inactivation for Giardia in 10 degrees Celsius water with a pH of 7.5 using a free chlorine dosage of 1 mg/L?

To answer this question, you need to look at the CT Values table for Inactivation of Giardia Cysts by Free Chlorine at 10°C.

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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					
	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
0.6	13	25	38	50	63	75	15	30	45	60	75	90
0.8	13	26	39	52	65	78	15	31	46	61	77	92
1	13	26	40	53	66	79	16	31	47	63	78	94
1.2	13	27	40	53	67	80	16	32	48	63	79	95
1.4	14	27	41	55	68	82	16	33	49	65	82	98
1.6	14	28	42	55	69	83	17	33	50	66	83	99
1.8	14	29	43	57	72	86	17	34	51	67	84	101
2	15	29	44	58	73	87	17	35	52	69	87	104
2.2	15	30	45	59	74	89	18	35	53	70	88	105
2.4	15	30	45	60	75	90	18	36	54	71	89	107
2.6	15	31	46	61	77	92	18	37	55	73	92	110
2.8	16	31	47	62	78	93	19	37	56	74	93	111
3	16	32	48	63	79	95	19	38	57	75	94	113

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

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Figure 7.2[32]

[32] Image by the EPA is in the public domain

The information provided in the question statement will help determine which CT table to use. In this case, it is Table C-3 which is specifically for inactivation of Giardia by Free Chlorine at 10°C

The problem states that the water has a pH of 7.5 so you look in the column that says pH = 7.5.

The supporting information (outlined in the boxes above) will help determine which exact column and row you need to use to find the answer. For this example, the chlorine concentration is 1 mg/L and the Log Inactivation is 1.0.

Therefore, the answer is 45 mg/L · min which is circled in red. It is the intersection of the 1 mg/L row and the 1.0 Log inactivation column.

The CT Tables provide the required CT needed to inactivate either *Giardia* or viruses . The ratio of the actual CT (calculated portion of the problem) and the required CT (found in the CT tables) is then calculated to determine if the water has been properly disinfected. 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.

Example: If the Actual CT is 28 mg/L · min and the Required CT is 22 mg/L · min, has the water been properly disinfected?

$$\frac{\text{Actual CT}}{\text{Required CT}} = \frac{28\text{ mg/L min}}{22\text{ mg/L min}} = 1.27$$

Since the ratio is greater than 1.0, the water has been properly treated and the CT is met.

Example: If the Actual CT is 16 mg/L · min and the Required CT is 32 mg/L · min, has the water been properly disinfected?

$$\frac{\text{Actual CT}}{\text{Required CT}} = \frac{16\text{ mg/L min}}{32\text{ mg/L min}} = 0.5$$

Since the ratio is less than 1.0, the water has NOT been properly treated and the CT is NOT met.

Finding the Correct CT Table

Typical CT problems 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 in the problem statement. You can use this information to identify which CT table to use.

Example: Given the following information, which CT table would you use?

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

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Appendix C. CT Values for Inactivations Achieved by Various Disinfectants

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					
	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
0.6	13	25	38	50	63	75	15	30	45	60	75	90
0.8	13	26	39	52	65	78	15	31	46	61	77	92
1	13	26	40	53	66	79	16	31	47	63	78	94
1.2	13	27	40	53	67	80	16	32	48	63	79	95
1.4	14	27	41	55	68	82	16	33	49	65	82	98
1.6	14	28	42	55	69	83	17	33	50	66	83	99
1.8	14	29	43	57	72	86	17	34	51	67	84	101
2	15	29	44	58	73	87	17	35	52	69	87	104
2.2	15	30	45	59	74	89	18	35	53	70	88	105
2.4	15	30	45	60	75	90	18	36	54	71	89	107
2.6	15	31	46	61	77	92	18	37	55	73	92	110
2.8	16	31	47	62	78	93	19	37	56	74	93	111
3	16	32	48	63	79	95	19	38	57	75	94	113

CHLORINE CONCENTRATION (mg/L)	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
<=0.4	17	35	52	69	87	104	21	42	63	83	104	125
0.6	18	36	54	71	89	107	21	43	64	85	107	128
0.8	18	37	55	73	92	110	22	44	66	87	109	131
1	19	37	56	75	93	112	22	45	67	89	112	134
1.2	19	38	57	76	95	114	23	46	69	91	114	137
1.4	19	39	58	77	97	116	23	47	70	93	117	140
1.6	20	40	60	79	99	119	24	48	72	96	120	144
1.8	20	41	61	81	102	122	25	49	74	98	123	147
2	21	41	62	83	103	124	25	50	75	100	125	150
2.2	21	42	64	85	106	127	26	51	77	102	128	153
2.4	22	43	65	86	108	129	26	52	79	105	131	157
2.6	22	44	66	87	109	131	27	53	80	107	133	160
2.8	22	45	67	89	112	134	27	54	82	109	136	163
3	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					
	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
0.6	26	51	77	102	128	153	31	61	92	122	153	183
0.8	26	53	79	105	132	158	32	63	95	126	158	189
1	27	54	81	108	135	162	33	65	98	130	163	195
1.2	28	55	83	111	138	166	33	67	100	133	167	200
1.4	28	57	85	113	142	170	34	69	103	137	172	206
1.6	29	58	87	116	145	174	35	70	106	141	176	211
1.8	30	60	90	119	149	179	36	72	108	143	179	215
2	30	61	91	121	152	182	37	74	111	147	184	221
2.2	31	62	93	124	155	186	38	75	113	150	188	225
2.4	32	63	95	127	158	190	38	77	115	153	192	230
2.6	32	65	97	129	162	194	39	78	117	156	195	234
2.8	33	66	99	131	164	197	40	80	120	159	199	239
3	34	67	101	134	168	201	41	81	122	162	203	243

CHLORINE CONCENTRATION (mg/L)	pH=9.0 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	35	70	105	139	174	209
0.6	36	73	109	145	182	218
0.8	38	75	113	151	188	226
1	39	78	117	156	195	234
1.2	40	80	120	160	200	240
1.4	41	82	124	165	206	247
1.6	42	84	127	169	211	253
1.8	43	86	130	173	216	259
2	44	88	133	177	221	265
2.2	45	90	136	181	226	271
2.4	46	92	138	184	230	276
2.6	47	94	141	187	234	281
2.8	48	96	144	191	239	287
3	49	97	146	195	243	292

Source: AWWA, 1991.

Figure 7.3[33]

Therefore, Table C-3 is the correct table to use for this data set. The title of the table tells you which CT value the table will provide. Table C-3 above is for *Giardia*, with free chlorine as the disinfectant, at a temperature of 10°C.

[33] Image by the EPA is in the public domain

Finding Required CT

Now you need the other information in the problem statement. Specifically, the pH and the dosage concentration. There are seven (7) boxes in the table each with different pH values. 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.

Example: Given the following information, what is the Required CT?

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

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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.

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Appendix C. CT Values for Inactivations Achieved by Various Disinfectants

Figure 7.4[34]

To find the required CT on the table, look for the box in the table that says pH = 7.5. Now look at the far left of the table and find the dosage of 0.2 mg/L as indicated in the problem statement. 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. Referring back to Table 7.1 you can identify the Log credit

[34] Image by the EPA is in the public domain

and resulting disinfection inactivation requirements. You should come up with a required inactivation from disinfection of 1 Log.

3 Log required – 2 Log credit for direct filtration = 1 Log remaining
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 (circled above).

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.

Example: 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. What is the time 0.2 mg/L of free chlorine is in contact with the water?

First you need to calculate the detention time.

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

$$\text{Pipe Volume} = 0.785 \times D^2 \times L$$

$$0.785 \times (1\text{ ft})^2 \text{ x } 5{,}000\text{ ft} = 3{,}925\ \text{ft}^3$$

Convert the volume to gallons.

$$3{,}925\ \text{ft}^3 \times \frac{7.48\text{ gal}}{\text{ft}^3} = 29{,}359\text{ gal}$$

Convert the flow rate to gallons per minute.

$$\frac{2{,}000{,}000\text{ gallons}}{1\text{ day}} \times \frac{1\text{ day}}{1{,}440\text{ minutes}} = 1{,}388.88\text{ gpm} = 1{,}389\text{ gpm}$$

Now you can calculate the detention time.

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{29{,}359 \text{ gal}}{1{,}389 \text{ gpm}} = 21.136789 \text{ mins} = 21 \text{ mins}$$

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

$$0.2 \text{ mg/L} \times 21 \text{ min} = 4.2 \text{ mg/L min}$$

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

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

$$1.2 \text{ mg/L} \times 20 \text{ min} = 24 \text{ mg/L min}$$

Example: Using the information from the previous examples, is CT met for this treatment plant?

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

$$4.2 \text{ mg/L} + 24 \text{ mg/L min} = 28.2 \text{ mg/L min}$$

To answer the question, it is helpful to organize the data in a table and to calculate the CT Ratio.

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 in solving this problem is identifying the CT Tables to use to find the required CT values. This particular problem uses CT Tables C-3 and C-10. Remember to subtract out the 2.5 Log credit for conventional treatment.

The next step is to organize the data in a table.

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 calculate the actual CT using the formula for detention time.

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

First determine the volume in the pipe in gallons.

$$\text{Pipe Volume} = 0.785 \times D^2 \times L$$

$$0.785 \times (3\text{ ft})^2 \text{ x } 9{,}000\text{ ft} = 63{,}585\text{ ft}^3$$

Convert the volume to gallons.

$$63{,}585\text{ ft}^3 \times \frac{7.48\text{ gal}}{\text{ft}^3} = 475{,}615.8\text{ gal} = 475{,}616\text{ gal}$$

Convert the flow rate to gallons per minute.

$$\frac{10{,}000{,}000\text{ gallons}}{1\text{ day}} \times \frac{1\text{ day}}{1{,}440\text{ minutes}} = 6{,}944.44\text{ gpm} = 6{,}944\text{ gpm}$$

Now you can calculate the detention time.

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{475{,}616\text{ gal}}{6{,}944\text{ gpm}} = 68.4930\text{ mins} = 68.5\text{ mins}$$

Now you multiply the detention time by the concentration, and you get CT through the pipeline.

$$0.4 \text{ mg/L} \times 68.5 \text{ min} = 27.4 \text{ mg/L min}$$

Therefore, the actual CT through the pipeline is 27.4 mg/L min.

Next determine the actual CT through the plant.

$$1.2 \text{ mg/L} \times 30 \text{ min} = 36 \text{ mg/L min}$$

Now you can finish populating the table and calculating the CT Ratios.

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.

Key Terms

- **CT** – concentration and time for a disinfectant

Practice Problems 7.1

1. What is the required CT inactivation in a conventional filtration plant for Giardia by free chlorine at 20°C with a pH of 8.0 and a chlorine concentration of 2.0 mg/L? (Look up value in the CT tables and remember to apply any credits.)

2. What is the required CT inactivation for viruses with chlorine dioxide, a pH of 9.0, and a temperature of 10°C?

3. What is the required CT inactivation in a direct filtration plant for Giardia by free chlorine at 15°C with a pH of 7.0 and a chlorine concentration of 2.8 mg/L?

4. A conventional water treatment plant is fed from a reservoir 1.5 miles away through a 7-foot diameter pipe. Disinfection is provided from the supply reservoir to the plant influent at a free chlorine residual of 0.6 mg/L. The daily flow is a constant 40 MGD. And the water is 10°C and has a pH of 8.5. The treatment plant maintains a chloramines residual of 2.0 mg/L. Tracer studies have shown the contact time (T_{10}) for the treatment plant at the rated capacity of 40 MGD to be 22 minutes. Does this plant meet compliance for CT inactivation for *Giardia*?

5. A conventional water treatment plant is fed from a reservoir 4 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 0.1 mg/L. The daily flow is a constant 25 MGD. The water is 10°C and has a pH of 7.0. The treatment plant maintains a chloramines residual of 1.5 mg/L. Tracer studies have shown the contact time (T_{10}) for the treatment plant at the rated capacity of 25 MGD to be 55 minutes. Does this plant meet compliance for CT inactivation for viruses?

6. A direct filtration water treatment plant is fed from a reservoir 0.5 miles away through a 3-foot diameter pipe. Disinfection is provided from the supply reservoir to the plant influent at a free chlorine residual of 0.6 mg/L. The daily flow is a constant 15 MGD. The water is 15°C and has a pH of 7.0. The treatment plant maintains a chloramines residual of 0.4 mg/L. Tracer studies have shown the contact time (T_{10}) for the treatment plant at the rated capacity of 15 MGD to be 30 minutes. Does this plant meet compliance for CT inactivation for *Giardia*?

7. A direct filtration plant is operated at a designed flow of 20 MGD with a contact time of 35 minutes. A free chlorine dose of 1.2 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 0.4 mg/L through a pipeline with a contact time of 12 minutes into a 650,000-gallon reservoir. The pH of the water is 8.5 and has a temperature of 15°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 is 0.5 ppm through 200 ft of 24" diameter pipe at a flow rate of 730 gpm? Assume the water is 15°C and has a pH of 8.0.

Exercise 7.1

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? (Look up value in the CT tables and remember to apply any credits.)

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. 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. 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 is 2.60 ppm through 150 ft of 48” diameter pipe at a flow rate of 1,200 gpm? Assume the water is 15°C and has a pH of 7.0.

UNIT 8

8.1 PRESSURE

Pressure is the amount of force that is "pushing" on a specific unit area. 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. This is why you see water tanks on top of hills.

Figure 8.1[35]

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 psi change there is a 2.31 foot in elevation change.

[35] Photo used with permission of SCV Water

1 foot = 0.433 psi

2.31 feet = 1 psi

Written as conversion factors, these relationships can be expressed as follows.

$$\frac{1 \text{ psi}}{2.31 \text{ ft}} \quad \text{or} \quad \frac{1 \text{ ft}}{0.433 \text{ psi}}$$

Remember, as with all conversion factors, these conversion factors can also be written as the inverse.

$$\frac{2.31 \text{ ft}}{1 \text{ psi}} \quad \text{or} \quad \frac{0.433 \text{ psi}}{1 \text{ ft}}$$

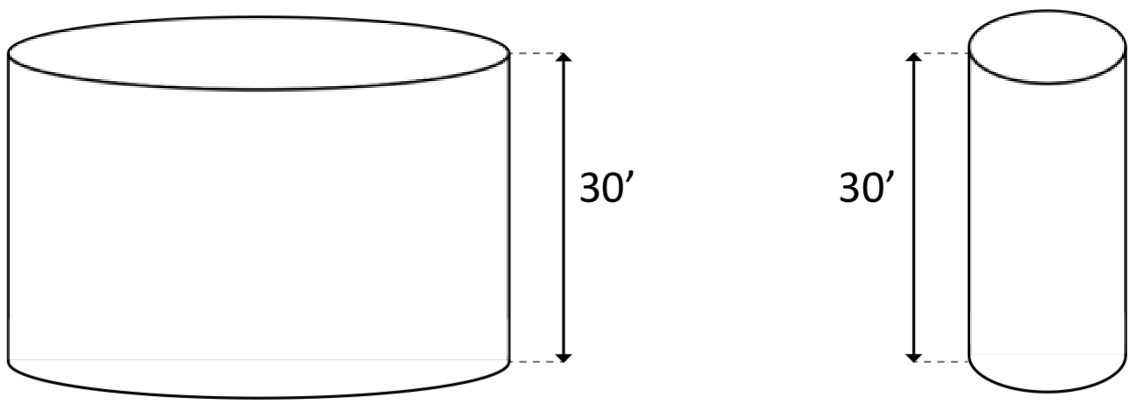


Figure 8.2[36]

Example: If both tanks above are filled with water, which one has a greater pressure at the base of it?

This is a trick question. The answer is neither! The pressure at the base of each tank is the same because the height of the water is the same.

What is the pressure at the base of each cylinder?

$$\frac{30 \text{ ft}}{1} \times \frac{1 \text{ psi}}{2.31 \text{ ft}} = 12.99 \text{ psi} \quad \text{or} \quad \frac{30 \text{ ft}}{1} \times \frac{0.433 \text{ psi}}{1 \text{ ft}} = 12.99 \text{ psi}$$

As you can see, it doesn’t matter which conversion factor you use. The answer remains the same and can be rounded to 13 psi.

[36] Image by Marilyn Hightower is licensed under CC BY 4.0

From this example, it is clear that the pressure exerted on the bottom of the tank is the same for either tank, but what about the force? Is the force exerted on the bottom of both tanks the same too?

Remember from Unit 3 that 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: Looking at these tanks again, assume that the diameter of the narrower tank is 10 feet and the diameter of the wider tank is 40 feet. Assume both tanks are filled with water. What is the force exerted on the bottom of each tank?

There are a couple ways to calculate the force. First, let's look at it in terms of tank volume. We'll start with the smaller 10-foot diameter tank.

$$\text{Volume of 10' diam tank} = 0.785 \times (10\text{ ft})^2 \times 30\text{ ft} = 2{,}355\text{ ft}^3$$

Now convert the volume to gallons.

$$2{,}355\text{ cf} \times \frac{7.48\text{ gal}}{1\text{ cf}} = 17{,}615.4\text{ gal}$$

$$\text{Volume of 40' diam tank} = 0.785 \times (40\text{ ft})^2 \times 30\text{ ft} = 37{,}680\text{ ft}^3$$

Now convert the volume to gallons.

$$37{,}680\text{ cf} \times \frac{7.48\text{ gal}}{1\text{ cf}} = 281{,}846.4\text{ gal}$$

Force is always expressed in pounds. If you multiply the volume in gallons by 8.34 lbs per gallon, you will be left with the pounds of force being exerted on the bottom of each tank.

For the 10 ft diameter tank the calculation is as follows:

$$17{,}615.4\text{ gal} \times \frac{8.34\text{ lbs}}{\text{gal}} = 146{,}912.436\text{ lbs} = 146{,}912\text{ lbs}$$

For the 40 ft diameter tank the calculation is as follows:

$$281{,}846.4\text{ gal} \times \frac{8.34\text{ lbs}}{\text{gal}} = 2{,}350{,}598.976\text{ lbs} = 2{,}350{,}599\text{ lbs}$$

Clearly, the force exerted on the bottom of the larger, 40-foot diameter tank, is significantly greater than the force exerted on the 10-foot diameter tank.
Let's look at this problem a different way. The formula for force is:

$$\text{Force} = \text{Pressure} \times \text{Area}$$

Typically, pressure would be calculated in psi, but this requires that the area be expressed in square inches in order to calculate force. Since the tank diameters are given in feet, you can convert pressure from psi, pounds per square inch, to pounds per square foot.

From the previous example, you know that the pressure on the bottom of both tanks is 13 psi. Convert pounds per square inch to pounds per square foot.

$$\frac{13 \text{ lbs}}{\text{in}^2} \times \frac{144 \text{ in}^2}{1 \text{ ft}^2} = \frac{1{,}872 \text{ lbs}}{\text{ft}^2}$$

The bottom of each tank is a circle and the area can be calculated as follows:

$$\text{Area of a Circle} = 0.785 \times D^2$$

$$\text{Area of 10 ft diam tank} = 0.785 \times (10 \text{ ft})^2 = 78.5 \text{ ft}^2$$

$$\text{Area of 40 ft diam tank} = 0.785 \times (40 \text{ ft})^2 = 1{,}256 \text{ ft}^2$$

Now you can substitute these values into the Force equation. For the 10-foot diameter tank the force is the following.

$$\text{Force} = \frac{1{,}872 \text{ lbs}}{\text{ft}^2} \times 78.5 \text{ ft}^2 = 146{,}952 \text{ lbs}$$

For the 40-foot diameter tank the force is the following.

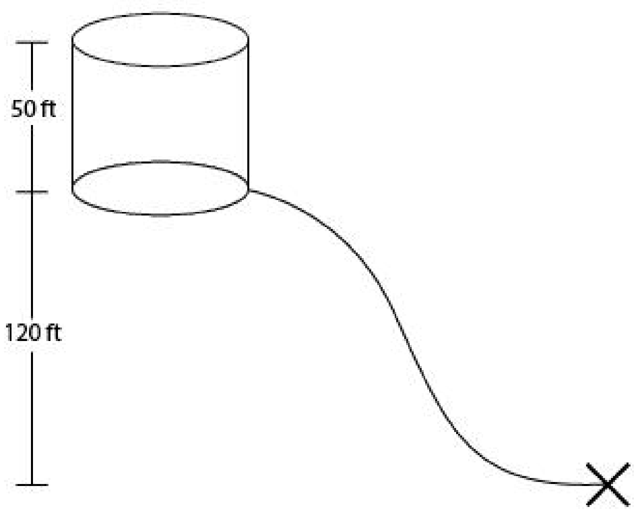
$$\text{Force} = \frac{1{,}872 \text{ lbs}}{\text{ft}^2} \times 1{,}256 \text{ ft}^2 = 2{,}351{,}232 \text{ lbs}$$

As you can see, the outcome is the same. The force being exerted on the bottom of the larger tank is significantly greater. The calculated value of the force is slightly different from the previous calculation due to rounding in the standard conversion factors.

Practice Problems 8.1

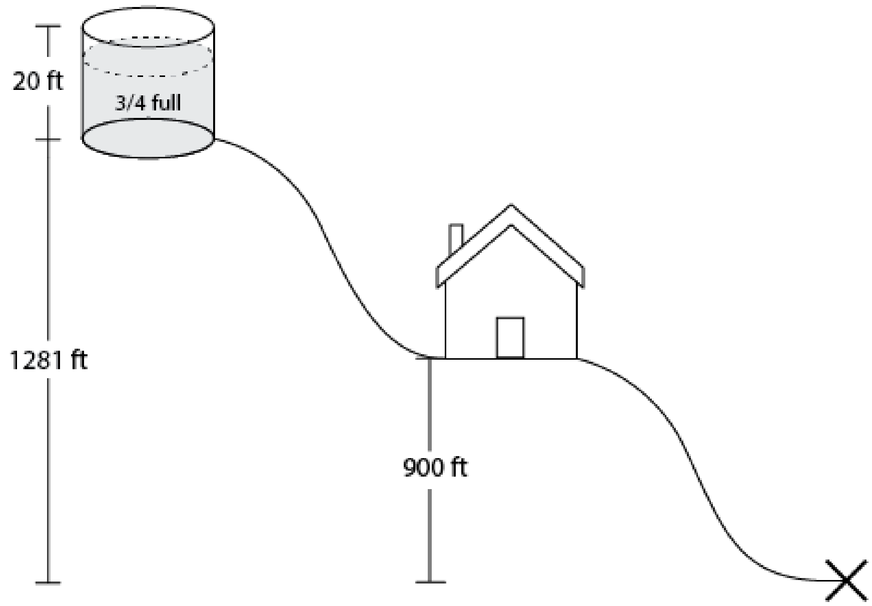
1. What is the pressure at the bottom of a 65-ft tank if the tank is half full?

2. A 50-foot-tall tank sits on a 120 foot tall hill. Assuming the tank is full, what is the pressure at the bottom of the hill?

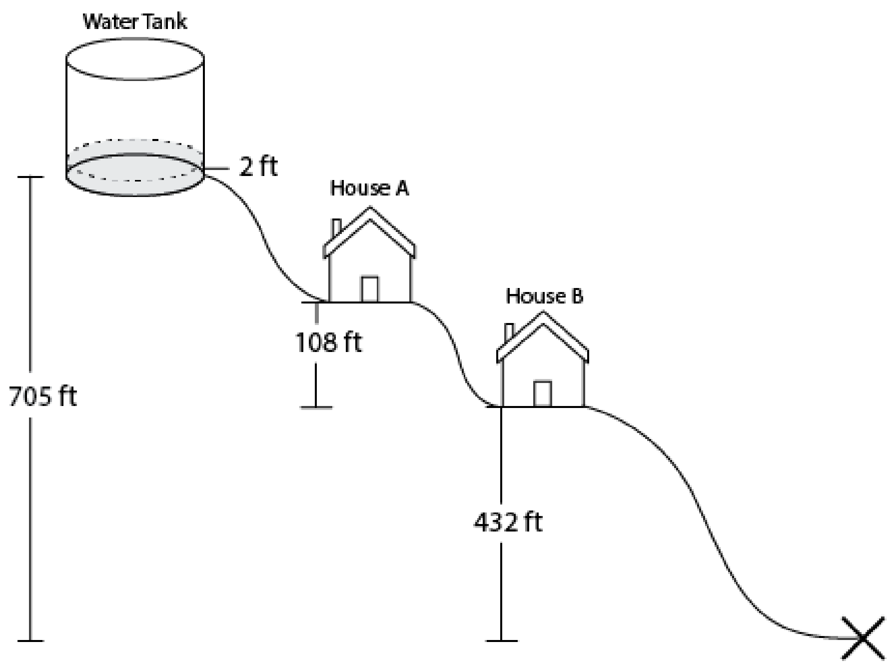


3. The opening of a 3.7” fire hydrant nozzle has a pressure of 212 psi. What is the corresponding force in pounds?

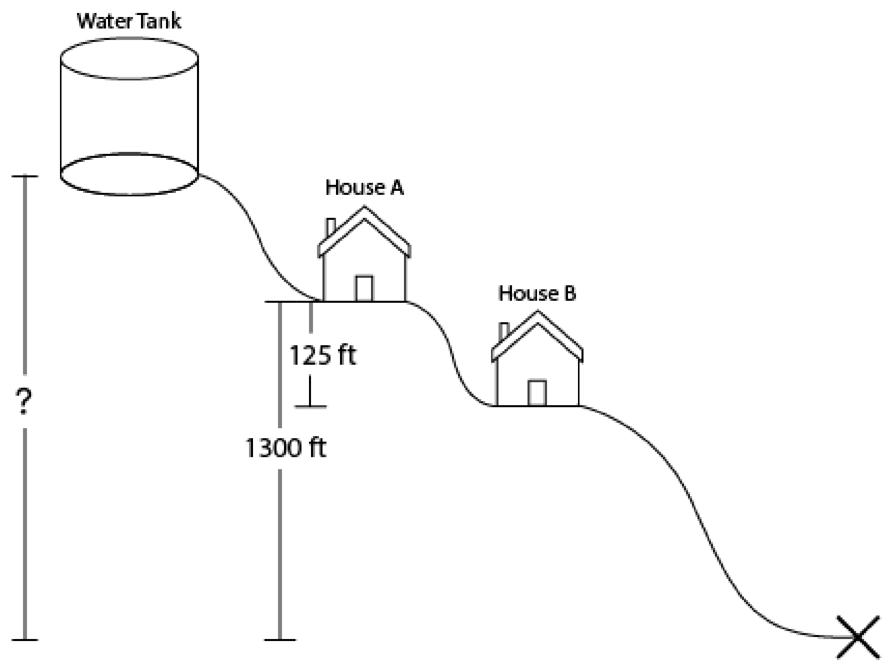
4. A home sits at an elevation of 900 ft above sea level. The base of a water tank that serves the home sits at an elevation of 1,281 ft above sea level. The tank is 20 feet tall and ¾ full. What is the pressure in psi at the home?



5. Two houses are served by a nearby water storage tank. House A is 108 ft above House B which sits at 432 ft above sea level. The base of the tank sits at 705 ft above sea level. The low water level in the tank is at 2.0 ft. At the low level, will House A meet the minimum pressure requirements of 60 psi?



6. House A sits at an elevation of 1,300 ft. Another house (B) needs to be built 125 ft below House A. At what elevation should the tank be built in order to give House B the maximum pressure of 210 psi?



7. A flowing pipeline has a pressure of 65 psi and a corresponding force of 2,398 pounds. What is the diameter of the pipe?

Exercise 8.1

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 75foot 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?

8.2 HEAD LOSS

As water travels through objects including pipes, valves, and angle points, or goes up hill, there are losses in pressure (or head) due to the friction. These losses are called "friction" or **head loss**. There are standard tables listing head loss factors (also termed C factor) for pipes of differing age and material, different types of valves and angle points. 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.

To calculate the total head loss, you find the sum all the individual head losses.

$$3 \text{ ft} + 1 \text{ ft} + 1 \text{ ft} + 1 \text{ ft} + 1 \text{ ft} + 0.5 \text{ ft} + 0.5 \text{ ft} = 8 \text{ ft of head loss}$$

In distribution systems, water is pumped from lower elevations to higher elevations in order to supply customers with water in different areas called zones. Water is also pumped out of the ground using groundwater wells and from treatment plants that typically treat water from surface water sources. The water is then sent throughout the distribution system to supply customers in different pressure zones. As water makes its way through the distribution system head loss is realized (as mentioned in the previous paragraph) and pumps must overcome the head loss from elevation changes, interior pipe conditions, valves, and sudden angles.

Knowing the head losses will help determine what size pump is needed in a specific pressure zone. However, there are other forces acting on the pump that either help or hinder its ability to pump water. 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 because it has to lift water from a lower elevation. Suction head provides some help (head pressure) to the pump in order to get water from point A to point B.

Suction Lift and Suction Head

Let's take a look at how to identify suction head versus suction lift.

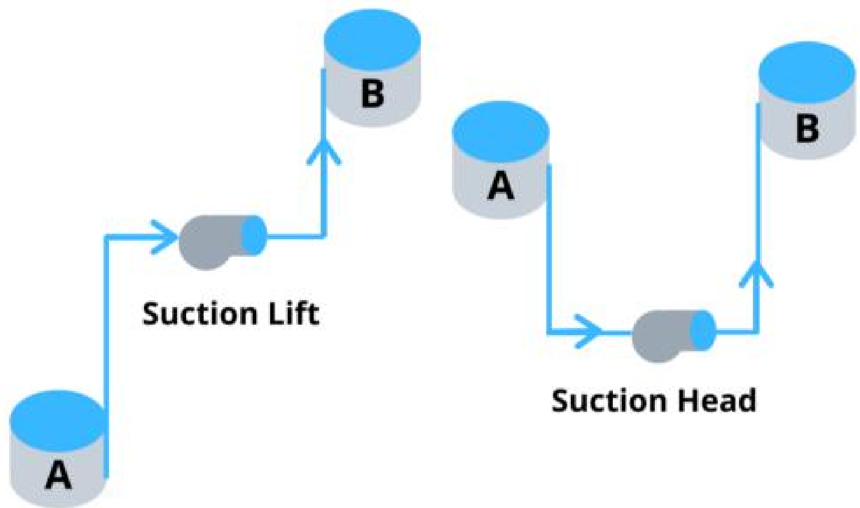


Figure 8.3[37]

Suction Lift

(Tank A Elevation + Pump Elevation) + (Pump Elevation + Tank B Elevation) = Total Head

Suction Head

(Tank B Elevation - Pump Elevation) - (Tank A Elevation – Pump Elevation) = Total Head

Friction can either be added or subtracted depending on where the measurement is being taken. See the two measuring points below (in red).

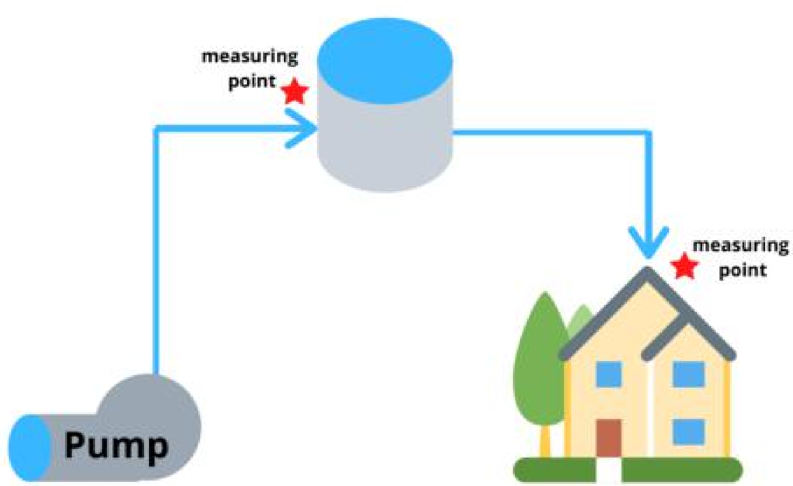


Figure 8.4[38]

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[37] Image by College of the Canyons OER Team is licensed under CC BY 4.0

[38] Image by College of the Canyons OER Team is licensed under CC BY 4.0

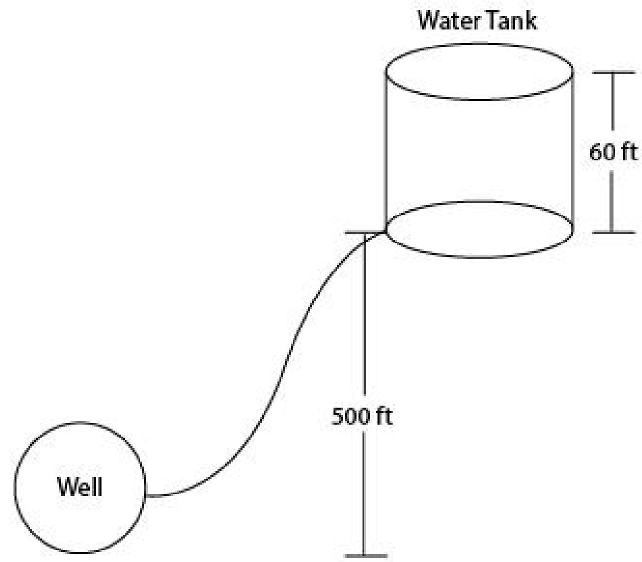
Friction will need to be added at the first measuring point because the pump will need to work harder to push water up to the tank. However, if water is traveling to a lower elevation like a home, then friction will need to be subtracted because the home will experience less pressure than it would have if there was no friction in the supply pipe.

Key Terms

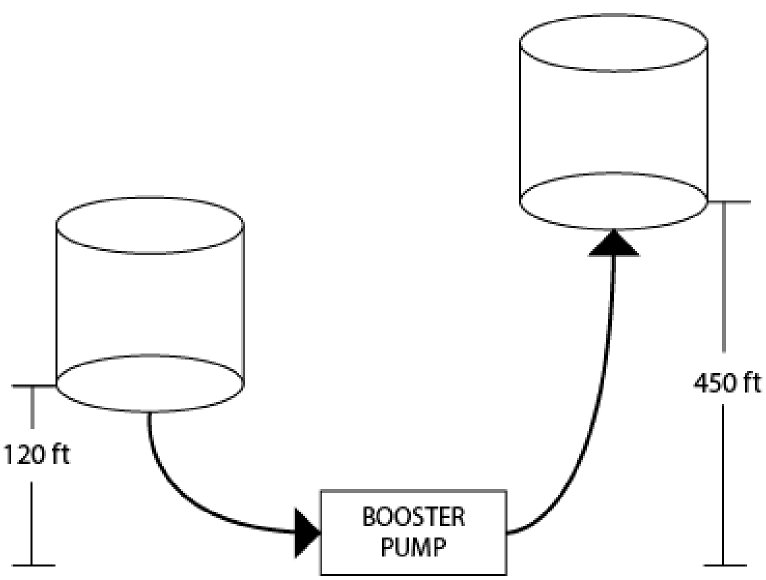
- **head loss** – loss in pressure or head in a water system
- **pressure** – the amount of force "pushing" on a specific unit area
- **suction lift** – (Tank A Elevation + Pump Elevation) + (Pump Elevation + Tank B Elevation) = Total Head
- **suction head** – (Tank B Elevation - Pump Elevation) - (Tank A Elevation – Pump Elevation) = Total Head

Practice Problems 8.2

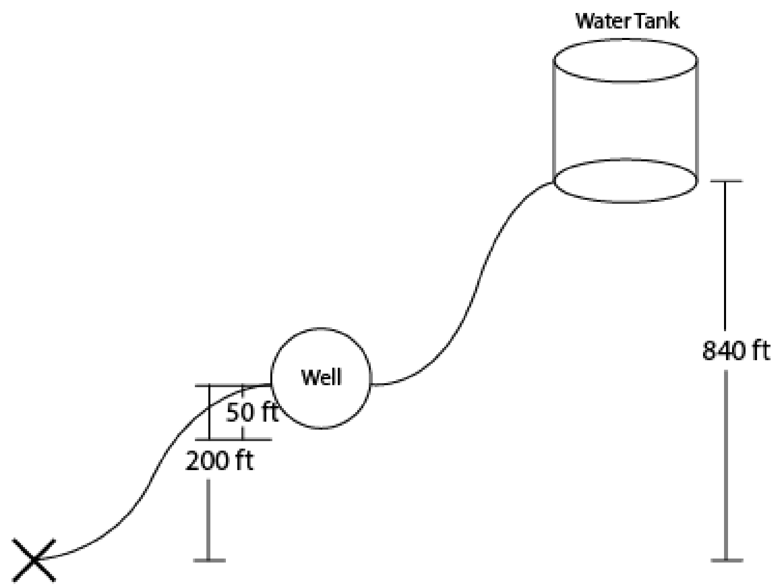
1. A well pumps directly to a 60-foot tall water tank that sits 500 feet above the elevation of the well. If the total head loss in the piping up to the tank is 14 feet, what is the total pressure in psi on the discharge side of the well?



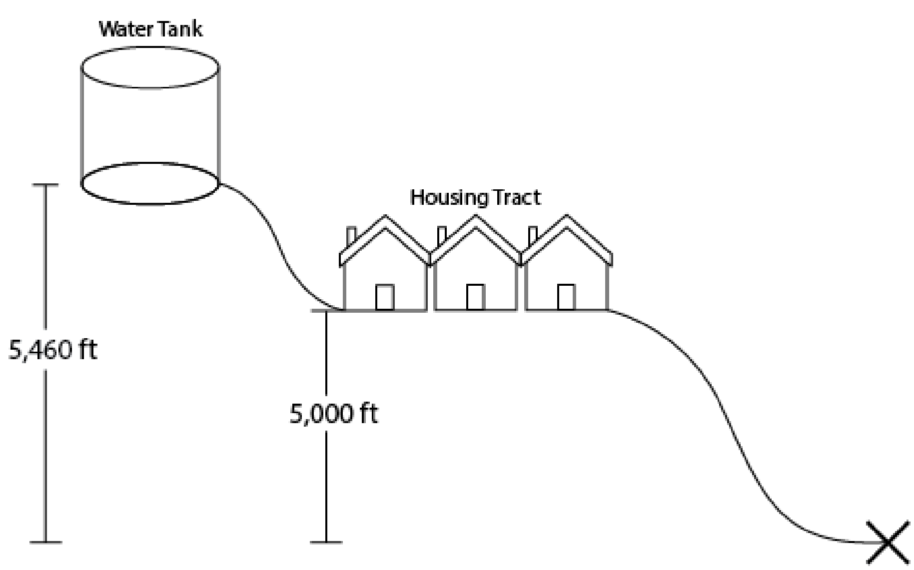
2. A booster pump receives water from a tank that is 120 feet above the pump and discharges to a tank that is 450 feet above the pump. What is the total head (TH)?



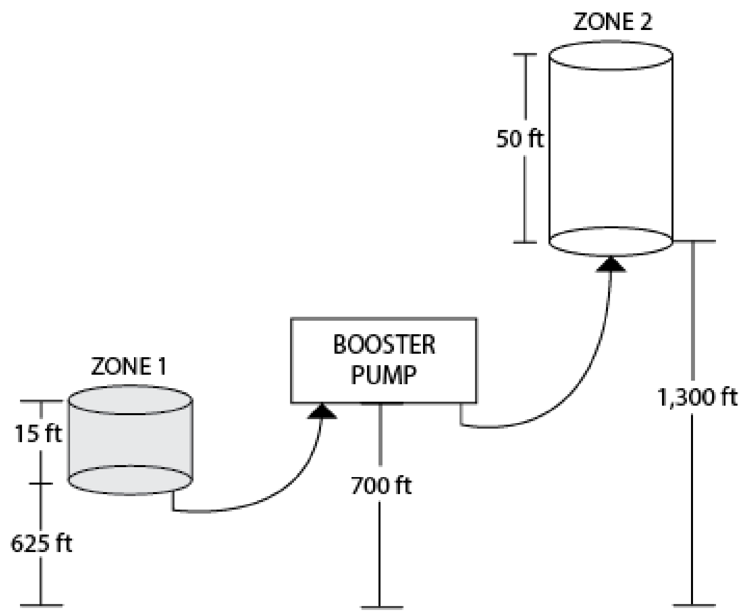
3. A well located at 200 feet above sea level has a below ground surface water depth of 50 ft and pumps to a water tank at an elevation of 840 ft above sea level. The water main from the well to the tank has a total head loss of 6 psi. What is the TH in feet?



4. A housing tract is located at an approximate average elevation of 5,000 ft above sea level and is served from a storage tank that is at 5,460 ft. The average head loss from the tank to the housing tract is 20.3 psi. What is the minimum water level in the tank to maintain a minimum pressure 30 psi?



5. A water utility has two different pressure zones (1 and 2.) The zone 1 Tank is 15 ft tall and sits at an elevation of 625 ft and the zone 2 Tank is 50 feet tall and sits at 1,300 ft. The booster pump from zone 1 to 2 sits at an elevation of 700 ft. The head loss is 11 psi. Tank 1 is full, and Tank 2 needs to be 1/2 full. What is the TH?



Exercise 8.2

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?

UNIT 9

9.1 WELL YIELD, SPECIFIC CAPACITY, AND DRAWDOWN

Many people in rural areas rely on their own well water as their primary and only source of water supply. Water agencies also rely on well water, in some cases, as their primary and only supply of water.

While the diagram below is of a single-family household well, the key parts are the same: well casing, well screen, and a submersible pump. The well casing is a tube that maintains the opening in the ground. The well screen is attached to the bottom of the casing and decreases the amount of sand that enters the well. The pump brings the water to the surface.

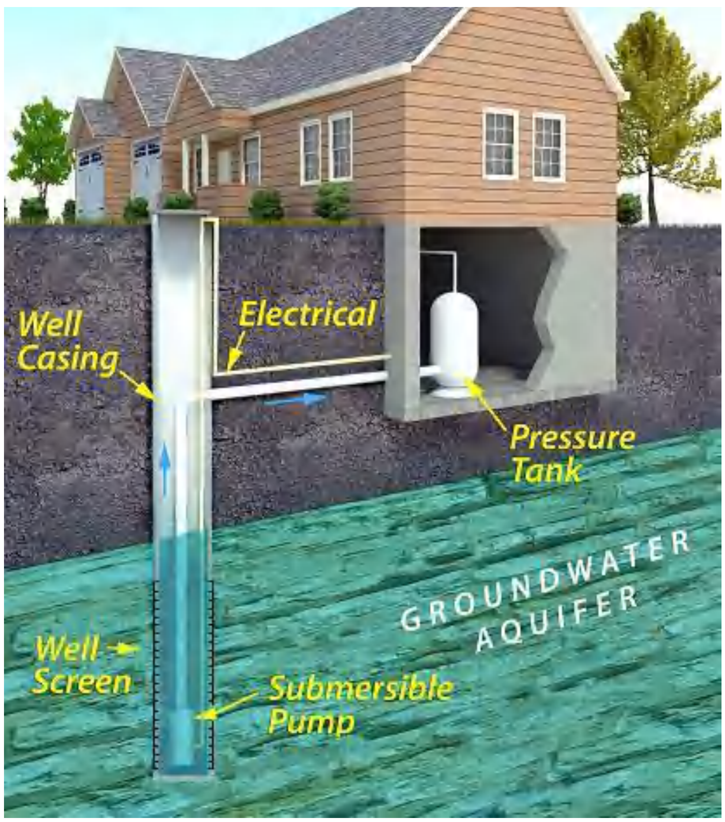


Figure 9.1[39]

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,

[39] Image by the EPA is in the public domain

pump tests are performed to determine if the underlying aquifer can supply enough water. Continuous pumping for an extended period 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.

Drawdown

In order to understand the term drawdown, you must also understand static water level and pumping water level. 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.

Drawdown = Pumping Water Level - Static Water Level

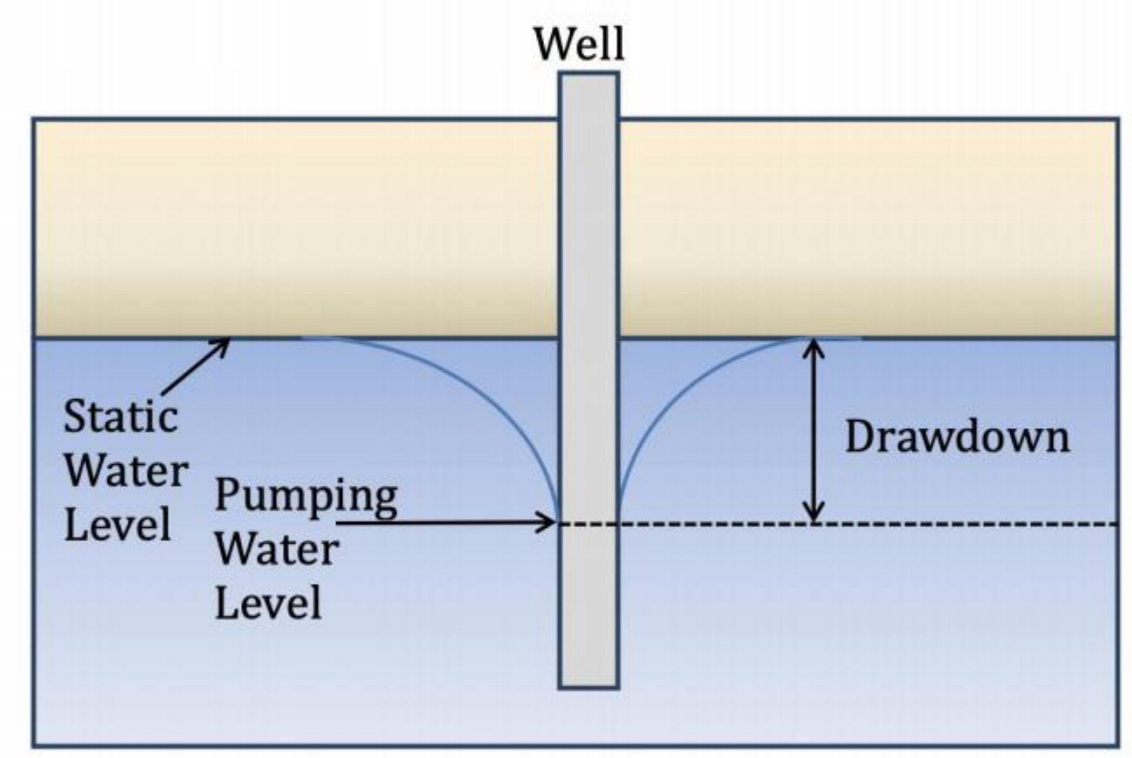


Figure 9.2[40]

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

[40] Image by College of the Canyons Water Technology faculty is licensed under

Cone of Depression

The triangular shape that results as a difference between the static water level and pumping water level is called the **cone of depression**. The bigger the well capacity, the bigger the cone of depression.

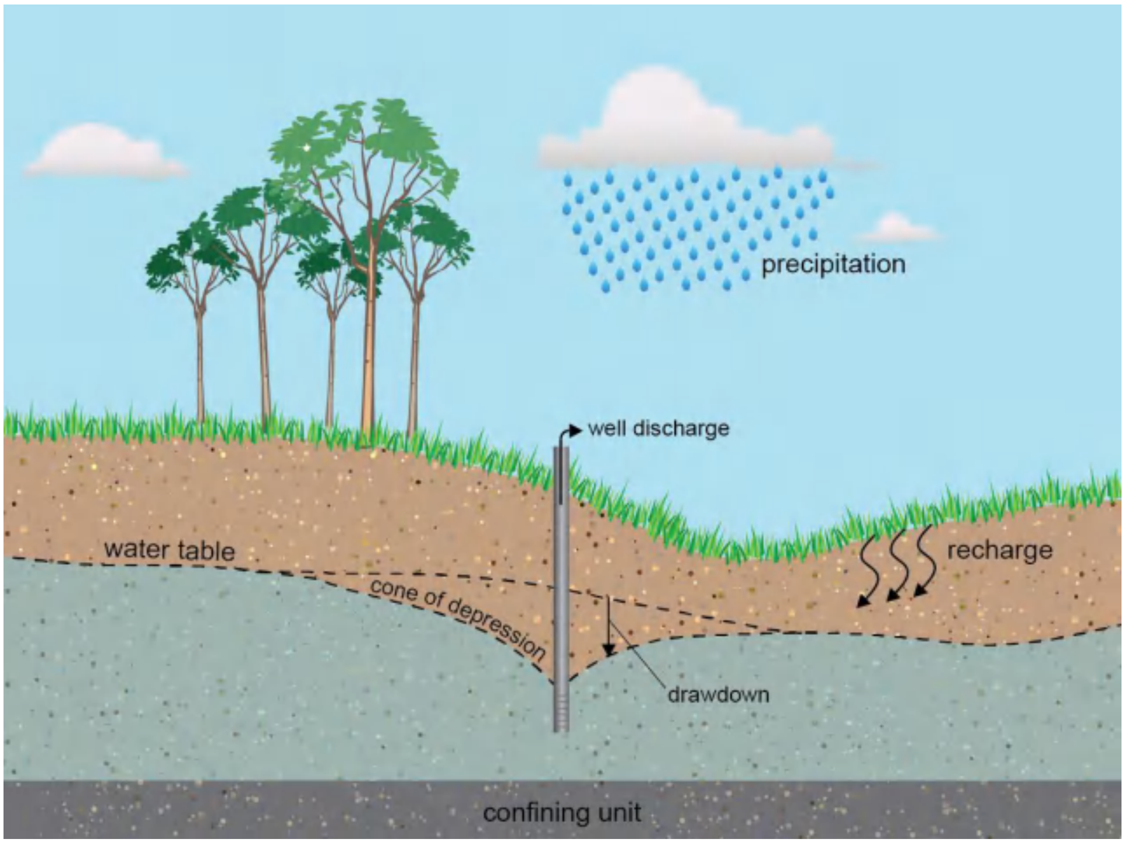


Figure 9.3[41]

Example: What is the drawdown of a well that has a pumping water level of 50 ft and a static water level of 20 ft?

Drawdown = Pumping Water Level - Static Water Level

Drawdown = 50 ft - 20 ft = 30 ft

Example: What is the pumping water level of a well that has a drawdown of 100 ft and a static water level of 40 ft?

Pumping Water Level = Drawdown + Static Water Level

Pumping Water Level = 100 ft + 40 ft = 140 ft

[41] Image by the USGS is in the public domain

Example: What is the static water level of a well that has a drawdown of 65 ft and a pumping water level of 127 ft?

Static Water Level = Pumping Water Level - Drawdown

Static Water Level = 127 ft - 65 ft = 62 ft

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

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

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.

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

Example: What is the specific capacity of a well that has a drawdown of 30 ft and flow rate of 1,000 gpm?

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

$$\text{Specific Capacity} = \frac{1{,}000 \text{ gpm}}{30 \text{ ft}} = \frac{33.33 \text{ gpm}}{\text{ft}}$$

Key Terms

- **cone of depression** – the triangular shape that results as a difference between static water level and pumping water level
- **specific capacity** – the well yield divided by the drawdown
- **well yield** – the amount of water a certain well can produce over a period of time

Practice Problems 9.1

1. A well has a static water level of 77 ft bgs and a pumping level of 111 ft bgs. What is the drawdown?

2. A groundwater well has a base elevation of 982 ft above sea level. If the drawdown on this well is 31 ft and the pumping level is 75 ft bgs, what is the static water elevation above sea level?

3. A deep well has a static water level of 148 ft bgs. A drawdown has been calculated out to be 83 ft. What is the pumping level of the well?

4. A well has an hour meter attached to a water meter totalizer. After 5 hours of operation, the well produced 374,000 gallons. Water is the well yield in gpm?

5. When a well was first constructed it was pumping 1,237 gpm. The efficiency of the well has dropped 42%. In addition, the drawdown has decreased by 22%. If the original drawdown was 66 ft what is the current specific capacity?

6. A well pumped 468 AF over a one-year period averaging 14 hours of operation per day. For half the year the static water level was 41 ft bgs and half the year 30 ft bgs. The pumping level averaged 72 ft bgs for half the year and 83 ft bgs the other half. What was the average specific capacity for the year?

7. A well has a specific capacity of 63 gpm per foot. The well operates at a constant 2,350 gpm. What is the drawdown?

8. A well has a calculated specific capacity of 18 gpm per foot and operates at a flow rate of 0.85 MGD. If the static water level is 56 ft bgs, what is the pumping level?

Exercise 9.1

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?

UNIT 10

10.1 HORSEPOWER AND EFFICIENCY

We discussed the theory of pressure in both feet (head pressure) and psi (pounds per square inch.) In this unit, 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 because of differences in elevation with above ground tanks, reservoirs, elevated storage tanks. In the Santa Clarita, tanks are clearly visible on the hill tops surrounding the valley floor, which creates water pressure to the customer's home

Figure 10.1[42]

Most water utilities have maps that show how pressure is broken into different zones with mechanisms for moving water between points within each zone. Moving water throughout the zones within the overall system is something that is carefully considered by distribution operators during daily work as well as during the design of the system itself or new portions of the system.

[42] Photo used with permission of SCV Water

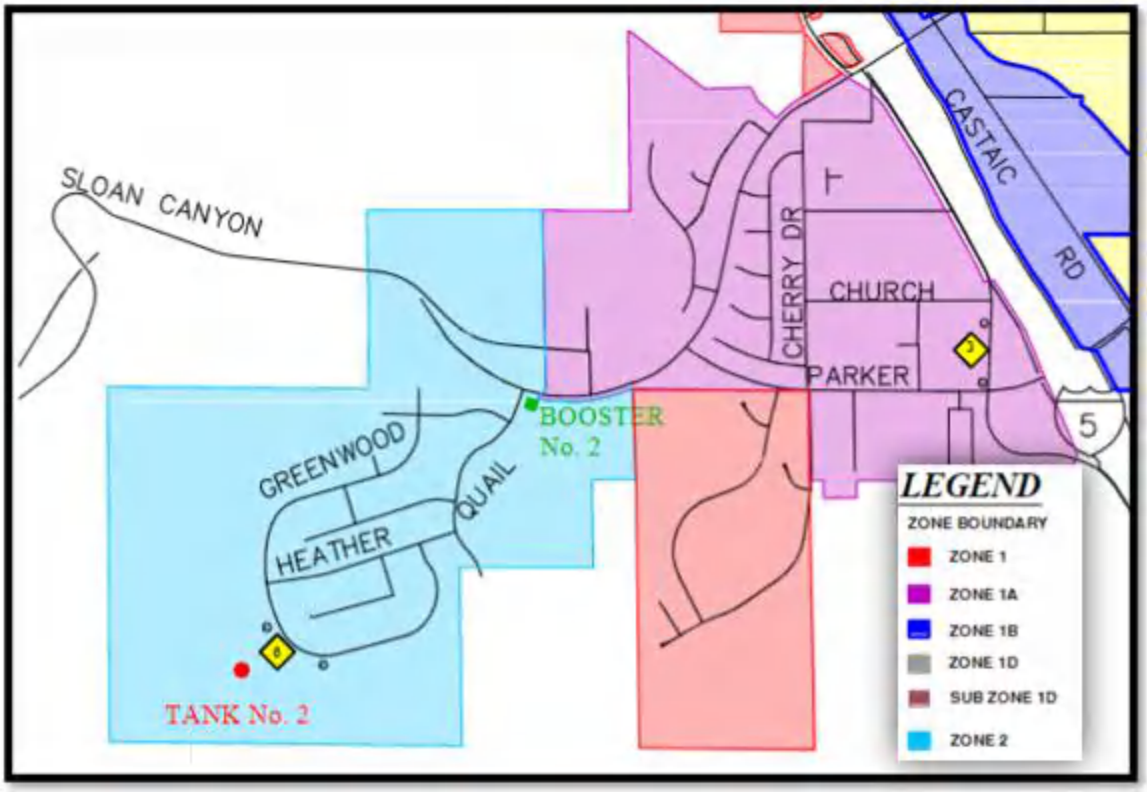


Figure 10.2[43]

How does the water move to the storage tanks? 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 horsepower 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.

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

[43] Photo used with permission of SCV Water

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 is 100% efficient. There are friction losses with each.

If the pump and the motor were both 100% efficient, then the resulting answer would be 100% x 100% or 1.0 x 1.0 = 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. This efficiency is termed the **wire-to-water efficiency**.

Pump Efficiency = 60%

Motor Efficiency = 80%

$$0.6 \times 0.8 = 0.48 \text{ or } 48\% \text{ efficient}$$

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. The formula below shows brake horsepower and motor horsepower, which includes the combined pump and motor inefficiencies.

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

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

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.

$$\frac{2.16\text{ MG}}{\text{D}} \times \frac{1{,}000{,}000\text{ gal}}{1\text{ MG}} \times \frac{1\text{ day}}{1{,}440\text{ min}} = 1{,}500\text{ gpm}$$

$$\frac{100\text{ psi}}{1} \times \frac{2.31\text{ ft}}{1\text{ psi}} = 231\text{ ft}$$

Now you can substitute these values into the equation and solve for horsepower.

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

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

To calculate, convert the percentages to decimals.

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

$$\text{Motor hp} = \frac{346{,}500}{2{,}187.9} = 158.371 = 158\text{ hp}$$

Practice Problems 10.1

1. What is the required water horsepower for 213 gpm and a total head pressure of 72 ft?

2. What is the water horsepower needed for a well that pumps 1,845 gpm against a pressure of 232 psi?

3. It has been determined that the wire-to-water efficiency at a pump station is 33%. If the pump station lifts 345 gpm to a tank 128 feet above, what is the motor horsepower needed?

4. What is the motor horsepower needed to pump 4,643 AF of water over a year with an average daily pumping operation of 6 hours? Assume the pump is pumping against 70 psi and has a pump efficiency of 90% and a motor efficiency of 75%.

Exercise 10.1

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%.

10.2 HEAD LOSS AND HORSEPOWER

As discussed in Unit 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.

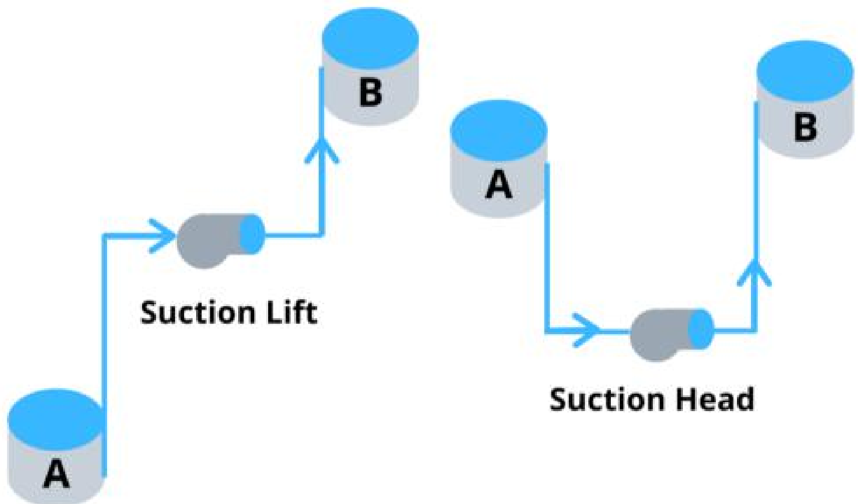


Figure 8.2[44]

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.

Example: A booster pump station is pumping water from Zone 1 at an elevation of 2,500 ft above sea level to Zone 2 which is at 3,127 ft above sea level. The pump station is located at an elevation of 1,824 ft above sea level. The losses through the piping and appurtenances equate to a total of 31 ft. Is this an example of Suction Lift or Suction Head? What is the total head?

Based on the elevations provided, this is an example of Suction Head. Both Zone 1 and Zone 2 are at a higher elevation than the pump.

To calculate the total head in feet, first determine the head between Zone 1 and the Pump.

2,500 ft - 1,832 ft = 676 ft

[44] Image by College of the Canyons OER Team is licensed under CC BY 4.0

Next determine the head between Zone 2 and the Pump.

3,127 ft - 1,832 ft = 1,303 ft

Now you can calculate the head in feet. Remember that this is a Suction Head configuration. Therefore, the pump only has to lift the water the height difference between the two Zones.

1,303 ft - 676 ft = 627 ft

Now to determine the total head, you must include the losses through the piping and appurtenances. These losses are additional head that the pump must work against.

627 ft + 31 ft = 658 ft

Therefore, 658 ft is the total head that would be used to determine the hp requirement or sizing of the pump.

Example: A well with pumps located 125 ft bgs pumps against a discharge head pressure of 85 psi to a tank located at an elevation 150 ft above the well. What is the level of water in the tank and what is the total head?

To calculate the feet of water in the tank, you need to convert the discharge head pressure to feet.

$$\frac{85 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 196.35 \text{ ft} = 196 \text{ ft}$$

The problem indicates that the tank is located 150 feet above the well. Therefore, the height of the water in the tank is the difference between the elevation and the discharge head pressure in feet.

196 ft - 150 ft = 46 ft

There are 46 feet of water in the tank.
To determine the total head, add the head from the pump to the surface to the discharge head in feet.

125 ft + 196 ft = 321 ft

Therefore, there are 321 feet of total head. Again, this total head would be used to calculate the horsepower required for the pump.

Practice Problems 10.2

1. A well is pumping water from an aquifer with a water table 55 feet below ground surface (bgs) to a tank 190 feet above the well. If the well flows 870 gpm, what is the required horsepower? (Assume the wire-to-water efficiency is 88%.)

2. A booster pump station is pumping water from Zone 1 at an elevation of 1,537 ft above sea level to Zone 2 which is at 1,745 ft above sea level. The pump station is located at an elevation of 1,124 ft above sea level. The pump was recently tested and the efficiencies for the pump and motor were 76% and 88% respectively. The losses through the piping and appurtenances equate to a total of 15 ft. If the pump flows 1,500 gpm, what is the required motor horsepower?

3. A well with pumps located 46 ft bgs pumps against a discharge head pressure of 140 psi to a tank located at an elevation 278 ft above the well. The well pumps at a rate of 1,260 gpm. What is the level of water in the tank and what is the required water horsepower? (Assume the wire-to-water efficiency is 70%.)

4. A 430 hp booster pump is pulling water from a 50-foot tall tank that is 85 feet below the pump line. It is then pumping against a discharge head pressure of 150 psi. What is the flow rate in gpm? Assume the wire-to-water efficiency is 92% and the tank is full.

Exercise 10.2

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.

10.3 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 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.

Example: A utility has 3 pumps that run at different flow rates and supply water to a 450,000 MG storage tank. Assume that only one pump runs per day. The TDH for the pumps is 73 ft. The utility needs to fill the tank daily and power costs are to be calculated at a rate of $0.088 per kW-Hr. Complete the table below.

Pump	Flow Rate (gpm)	hp	Efficiency	Run Time (hr)	Total Cost
1	720	70			
2	900	125			
4	3,100	450			

PUMP 1

First Calculate Efficiency:

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

$$70\text{ hp} = \frac{(720\text{ gpm})(73\text{ ft})}{(3{,}960)(?\ \%)}$$

$$(?\ \%) = \frac{(720\text{ gpm})(73\text{ ft})}{(3{,}960)70\text{ hp}}$$

$$(?\ \%) = \frac{52{,}560}{277{,}200} = 0.18961 \times 100 = 18.96\% = 19\%$$

Run Time to fill the 450,000-gallon tank.

$$450{,}000 \text{ gal} \times \frac{\text{min}}{720 \text{ gal}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 10.4166667 \text{ hr} = 10.42 \text{ hr}$$

Total Cost to fill the tank.

$$\frac{70 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 52.22 \text{ kW}$$

$$\frac{52.22 \text{ kW}}{1} \times \frac{\$\,0.088}{1 \text{ kW-hr}} \times \frac{10.42 \text{ hr}}{1 \text{ day}} = \$\,47.88 \text{ per day} = \$\,48 \text{ per day}$$

PUMP 2

First Calculate Efficiency:

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

$$125 \text{ hp} = \frac{(900 \text{ gpm})(73 \text{ ft})}{(3{,}960)(?\ \%)}$$

$$(?\ \%) = \frac{(900 \text{ gpm})(73 \text{ ft})}{(3{,}960)125 \text{ hp}}$$

$$(?\ \%) = \frac{65{,}700}{495{,}000} = 0.132727 \times 100 = 13.27\% = 13\%$$

Run Time to fill the 450,000-gallon tank.

$$450{,}000 \text{ gal} \times \frac{\text{min}}{900 \text{ gal}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 8.3333 \text{ hr} = 8.33 \text{ hr}$$

Total Cost to fill the tank.

$$\frac{125 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 93.25 \text{ kW}$$

$$\frac{93.25 \text{ kW}}{1} \times \frac{\$ 0.088}{1 \text{ kW-hr}} \times \frac{8.33 \text{ hr}}{1 \text{ day}} = \$ 68.35598 \text{ per day} = \$ 68 \text{ per day}$$

PUMP 4

First Calculate Efficiency:

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

$$450 \text{ hp} = \frac{(3{,}100 \text{ gpm})(73 \text{ ft})}{(3{,}960)(? \ \%)}$$

$$(? \ \%) = \frac{(3{,}100 \text{ gpm})(73 \text{ ft})}{(3{,}960)450 \text{ hp}}$$

$$(? \ \%) = \frac{226{,}300}{1{,}782{,}000} = 0.126992 \times 100 = 12.69\% = 13\%$$

Run Time to fill the 450,000-gallon tank.

$$450{,}000 \text{ gal} \times \frac{\text{min}}{3{,}100 \text{ gal}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 2.41935 \text{ hr} = 2.42 \text{ hr}$$

Total Cost to fill the tank.

$$\frac{450 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 335.7 \text{ kW}$$

$$\frac{335.7 \text{ kW}}{1} \times \frac{\$ 0.088}{1 \text{ kW-hr}} \times \frac{2.42 \text{ hr}}{1 \text{ day}} = \$ 71.49067 \text{ per day} = \$ 71 \text{ per day}$$

Pump	Flow Rate (gpm)	hp	Efficiency	Run Time (hr)	Total Cost
1	720	70	19%	10.42	$48
2	900	125	13%	8.33	$68
4	3,100	450	13%	2.42	$71

Key Terms

- **horsepower** – 1 horsepower = 0.746 kilowatts of power
- **wire-to-water efficiency** – the product of pump efficiency and motor efficiency

Practice Problems 10.3

1. A well flows an estimated 4,500 gpm against a discharge head pressure of 212 psi. What is the corresponding hp and kW if the pump has an efficiency of 55% and the motor 71%?

2. Based on the above question, how much would the electrical costs be if the rate is $0.15 per kW-Hr and the pump runs for 6 hours a day?

3. A utility has 3 pumps that run at different flow rates and supply water to an 800,000 gallon storage tank. Assume that only one pump runs per day. The TDH for the pumps is 130 ft. The utility needs to fill the tank daily and power costs are to be calculated at a rate of $0.10 per kW-Hr. Complete the table below.

Pump	Flow Rate (gpm)	hp	Efficiency	Run Time (hr)	Total Cost
1	630	65			
2	1,150	95			
3	2,440	375			

4. A well draws water from an aquifer that has an average water level of 100 ft bgs and pumps to a tank 300 ft above it. Friction loss to the tank is approximately 28 psi. If the well pumps at a rate of 1,900 gpm and has a wire-to-water efficiency of 45%, how much will it cost to run this well 10 hours per day. Assume the electrical rate is $0.22 per kW-Hr.

5. A utility manager is trying to determine which hp motor to purchase for a pump station. A 500 hp motor with a wire-to-water efficiency of 70% can pump 3,300 gpm. Similarly, a 300 hp motor with a wire-to-water efficiency of 80% can pump 2,500 gpm. With an electrical rate of $0.111 per kW-Hr, how much would it cost to run each motor to achieve a daily flow of 1.5 MG? Which one is less expensive to run?

6. Approximately 170 kW of power are needed to run a certain booster pump. If the booster has a wire-to-water efficiency of 81% and is pumping against 205 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 ($) @ $0.12/kW-Hr
A	900	12	60%	150		
B	1,550	19	78%	50		
C	3,375	8	69%	110		

8. It costs \$103.61 in electricity to run a well for 10 hours a day. The well has a TDH of 167 psi and an overall efficiency of 82.3%. The cost per kW-Hr is \$0.156. What is the cost of the water per gallon?

Exercise 10.3

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 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 per day 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. Assume that only one pump runs per day. 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?

UNIT 11

11.1 PER CAPITA WATER USE AND WATER USE EFFICIENCY

Water use is often expressed as **gallons per capita per day (GPCD)**. The term "per capita" means per person and the term "per day" means in a 24-hour period. Since the last drought, this term has been increasingly used to describe water use within communities, particularly for comparison of communities to one another.

Typically, to find the GPCD, the requirements from the state include looking at the entire water used in one year and comparing it to the total population served. This is a simple fraction.

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

This formula can provide an adequate estimate of water use, but if the utility provides water to large commercial or industrial customers, the GPCD will not reflect actual use for a person.

There are many communities that are hubs of employment and tourism in Southern California that can distort GPCD. For example, in Anaheim, the total systemwide GPCD is 105 GPCD in March 2020, but the residential GPCD is only 58.[45] Can you imagine why? Anaheim is home to Disneyland, so there are many tourists who come and stay overnight to visit Disneyland and use a lot of water along the way. Total GPCD does not necessarily measure **residential GPCD (R-GPCD)**.

$$\text{GPCD} = \frac{\text{total residential water use}}{\text{population}}$$

[45] Pacific Institute. "California Water Database." https://pacinst.org/gpcd/map/

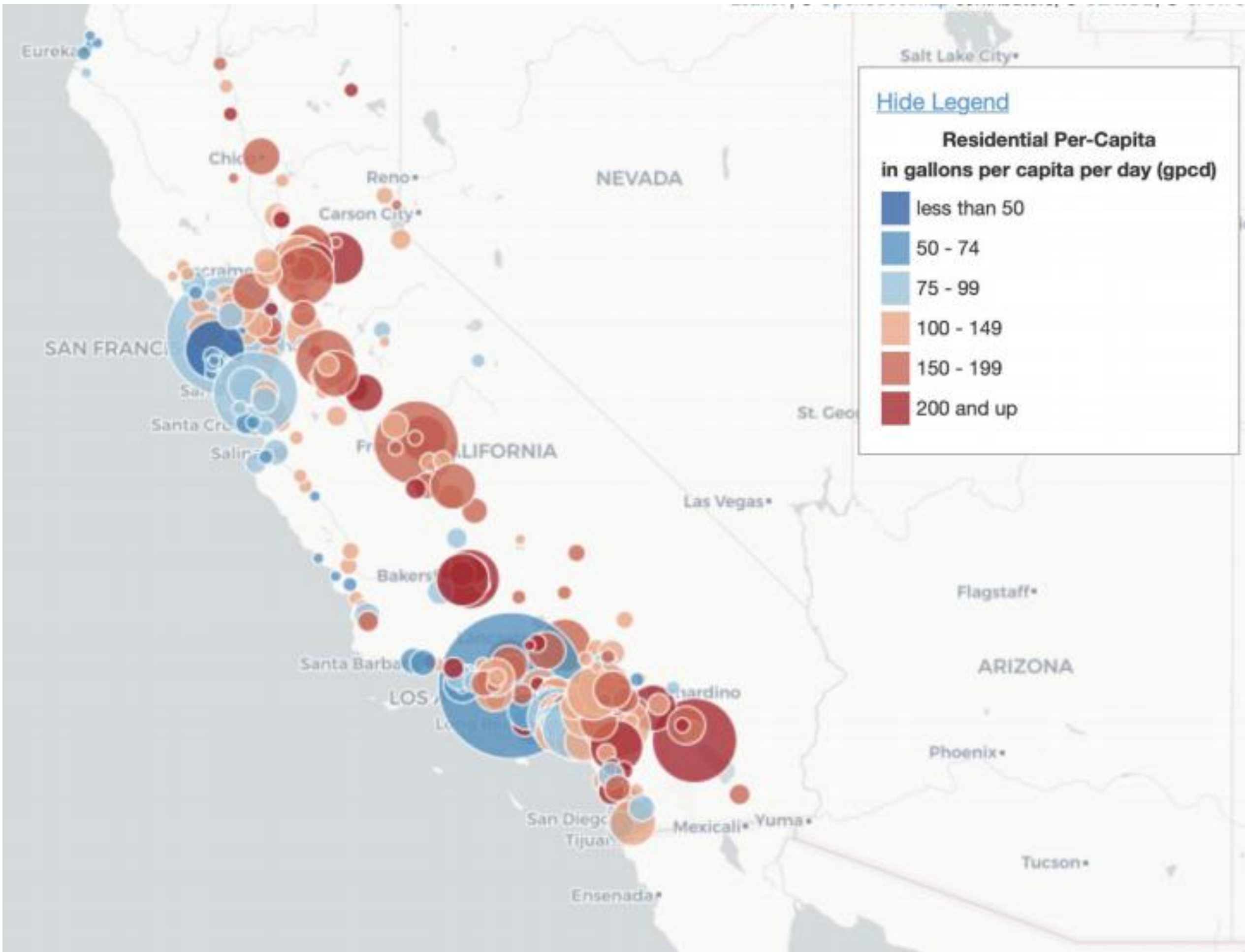


Figure 11.1[46]

One way to understand residential GPCD is to consider the pattern in the map. Communities that are on the coasts have a low GPCD while communities that are inland have a much higher GPCD. This reflects that R-GPCD is related to both indoor and outdoor water use. The demands for water by plants inland communities are much greater than in coastal communities, so the R-GPCDs for inland communities are far greater than in coastal communities.

Example: A community has a population of 300,000 and a total water use of 80,000 acre-feet per year. What is the GPCD for the community?

First, convert 80,000 acre-feet per year to gallons per year

$$\frac{80{,}000 \text{ AF}}{\text{year}} \times \frac{325{,}851 \text{ gal}}{1 \text{ AF}} = 26{,}068{,}080{,}000 \ \frac{\text{gal}}{\text{year}}$$

[46] Map generated from data by Pacific Institute. "California Water Database." https://pacinst.org/gpcd/table/

That's a lot of gallons. This is why water resources managers work in acre-feet.

Now divide the total gallons by the population.

$$\frac{26{,}068{,}080{,}000 \ \frac{\text{gal}}{\text{year}}}{300{,}000 \text{ people}} = 86{,}893 \text{ gal per person per year}$$

Finally, divide the amount per person per year by the number of days in a year.

$$\frac{86{,}893 \text{ gal per person per year}}{365 \text{ days per year}} = 238 \text{ gallons per person}$$

From this example, you can see that by converting from acre-feet to gallons, dividing by population and then converting from per year to per day, you can calculate the GPCD for the entire community.

GPCD calculations can be useful in making estimations about how to meet typical demand.

Example: If a small water system has one well that can pump 250 gallons per minute to serve a population of 1,575 people with an average GPCD of 100, how many hours must this pump run to meet the demand?

Assuming this is the only source of water, calculate the daily demand in the system. If the average GPCD is 100 gallons per person per day, then the daily demand in the system is:

$$1{,}575 \text{ people} \times \frac{100 \text{ gal}}{\text{person - day}} = 157{,}500 \text{ gallons per day}$$

Then you need to divide the daily demand by the number of gallons per minute that the well can product.

$$\frac{157{,}500 \text{ gallons per day}}{250 \text{ gallons per min}} = 630 \text{ minutes}$$

$$630 \text{ minutes} \times \frac{1 \text{ hour}}{60 \text{ min}} = 10.5 \text{ hours} = 10 \text{ hours } 30 \text{ minutes}$$

This means that the pump must run for 10.5 hours to supply daily demand.

You can see how GPCD can be a useful calculation in reporting to the state and estimating how to meet demand of customers. Sometimes it is useful to focus on the residential GPCD or R-GPCD to measure conservation.

Example: In a community of 300,000, approximately 60% of the 80,000 acre-feet of water is used by the residential sector. What is the R-GPCD?

First, you need to find the amount of water used by the residential sector.

$$\frac{80{,}000 \text{ AF}}{\text{year}} \times 0.60 = 48{,}000 \frac{\text{AF}}{\text{year}}$$

Now convert the acre-feet per year to gallons per year.

$$\frac{48{,}000 \text{ AF}}{\text{year}} \times \frac{325{,}851 \text{ gal}}{1 \text{ AF}} = 15{,}640{,}848{,}000 \frac{\text{gal}}{\text{year}}$$

Now divide the total gallons by the population.

$$\frac{15{,}640{,}848{,}000 \frac{\text{gal}}{\text{year}}}{300{,}000 \text{ people}} = 52{,}136 \text{ gal per person per year}$$

Finally, divide the amount per person by the number of days in a year.

$$\frac{52{,}136 \text{ gal per person per year}}{365 \text{ days per year}} = 142 \text{ gallons per person per year}$$

There is a considerable difference between total GPCD of 238 and R-GPCD of 142 in many communities because non-residential use from businesses, schools, and parks can be considerable.

What are the components of R-GPCD?

The biggest component is typically landscaping. In California, 60-70% of residential use is for outdoor landscaping, including front yards, backyards, pools, spas and any other water features. The state of California and local water agencies have encouraged residents to remove turf grass, particularly in their front yards where it is mostly “aesthetic” and replace it with lower-water use plants. Slowly this is decreasing outdoor residential water use.

Indoor water use results from washing our hands, flushing the toilet, showering and cleaning. The state of California has found that changing the residential building code (called the Cal

Green Building Code) has resulted in considerable savings. The table below measures flow rates for various fixtures in units of gallons per minute (gpm) for showers and faucets, gallons per flush (gpf) for toilets and gallons per cubic foot (gpft^2) for clothes washers.

	1975	1980	1992	2009	2011	2020
Shower (gpm)	3.5	2.5	2.5	2.5	2.0	1.8
Toilets (gpf)	5.0	3.6	1.6	1.6	1.28	1.28
Faucets (gpm)	2.5	2.5	2.5	2.2	1.8	1.2
Clothes washers (gpft^2)	15	15	15	8.5	6	4.7

Example: How much water would a family of four save over a year from replacing two toilets from 1975 with two toilets purchased in 2020. Assume each person flushes each two times a day. (Typically, people use the bathroom 4-7 times per day, but not always at their house. Some of this water use is accounted for at schools or businesses and restaurants).

First, calculate the amount of water saved with one flush by converting from a toilet from 1975 at 5 gallons per flush to a toilet from 2020 with 1.28 gallons per flush.

$$5 \text{ gallons per flush} - 1.28 \text{ gallons per flush} = 3.72 \text{ gallons per flush}$$

Now calculate how many flushes the family runs through in a day. Each toilet was flushed twice a day by each family member or eight flushes.

$$4 \text{ family members} \times 2 \text{ flushes per toilet} = 8 \text{ flushes per toilet}$$

$$\frac{8 \text{ flushes}}{\text{day}} \times \frac{3.72 \text{ gallons}}{\text{flush}} = \frac{29.76 \text{ gallons}}{\text{day}}$$

29.76 gallons per day may not sound like a lot of water in a day, but you can quickly calculate the water savings over a year.

$$\frac{29.76 \text{ gallons}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} = 10{,}862.4 \text{ gallons per year}$$

Toilets are typically the best way to increase water savings within the home.

Key Terms

- **GPCD** – gallons per capita per day
- **R-GPCD** – residential gallons per capita per day

Practice Problems 11.1

1. What is the average GPCD of a small community of 4,761 people that use approximately 605,000 gallons per day?

2. A water utility produced 23,000 acre-feet of water last year that supplied a population of 68,437. What was the GPCD for this community?

3. A water utility in northern California has 71% of its 41,000 acre-feet of water used by the residential sector. If the total population is 37,500, what is the R-GPCD?

4. How much water would a family of six save over ten years from replacing three toilets from 1993 with three toilets purchased in 2020. Assume each person flushes each toilet twice a day.

5. A small water system has one well that pumps 130 gpm. This well serves a population of 633 with an average gpcd of 210. How many hours per day must this well run to meet the demand?

6. What is the GPCD of a community with 6,000,000 people if the annual water used is 372,000 AF?

7. A water district has a goal of 125 gpcd and an annual water projection of 28,640 AF. What is the population that can be served?

8. A house of 5 people used 42 CCF of water in 45 days. What is their gpcd within their household?

9. In question 8, what would the gpcd be if you took out 70% of the usage and classified it as outdoor usage?

Exercise 11.1

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 acre-feet of water last year that supplied a population of 50,000. What was the GPCD for this community?

3. A water utility in northern California has 80% of its 20,000 acre-feet of water used by the residential sector. If the total population is 42,300, what is the R-GPCD?

4. How much water would a family of four save over ten years from replacing two toilets from 1993 with two toilets purchased in 2020. Assume each person flushes each toilet three times a day.

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 within their household?

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

UNIT 12

12.1 BLENDING AND DILUTING

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.

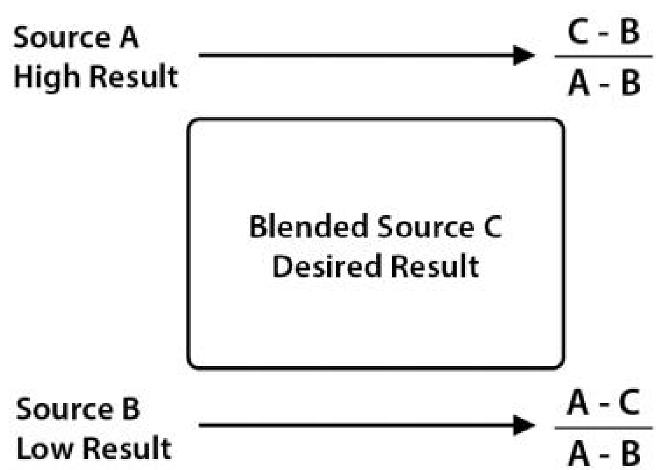


Figure 11.1[47]

[47] Image by Marilyn Hightower is licensed under CC BY 4.0

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.

Example: A water utility would like to blend water source A and water source B. Water source A has 10 ppm of a particular contaminant and water source B has 2 ppm of the contaminant. The goal is to reduce the total contaminant level to 5 ppm. How much water from source A and source B need to be blended to produce this result?

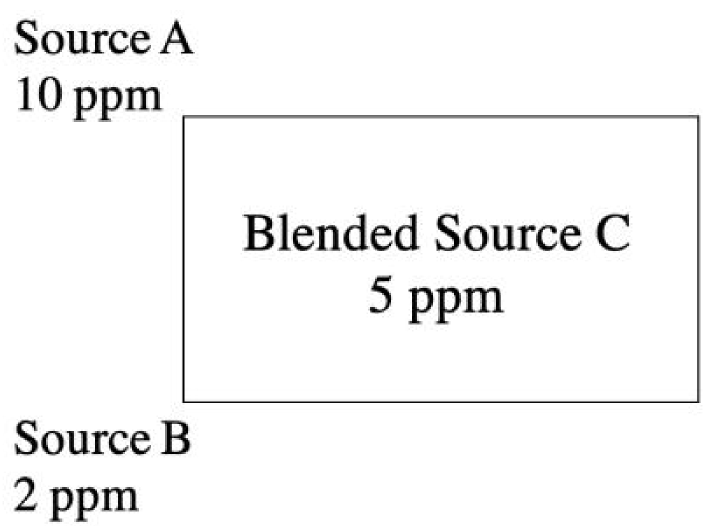


Figure 11.2[48]

[48] Image by College of the Canyons Water Technology faculty is licensed under CC BY 4.0

To determine the percentage of Source A required for the blend, the desired result, C, minus the low result, B, is divided by the high result, A, minus the low result, B.

$$\frac{C - B}{A - B} =$$

$$\frac{5 \text{ ppm} - 2 \text{ ppm}}{10 \text{ ppm} - 2 \text{ ppm}} = \frac{3 \text{ ppm}}{8 \text{ ppm}} = 0.375$$

This says that 37.5% of Source A is needed to achieve the desired blended result.

To determine the percentage of Source B required for the blend, the high result, A, minus the desired result, C, is divided by the high result, A, minus the low result, B.

$$\frac{A - C}{A - B} =$$

$$\frac{10 \text{ ppm} - 5 \text{ ppm}}{10 \text{ ppm} - 2 \text{ ppm}} = \frac{5 \text{ ppm}}{8 \text{ ppm}} = 0.625$$

This says that 62.5% of Source B is needed to achieve the desired blended result.

Example: If the flow rate is 5,000 gpm, what are the flow rates needed from each water source to achieve the desired blended result?

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.

Source A:

$$5{,}000 \text{ gpm} \times 0.375 = 1{,}875 \text{ gpm}$$

Source B:

$$5{,}000 \text{ gpm} \times 0.625 = 3{,}125 \text{ gpm}$$

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.

Practice Problems 12.1

1. A well has a nitrate level that exceeds the MCL of 63 mg/L. Over the last 4 sample results it has averaged 71 mg/L. A nearby well has a nitrate level of 40 mg/L. If both wells combined pump up to 1,575 gpm, how much flow is required from each well to achieve a nitrate level of 50 mg/L?

2. A well (A) has shown quarterly arsenic levels above the MCL over the last year, of 16 ug/L, 22 ug/L, 20 ug/L and 10 ug/L. A utility wants to blend this well to a level of 6.0 ug/L with a well (B) that has a level of 2.1 ug/L. The total production needed from both of these wells is 4,100 gpm. How much can each well produce?

3. A well with a PCE level of 12.4 ug/L is supplying approximately 65% of total water demand. It is being blended with a well that has a PCE level of 1.5 ug/L. Will this blended supply meet the MCL for PCE of 7.0 ug/L?

4. Well A has a total dissolved solids (TDS) level of 625 mg/L. It is pumping 2,300 gpm, which is 50% of the total production from two wells. The other well (B) blends with well A to achieve a TDS level of 450 mg/L. What is the TDS level for Well B?

5. Two wells need to achieve a daily flow of 2.1 MG and a total hardness level of 110 mg/L as calcium carbonate ($CaCO_3$.) Well #1 has a total hardness level of 390 mg/L as $CaCO_3$ and Well #2 has a level of 63 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 480 mg/L. The utility needs to purchase the water to blend with the well. The purchased water has a sulfate level of 55 mg/L. They need to bring the sulfate levels down to 225 mg/L and supply a demand of 2.0 MGD. The purchased water costs $475/AF. How much will the purchased water cost for the entire year?

Exercise 12.1

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 combined 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?

UNIT 13

13.1 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. This does not mean that human beings are not involved. Distribution and treatment operators learn to use SCADA to help them in their work.

Figure 13.1[49]

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, and tank levels. 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, or fiber optics. This information is sent to a central control computer typically located at an office or operations control center.

[49] Photo used with permission of SCV Water

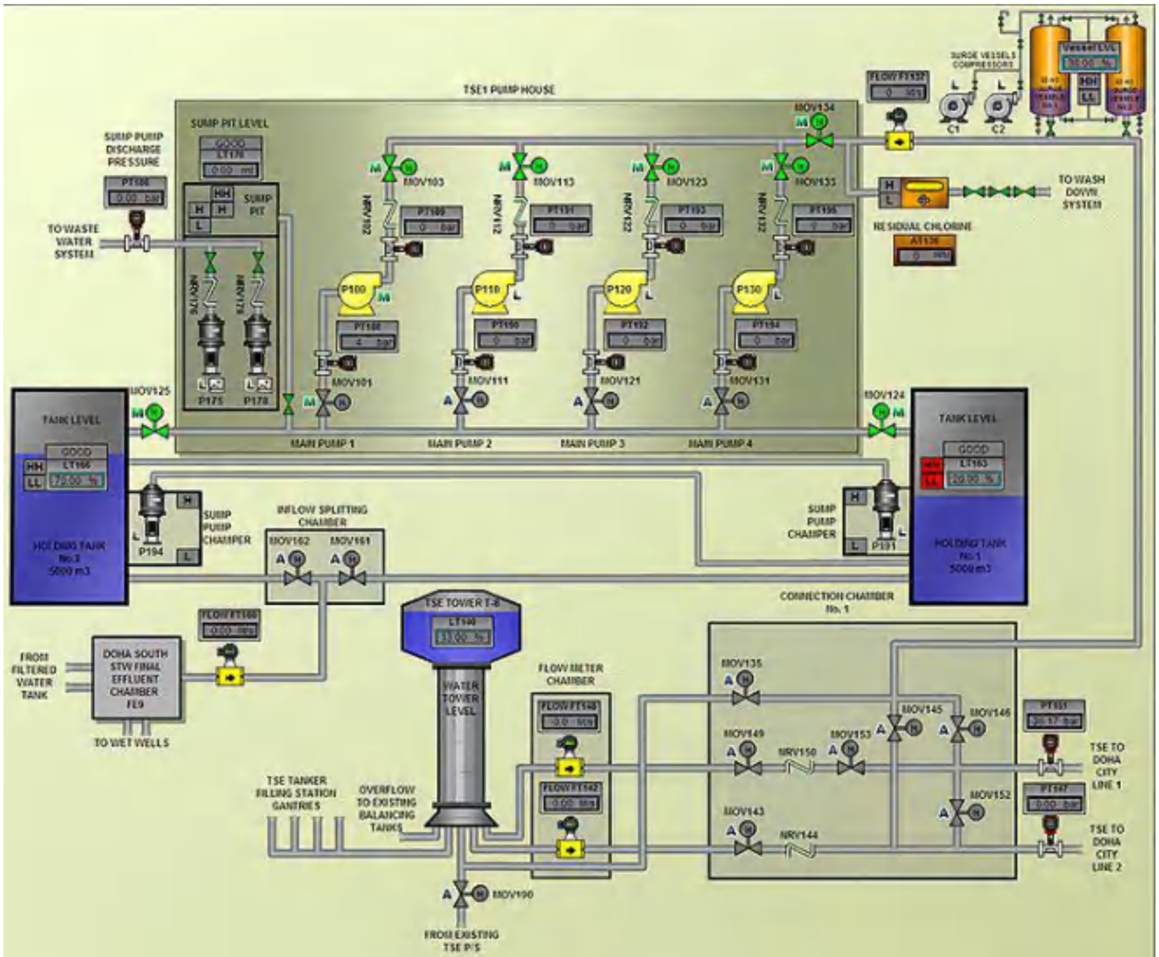


Figure 13.2[50]

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 which is 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.

When using this system to measure tank levels there are a couple of things to consider. First, assume the tank in the image below is 40 feet tall. 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. In this image you can see it on the top right side of the tank. 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

[50] Image is in the public domain

bottom to what is referred to as the "zero" level. In solving water related problems, the "overflow" (actual top level) and the "bottom" (actual location of the zero level) may be provided in the problem statement.

Figure 13.3[51]

Example: A water utility has a 40 ft tall tank with a diameter of 30 ft as shown below. They are using the 4-20 mA signal to measure the level of water in the storage tank. What is the mA reading if the tank is half full (20 ft)?

Since there is no reference in the problem statement 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.

So, what signal would you expect to receive if the water level in the tank is at 20ft?

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

[51] Photo used with permission of SCV Water

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.

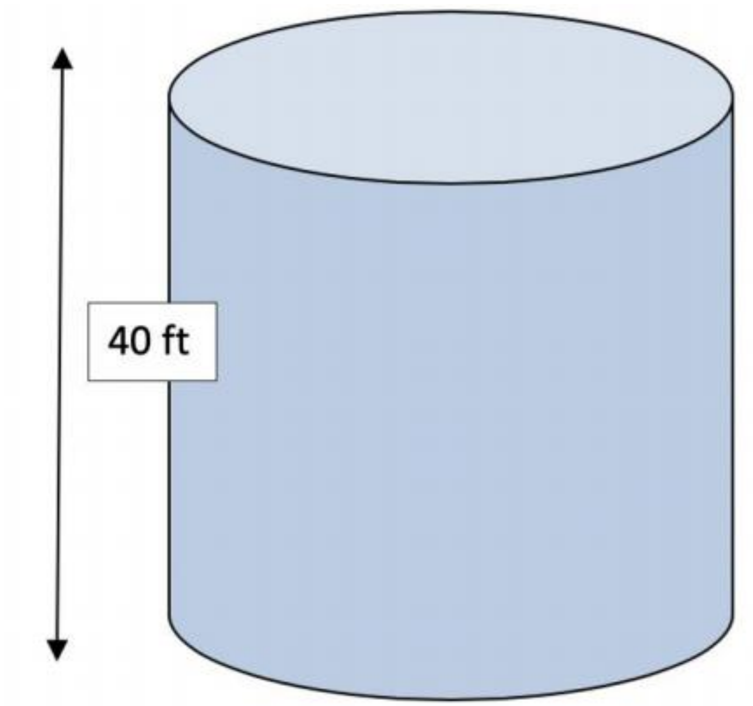


Figure 13.4[52]

This relationship can be written as an equation. The meter read minus the offset divided by the span equals the percent of the value being measured.

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

Example: Using the same 40 ft tall tank from the previous example, a 10 mA reading was collected for the height of the water level in the tank. What is the water height in feet?

The reading is 10 mA. The offset is 4 mA and the span is 16 mA.

Span = 20 mA - 4 mA = 16 mA

Now you can substitute the values into the equation.

[52] Image by College of the Canyons Water Technology faculty is licensed under [CC BY 4.0](CC BY 4.0)

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

$$\frac{10 \text{ mA} - 4 \text{ mA}}{16 \text{ mA}} = \frac{6 \text{ mA}}{16 \text{ mA}} = 0.375$$

$$0.375 \times 100 = 37.5\% \text{ full}$$

To determine the water level in the tank in feet, multiply the percent full by the actual height of the tank.

$$0.375 \times 40 \text{ ft} = 15 \text{ ft}$$

Therefore, the water level in the tank is 15 ft when the system shows a 10 mA reading.

Key Terms

- **SCADA** – the acronym for Supervisory Control and Data Acquisition; a computerized system allowing a water system to operate automatically

Practice Problems 13.1

1. A 4-20 mA signal is being used to measure the water level in a water storage tank. The tank is 50 feet tall and the low level signal is set at 0 feet and the high level at 50 feet. What is the level in the tank with a 17 mA reading?

2. A 48 ft tall water tank uses a 4-20 mA signal for calculating the water level. If the 4 mA level is set at 5 feet from the bottom and the 20 mA is set at 5 feet from the top, what is the level in the tank with a 9 mA reading?

3. A chlorine analyzer uses a 4-20 mA signal to monitor the chlorine residual. The 4-20 mA range is 0.8 mg/L – 4.6 mg/L respectively. If the reading is 10 mA, what is the corresponding residual in mg/L?

4. A water tank is 52 ft tall and has 41 ft of water in it. If the 4-20 mA set points are at 4 ft and 50 ft respectively, what is the mA reading?

5. A water tank with a 75 ft diameter is 25 ft tall. The 4-20 mA set points are 2 ft and 22 ft respectively. If the current level reading is 12 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 205 psi bgs and the 4 mA signal at 15 psi bgs. If the reading is 14 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 actual elevations above the mean sea level (MSL). The ground surface elevation at this well is 1,400 ft and this is where the 4 mA signal is set. The 20 mA signal is set at 740 ft. What is the elevation and the feet bgs with an 11 mA reading?

8. A chemical injection system is monitored with a 4-20 mA signal. The reading is 9 mA at 4.71 mg/L and the 4 mA set point is at 1.0 mg/L. What is the 20 mA set point?

Exercise 13.1

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 actual 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?

UNIT 14

14.1 WATER UTILITY MANAGEMENT

Every water utility has a management staff that directs, plans, organizes, coordinates, and communicates the direction of the organization. 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? How much needs to be saved for emergencies? Does the utility have any debt to pay off? How much are salaries and benefits? 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 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, and pressures. 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.

Emergencies

Good financial management means being prepared for emergencies. What sorts of emergencies? It might mean extra funds to purchase water during a drought year. It might mean extra funds to pay for security during a time of crisis or overtime for staff for an unplanned outage due to an earthquake. It is hard to anticipate the precise nature of a crisis, but often having a contingency fund for such emergencies is useful.

Debt

More times than not, utilities will take on large amounts of debt to cover major capital improvement projects that expand their systems for future water users. Financing a project with debt allows current and future water users to share in the costs rather than saddling only current users with the cost of the project by paying all costs at the time of the project. Additionally, 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 and have the right people pay for the right project

Revenues and Rates

For water utilities to pay for all their expenses (i.e., pumping, chemicals, material, salaries, benefits) 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. 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), 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 when certain pieces 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 defined, let's take a look at how it all works mathematically. The table on the following page demonstrates some O&M numbers for a typical small utility.

O&M Item	Monthly Averages	Cost per Unit or Number	Monthly Cost	Annual Cost
Water Production Groundwater Purchased Water	440 MG 190 MG	$230 $1,200	$101,200 $228,000	$1,214,400 $2,736,000
Staffing Hourly Employees Salary Employees Benefits	$3,500 $6,200 40% of Pay	15 10	$52,500 $62,000 $45,800	$630,000 $744,000 $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**

Example: Using the above table, calculate the percentage of the annual budget for each O&M Item listed in the table below. (If you need to review how to calculate a percentage, see Unit 3 in the Water 130 textbook.)

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	

Per the table, the total annual budget for the small water utility is \$6,286,030. The total annual cost for water production is \$3,950,400. The question is asking what percentage of \$6,286,030 is \$3,950,400.

Water Production:

First, you need to total the annual water production costs.

$$\$1,214,400 + \$2,736,000 = \$3,950,400$$

Now you can solve for the percentage.

$$\$3,950,400 = x\% \times \$6,286,030$$

$$x\% = \frac{\$3,950,400}{\$6,286,030} = 0.628441$$

$$0.628441 \times 100 = 62.84\%$$

Therefore, the total annual cost for water production is approximately 63% of the entire annual budget.

Staffing:

First, you need to total the staffing costs.

$$\$630,000 + \$744,000 + \$549,600 = \$1,923,600$$

$$\$1,923,600 = x\% \times \$6,286,030$$

$$x\% = \frac{\$1,923,600}{\$6,286,030} = 0.3060119$$

$$0.3060119 \times 100 = 30.60\%$$

Therefore, the total annual cost for staffing is approximately 31% of the entire annual budget.

Chemicals:

$$\$178,330 = x\% \times \$6,286,030$$

$$x\% = \frac{\$178,330}{\$6,286,030} = 0.028369$$

$$0.028369 \times 100 = 2.84\%$$

Therefore, the total annual cost for chemicals is approximately 3% of the entire annual budget.

Vehicle Maintenance:

$$\$51,000 = x\% \times \$6,286,030$$

$$x\% = \frac{\$51,000}{\$6,286,030} = 0.008113$$

$$0.008113 \times 100 = 0.81\%$$

Therefore, the total annual cost for vehicle maintenance is less than 1% of the entire annual budget.

Leaks and Repairs:

$$\$90,000 = x\% \times \$6,286,030$$

$$x\% = \frac{\$90,000}{\$6,286,030} = 0.014317$$

$$0.014317 \times 100 = 1.43\%$$

Therefore, the total annual cost for leaks and repairs is 1.43% of the entire annual budget.

Pumps and Motors:

$$\$72,000 = x\% \times \$6,286,030$$

$$x\% = \frac{\$72,000}{\$6,286,030} = 0.01145$$

$$0.01145 \times 100 = 1.15\%$$

Therefore, the total annual cost for leaks and repairs is approximately 1% of the entire annual budget.

Treatment Equipment:

$$\$7,200 = x\% \times \$6,286,030$$

$$x\% = \frac{\$7,200}{\$6,286,030} = 0.001145$$

$$0.001145 \times 100 = 0.11\%$$

Therefore, the total annual cost for treatment equipment is approximately 0% of the entire annual budget.

Miscellaneous:

$$\$13,500 = x\% \times \$6,286,030$$

$$x\% = \frac{\$13,500}{\$6,286,030} = 0.00215$$

$$0.00215 \times 100 = 0.21\%$$

Therefore, the total annual cost for miscellaneous items is less than 1% of the entire annual budget.

When calculating budget percentages, it is important to verify that all the percentages add to 100%. Note that in this example, the total is 99.99%. This is entirely due to rounding.

O&M Item	Percentage of Annual Budget
Water Production GW & Purchased	62.84%
Staffing Salary & Benefits	30.60%
Chemicals	2.84%
Vehicle Maintenance	0.81%
Leaks and Repairs (Materials Only)	1.43%
Pumps and Motors (Materials Only)	1.15%
Treatment Equipment	0.11%
Miscellaneous	0.21%
TOTAL:	99.99%

Clearly, the majority of the budget is allocated to water production and staffing. **Fixed costs** are costs that are the same from year to year. **Variable costs** are costs that change from year to year. 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 these would actually be considered fixed.

Fixed Costs **Reason**

______________________ ______________________________

______________________ ______________________________

______________________ ______________________________

______________________ ______________________________

______________________ ______________________________

Variable Costs	**Reason**

Fixed and Variable Costs

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, and tires. There are also some unknown maintenance issues such as a bad battery or a faulty water pump. These examples can be looked at as either fixed or variable costs. The idea is not to "pigeonhole" these expenses as fixed or variable. Instead, you want 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.

Key Terms

- **fixed costs** – costs that are the same from year to year
- **variable costs** –costs that vary over time

Practice Problems 14.1

1. A utility vehicle costs on average $730 per year for maintenance. A replacement vehicle would cost $32,000. The utility has a vehicle policy that states all vehicles with 155,000 miles or more shall be replaced. The policy also states that once maintenance costs exceed 50% of the cost of a replacement vehicle, the vehicle shall be replaced. This particular vehicle averages 22,000 miles per year.

    a. Will the vehicle cost more than 50% of a new vehicle cost before reaching 155,000 miles?

    b. What is the total maintenance cost if the vehicle reaches 155,000 miles?

2. A pump that has been in operation for 15 years pumps a constant 450 gpm through 65 feet of dynamic head. The pump uses 6,537 kW-Hr of electricity per month at a cost of $0.095 per kW-Hr. The old pump efficiency has dropped to 50%. Assuming a new pump that operates at 90% efficiency is available for $10,270, how long would it take to pay for replacing the old pump?

3. A utility has annual operating expenses of $4.7 million and a need for $2.1 million in capital improvements. The current water rate is $1.30 per CCF. Last year the utility sold 7270 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 to meet their operational and capital requirements and add approximately $400K to a reserve account?

5. A 300 hp well operates 6 hours a day and flows 1,700 gpm. The electricity cost is $0.118 per kW-Hr. The well is also dosed with a 55% calcium hypochlorite tablet chlorinator to a dosage of 1.65 ppm. The tablets cost $1.20 per pound. The labor burden associated with the well maintenance is $60 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 $950,000. Salaries and benefits account for approximately 85% of this budget. The company has 9 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 $3.40 per pound and salt is $0.50 per pound. It takes approximately 4 pounds of salt to create 1 gallon of 1.75% chlorine with a specific gravity of 1.20. Assuming that the plant is dosing 12.5 MGD to a dosage of 2.75, what would be the annual cost of each? Which one is more cost effective?

Exercise 14.1

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 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 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?

PRACTICE PROBLEM SOLUTIONS

Practice Problems 1.1a

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

1. 1 MGD = 694 gpm

$$\frac{1{,}000{,}000\ \cancel{\text{gal}}}{\cancel{\text{day}}} \times \frac{1\ \cancel{\text{day}}}{24\ \cancel{\text{hr}}} \times \frac{1\ \cancel{\text{hr}}}{60\ \cancel{\text{min}}} = 694\text{ gpm}$$

2. 86,400 seconds = 1 day

$$\frac{86{,}400\ \cancel{\text{sec}}}{1} \times \frac{1\ \cancel{\text{min}}}{60\ \cancel{\text{sec}}} \times \frac{1\ \cancel{\text{hr}}}{60\ \cancel{\text{min}}} \times \frac{1\text{ day}}{24\ \cancel{\text{hr}}} = 1\text{ day}$$

3. 1 MGD = 3.069 AF/D

$$\frac{1{,}000{,}000\ \cancel{\text{gal}}}{\text{day}} \times \frac{1\text{ AF}}{325{,}851\ \cancel{\text{gal}}} = 3.069\text{ AF/day}$$

Practice Problems 1.1b

Solve the following conversion problems using combined conversion factors when possible

1. Convert 3,837,000 lbs to AF

$$\frac{3{,}837{,}000\text{ lbs}}{1} \times \frac{1\text{ gal}}{8.34\text{ lbs}} \times \frac{1\text{ AF}}{325{,}851\text{ gal}} = 1.4\text{ AF}$$

2. Convert 12.75 cfs to MGD

$$\frac{12.75\text{ cfs}}{1} \times \frac{1\text{ MGD}}{1.547\text{ cfs}} = 8.24\text{ MGD}$$

3. A well is pumping water at a rate of 8.25 gpm. If the pump runs 12 hours per day, how many acre feet are pumped out of the well in one year?

$$\frac{8.13\text{ gal}}{\text{min}} \times \frac{60\text{ min}}{1\text{ hr}} \times \frac{12\text{ hr}}{1\text{ day}} \times \frac{365\text{ day}}{1\text{ year}} \times \frac{1\text{ AF}}{325{,}851\text{ gal}} = 6.56\text{ AFY}$$

4. A rectangular basin contains 4.45 AF of water. How many gallons are in the basin?

$$\frac{4.45\text{ AF}}{1} \times \frac{325{,}851\text{ gal}}{1\text{ AF}} = 1{,}450{,}037\text{ gal} = 1.45\text{ MG}$$

5. A fire hydrant is leaking at a rate of 10 ounces per minute. How many gallons will be lost in one week? (There are 128 ounces in one gallon.)

$$\frac{10\text{ oz}}{1\text{ min}} \times \frac{1\text{ gal}}{128\text{ oz}} \times \frac{1{,}440\text{ min}}{1\text{ day}} \times \frac{7\text{ day}}{1} = 787.5\text{ gal}$$

6. A pipe flows at a rate of 6.3 cfs. How many MG will flow through the pipe in 3 days?

$$\frac{6.3\text{ cfs}}{1} \times \frac{1\text{ MGD}}{1.547\text{ cfs}} \times 3\text{ days} = 12.2\text{ MG}$$

7. A water utility operator needs to report the total amount of water drained from two separate basins. The 18" pipe in Basin A drained water at a rate of 12.4 cfs for four hours each day. The 12" pipe in Basin B drained water at a rate of 3.1 cfs for 16 hours each day. What is the total amount of water drained in million gallons in 30 days?

$$\text{Basin A: } \frac{12.4\text{ cf}}{\text{sec}} \times \frac{3{,}600\text{ sec}}{1\text{ hr}} \times \frac{4\text{ hr}}{1\text{ day}} \times \frac{7.48\text{ gal}}{1\text{ cf}} \times \frac{30\text{ day}}{1} = 40{,}068{,}864\text{ gal} = 40.1\text{ MG}$$

Basin B: $\frac{3.1\text{ cf}}{\text{sec}} \times \frac{3{,}600\text{ sec}}{1\text{ hr}} \times \frac{10\text{ hr}}{1\text{ day}} \times \frac{7.48\text{ gal}}{1\text{ cf}} \times \frac{30\text{ day}}{1} = 25{,}043{,}040\text{ gal} = 25.0\text{ MG}$

Total = Basin A + Basin B = 40.1 MG + 25.0 MG = 65.1 MG

8. A water utility operator drove a total of 22,841 miles in one year. What were the average miles driven per day? Assume that the vehicle operated 6 days per week.

$$\frac{22{,}841\text{ miles}}{1\text{ year}} \times \frac{1\text{ year}}{52\text{ weeks}} \times \frac{1\text{ week}}{6\text{ days}} = \frac{73.2\text{ miles}}{\text{day}}$$

9. Water travels 52 miles per day through an aqueduct. What is the velocity of the water in feet per second?

$$\frac{52\text{ miles}}{1\text{ day}} \times \frac{5{,}280\text{ ft}}{1\text{ mile}} \times \frac{1\text{ day}}{86{,}400\text{ sec}} = 3.2\text{ fps}$$

10. How many days will it take to fill an Olympic size swimming pool with 660,000 gallons of water if the flow rate is 150 gpm?

$$\frac{660{,}000\text{ gallons}}{1} \times \frac{1\text{min}}{150\text{ gallons}} = 4{,}400\text{ min} \times \frac{1\text{ day}}{1{,}440\text{ min}} = 3.1\text{ days}$$

Practice Problems 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 four groundwater wells and two connections to a surface water treatment plant. Complete the table below.

Source of Supply	Flow Rate (cfs)	Daily Operation (Hrs)	Total Flow (MGD)	Annual Flow (AFY)
Well 1	3.2	5	0.431	482.6
Well 2	5	10	1.346	1,508.1
Well 3	1.4	12	0.452	506.7
Well 4	2.7	18	1.309	1,465.9
SW Pump 1	4.2	4	0.452	506.7
SW Pump 2	0.5	20	0.269	301.6

Well 1: Total Flow in MGD

$$\frac{3.2\text{ cfs}}{1} \times \frac{448.8\text{ gpm}}{1\text{ cfs}} \times \frac{60\text{ min}}{1\text{ hr}} \times \frac{5\text{ hrs}}{1\text{ day}} = 430{,}848\frac{\text{gal}}{\text{day}} \times \frac{1\text{ MG}}{1{,}000{,}000\text{ gal}} = 0.431\text{ MGD}$$

Well 1: Annual Flow in AFY

$$\frac{430{,}848\text{ gal}}{\text{day}} \times \frac{1\text{ AF}}{325{,}851\text{ gal}} \times \frac{365\text{ day}}{1\text{ year}} = 482.6\text{ AFY}$$

Well 2: Total Flow in MGD

$$\frac{5\text{ cfs}}{1} \times \frac{448.8\text{ gpm}}{1\text{ cfs}} \times \frac{60\text{ min}}{1\text{ hr}} \times \frac{10\text{ hrs}}{1\text{ day}} = 1{,}346{,}400\frac{\text{gal}}{\text{day}} \times \frac{1\text{ MG}}{1{,}000{,}000\text{ gal}} = 1.346\text{ MGD}$$

Well 2: Annual Flow in AFY

$$\frac{1{,}346{,}400 \text{ gal}}{\text{day}} \times \frac{1 \text{ AF}}{325{,}851 \text{ gal}} \times \frac{365 \text{ day}}{1 \text{ year}} = 1{,}508.1 \text{ AFY}$$

Well 3: Total Flow in MGD

$$\frac{1.4 \text{ cfs}}{1} \times \frac{448.8 \text{ gpm}}{1 \text{ cfs}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{12 \text{ hrs}}{1 \text{ day}} = 452{,}390.4 \frac{\text{gal}}{\text{day}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 0.452 \text{ MGD}$$

Well 3: Annual Flow in AFY

$$\frac{452{,}390.4 \text{ gal}}{\text{day}} \times \frac{1 \text{ AF}}{325{,}851 \text{ gal}} \times \frac{365 \text{ day}}{1 \text{ year}} = 506.7 \text{ AFY}$$

Well 4: Total Flow in MGD

$$\frac{2.7 \text{ cfs}}{1} \times \frac{448.8 \text{ gpm}}{1 \text{ cfs}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{18 \text{ hrs}}{1 \text{ day}} = 1{,}308{,}700.8 \frac{\text{gal}}{\text{day}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 1.309 \text{ MGD}$$

Well 4: Annual Flow in AFY

$$\frac{1{,}308{,}700.8 \text{ gal}}{\text{day}} \times \frac{1 \text{ AF}}{325{,}851 \text{ gal}} \times \frac{365 \text{ day}}{1 \text{ year}} = 1{,}465.9 \text{ AFY}$$

SW Pump 1: Total Flow in MGD

$$\frac{4.2 \text{ cfs}}{1} \times \frac{448.8 \text{ gpm}}{1 \text{ cfs}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{4 \text{ hrs}}{1 \text{ day}} = 452{,}390.4 \frac{\text{gal}}{\text{day}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 0.452 \text{ MGD}$$

SW Pump 1: Annual Flow in AFY

$$\frac{452{,}390.4 \text{ gal}}{\text{day}} \times \frac{1 \text{ AF}}{325{,}851 \text{ gal}} \times \frac{365 \text{ day}}{1 \text{ year}} = 506.7 \text{ AFY}$$

SW Pump 2: Total Flow in MGD

$$\frac{0.5 \text{ cfs}}{1} \times \frac{448.8 \text{ gpm}}{1 \text{ cfs}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{20 \text{ hrs}}{1 \text{ day}} = 269{,}280 \frac{\text{gal}}{\text{day}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 0.269 \text{ MGD}$$

SW Pump 2: Annual Flow in AFY

$$\frac{269{,}280 \text{ gal}}{\text{day}} \times \frac{1 \text{ AF}}{325{,}851 \text{ gal}} \times \frac{365 \text{ day}}{1 \text{ year}} = 301.6 \text{ AFY}$$

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	482.6	55	26,543
Well 2	1,508.1	64	95,518
Well 3	506.7	35	17,735
Well 4	1,465.9	70	102,613
SW Pump 1	506.7	325	164,678
SW Pump 2	301.6	275	82,940
Total Annual Cost			$490,027

$$\frac{482.6 \text{ AF}}{1 \text{ year}} \times \frac{\$\ 55}{1 \text{ AF}} = \$\ 26{,}543 \text{ per year}$$

$$\frac{1{,}508.1 \text{ AF}}{1 \text{ year}} \times \frac{\$\ 64}{1 \text{ AF}} = \$\ 95{,}518 \text{ per year}$$

$$\frac{506.7 \text{ AF}}{1 \text{ year}} \times \frac{\$\ 35}{1 \text{ AF}} = \$\ 17{,}735 \text{ per year}$$

$$\frac{1{,}465.9 \text{ AF}}{1 \text{ year}} \times \frac{\$\ 70}{1 \text{ AF}} = \$\ 102{,}613 \text{ per year}$$

$$\frac{506.7 \text{ AF}}{1 \text{ year}} \times \frac{\$\ 325}{1 \text{ AF}} = \$\ 164{,}678 \text{ per year}$$

$$\frac{301.6 \text{ AF}}{1 \text{ year}} \times \frac{\$\ 275}{1 \text{ AF}} = \$\ 82{,}940 \text{ per year}$$

Practice Problems 2.1

1. What is the area of the opening of a 21" diameter pipe?

$$\frac{21\ \cancel{in}}{1} \times \frac{1\ ft}{12\ \cancel{in}} = 1.75\ ft$$

$$0.785 \times (1.75\ ft)^2 = 0.785 \times 3.0625\ ft^2 = 2.4\ ft^2$$

2. What is the cross-sectional area of a rectangular channel that has a width of 5 feet 8 inches and a height of 8 feet 5 inches?

$$\frac{8\ \cancel{in}}{1} \times \frac{1\ ft}{12\ \cancel{in}} = 0.667\ ft \qquad \frac{5\ \cancel{in}}{1} \times \frac{1\ ft}{12\ \cancel{in}} = 0.417\ ft$$

$$5.667\ ft \times 8.417\ ft = 47.7\ ft^2$$

3. A trapezoidal channel is 12 feet wide at the bottom and 22 feet wide at the water line when the water is 7 feet deep. What is the cross-sectional area of the channel?

$$\frac{12\ ft + 22\ ft}{2} \times 7\ ft = \left(\frac{34\ ft}{2}\right)(7\ ft) = (17\ ft)(7\ ft) = 119\ ft^2$$

4. A 35-foot diameter spherical tank needs to be painted. If one gallon of paint will cover 400 sf, how many gallons of paint will be required to put two coats of paint on the exterior of the tank?

$$4 \times 0.785 \times (35\ ft)^2 = 3{,}846.5\ ft^2$$

$$\text{Requires 2 coats - total area: } 3{,}846.5\ ft^2 + 3{,}846.5\ ft^2 = 7{,}693\ ft^2$$

$$\frac{7{,}693\ ft^2}{1} \times \frac{1\ gal}{400\ ft^2} = 19.23\ gal = 20\ \text{gallons of paint}$$

5. What is the surface area of a 45-foot-tall standpipe with a diameter of 20 feet?

$$\text{Circumference} = \pi \times 20\ ft = 62.83\ ft$$

$$\text{Area} = L \times W = 62.83\ ft \times 45\ ft = 2{,}827.43\ ft^2$$

6. What is the surface area of a 27-foot diameter sphere?

$$4 \times 0.785 \times (27 \text{ ft})^2 = 4 \times 0.785 \times 729 \text{ ft}^2 = 2{,}289.1 \text{ ft}^2$$

7. The inside of a rectangular structure measuring 15 feet tall by 25 feet long by 12 feet wide needs painting. What is the total surface area? Include all six interior surfaces.

Area of the ends = L $\times$ W = 12 ft $\times$ 15 ft $=$ 180 ft^2

2 ends: Area = 180 ft^2 $+$ 180 ft^2 = 360 ft^2

Area of the sides = L $\times$ W = 25 ft $\times$ 15 ft $=$ 375 ft^2

4 sides: Area = 375 ft^2 $+$ 375 ft^2 + 375 ft^2 $+$ 375 ft^2 = 1,500 ft^2

Total Area = 360 ft^2 $+$ 1,500 ft^2 $=$ 1,860 ft^2

8. What is the entire interior surface area of a 275 foot long, 27 inch diameter pipe that is capped with half of a sphere? The sphere is not included in the length of the pipe.

First convert inches to feet:

$$\frac{27 \cancel{\text{in}}}{1} \times \frac{1 \text{ ft}}{12 \cancel{\text{in}}} = 2.25 \text{ ft}$$

Area of the interior of the pipe:

Circumference $= \pi \times$ 2.25 ft = 7.1 ft

Area = L $\times$ W = 7.1 ft $\times$ 275 ft $=$ 1,952.5 ft^2

Area of the half sphere on the end of the pipe:

$$4 \times 0.785 \times (2.25 \text{ ft})^2 = 4 \times 0.785 \times 5.0625 \text{ ft}^2 = 15.89625 \text{ ft}^2$$

$$\text{Half the sphere} = \frac{15.89625 \text{ ft}^2}{2} = 7.9 \text{ ft}^2$$

Total Area = 1,952.5 ft^2 $+$ 7.9 ft^2 $=$ 1,960.4 ft^2

Practice Problems 2.2

1. What is the volume of a 52-foot diameter sphere?

$$\text{Volume} = \frac{\pi(52\text{ ft})^3}{6} = \frac{\pi(140{,}608\text{ ft}^3)}{6} =$$

$$\text{Volume} = \frac{441{,}509.12\text{ ft}^3}{6} = 73{,}585\text{ ft}^3$$

2. What is the volume of a 36” diameter pipe that is 1,500 feet long?

$$\frac{36\,\cancel{\text{in}}}{1} \times \frac{1\text{ ft}}{12\,\cancel{\text{in}}} = 3\text{ ft}$$

$$\text{Volume of a Cylinder} = 0.785 \times (3\text{ ft})^2 \times 1{,}500\text{ ft} = 10{,}597.5\text{ ft}^3 = 10{,}598\text{ ft}^3$$

3. A half-full aqueduct is 10 miles long. It is 15 feet wide at the bottom, 24 feet wide at the top, and 25 feet tall. How many acre feet of water are in the aqueduct?

There are two ways to approach this problem since the aqueduct is only half full. First, we’ll calculate the volume of the entire aqueduct and then divide it by 2 to get the volume when it is half full.

$$\text{Trapezoid} = \frac{b_1 + b_2}{2} \times \text{H} \times \text{L} = \frac{15\text{ ft} + 24\text{ ft}}{2} \times 25\text{ ft} \times \left(\frac{10\text{ miles}}{1} \times \frac{5{,}280\text{ ft}}{1\text{ mile}}\right) =$$

$$\frac{39\text{ ft}}{2} \times 25\text{ ft} \times 52{,}800\text{ ft} = 19.5\text{ ft} \times 25\text{ ft} \times 52{,}800\text{ ft} = 25{,}740{,}000\text{ ft}^3$$

$$25{,}740{,}000\text{ ft}^3 \times \frac{7.48\text{ gal}}{1\text{ ft}^3} \times \frac{1\text{ AF}}{325{,}829\text{ gal}} = 590.91\text{ AF} = 591\text{ AF}$$

This is the volume of the entire aqueduct. Since it is only half full, divide this volume by 2.

$$\frac{591\text{ AF}}{2} = 296\text{ AF}$$

The second way to approach this problem is to calculate the volume with the water level at half. Since the aqueduct is 25 feet tall, the height of the water when it is half full is 12.5 feet.

$$\text{Trapezoid} = \frac{b_1 + b_2}{2} \times H \times L = \frac{15\text{ ft} + 24\text{ ft}}{2} \times 12.5\text{ ft} \times \left(\frac{10\text{ miles}}{1} \times \frac{5{,}280\text{ ft}}{1\text{ mile}}\right) =$$

$$\frac{39\text{ ft}}{2} \times 12.5\text{ ft} \times 52{,}800\text{ ft} = 19.5\text{ ft} \times 12.5\text{ ft} \times 52{,}800\text{ ft} = 12{,}870{,}000\text{ ft}^3$$

$$12{,}870{,}000\text{ ft}^3 \times \frac{7.48\text{ gal}}{1\text{ ft}^3} \times \frac{1\text{ AF}}{325{,}829\text{ gal}} = 295.45\text{ AF} = 295\text{ AF}$$

You will notice that the solutions differ by 1 AF. This is due to rounding. Both ways of calculating the volume in the aqueduct are correct.

4. A sedimentation basin is 110 feet long, 40 feet wide, and 30 feet deep. How much water can it hold in million gallons?

$$\text{Volume of a Rectangular Prism} = 110\text{ ft} \times 40\text{ ft} \times 30\text{ ft} = 132{,}000\text{ ft}^3$$

$$132{,}000\text{ ft}^3 \times \frac{7.48\text{ gal}}{1\text{ ft}^3} \times \frac{1\text{ MG}}{1{,}000{,}000\text{ gal}} = 0.98736\text{ MG} = 1\text{ MG}$$

5. A 35-foot-tall standpipe with a 15 foot diameter is topped with a half sphere. How many gallons will it hold?

Find the volume of the standpipe, which is cylindrical in shape.

$$\text{Volume of a Cylinder} = 0.785 \times D^2 \times H = 0.785 \times (15\text{ ft})^2 \text{ x } 35\text{ ft} =$$

$$0.785 \times 225\text{ ft}^2 \text{ x } 35\text{ ft} = 6{,}181.875\text{ ft}^3$$

Now find the volume of the half sphere on the top of the standpipe.

$$\text{Volume} = \frac{\pi(15\text{ ft})^3}{6} = \frac{\pi(3{,}375\text{ ft}^3)}{6} = \frac{10{,}597.5\text{ ft}^3}{6} = 1{,}766.25\text{ ft}^3$$

$$\text{Volume} = \frac{1{,}766.25\text{ ft}^3}{2} = 883.125\text{ ft}^3$$

The total volume is equal to the volume of the standpipe plus the volume of the half sphere. Then convert the cubic feet to gallons.

$$1{,}766.25\text{ ft}^3 + 883.125\text{ ft}^3 = 2{,}649.375\text{ ft}^3 = 2{,}649\text{ ft}^3$$

$$2{,}649\text{ ft}^3 \times \frac{7.48\text{ gal}}{1\text{ ft}^3} = 19{,}814.52\text{ gal} = 19{,}815\text{ gal}$$

Practice Problems 2.3

1. A water utility operator needs to determine the cost of painting an above ground storage tank. The tank is 50 feet tall and has a diameter of 28 feet. One gallon of paint can cover 200 sf and costs $36.27 per gallon. What is the total cost to paint the storage tank?

$$\text{Circumference} = \pi \times 28 \text{ ft} = 87.92 \text{ ft}$$

$$\text{Area of the tank wall} = \text{L} \times \text{W} = 87.92 \text{ ft} \times 50 \text{ ft} = 4{,}396 \text{ ft}^2$$

$$\text{Area of the top of the tank} = 0.785 \times (28 \text{ ft})^2 = 615.44 \text{ ft}^2$$

$$\text{Total Area} = 4{,}396 \text{ ft}^2 + 615.44 \text{ ft}^2 = 5{,}011.44 \text{ ft}^2$$

$$\text{Total Gallons of Paint} = 5{,}011.44 \text{ ft}^2 \times \frac{1 \text{ gal of paint}}{200 \text{ ft}^2} = 25.0572 \text{ gal} = 26 \text{ gallons of paint}$$

$$\text{Total Cost} = 26 \text{ gal} \times \frac{\$36.27}{1 \text{ gal}} = \$943.02$$

2. A local amusement park requires a 0.5 MG storage tank. If the diameter of the tank is 55 feet, how tall will the tank need to be in order to store the 4.2 MG?

$$4.2 \text{ MG} = 0.785 \times (55 \text{ ft})^2 \times \text{H}$$

$$\text{H} = \frac{0.5 \text{ MG} \times \dfrac{1 \text{ ft}^3}{7.48 \text{ gal}}}{0.785 \times (55 \text{ ft})^2} = \frac{66{,}844.9198 \text{ ft}^3}{0.785 \times 3{,}025 \text{ ft}^2} = \frac{66{,}844.9198 \text{ ft}^3}{2{,}374.625 \text{ ft}^2} = 28.15 \text{ ft}$$

3. How many gallons of water are in a 32-foot diameter storage tank that sits on a 15 foot diameter, 45 foot tall pipe?

$$\text{Volume of the Sphere} = \frac{\pi(32 \text{ ft})^3}{6} = \frac{3.14(32{,}768 \text{ ft}^3)}{6} = \frac{102{,}891.52 \text{ ft}^3}{6} = 17{,}148.59 \text{ ft}^3$$

$$17{,}148.59 \text{ ft}^3 \times \frac{7.48 \text{ gal}}{1 \text{ ft}^3} = 128{,}271.5 \text{ gal}$$

$$\text{Pipe Volume} = 0.785 \times \text{D}^2 \times \text{H} = 0.785 \times (15 \text{ ft})^2 \text{ x } 42 \text{ ft} = 7{,}418.3 \text{ ft}^3$$

$$7{,}418.3\ \text{ft}^3 \times \frac{7.48\ \text{gal}}{1\ \text{ft}^3} = 55{,}488.5\ \text{gal}$$

Total Gallons = 128,271.5 gal + 55,488.5 gal = 183,760 gal

4. A water tank truck delivered 30 loads of water to a construction site. The water tank on the truck is shaped like a pill. Each end has a 10-foot diameter and the center section is 15 feet long. If the water costs $352 an AF, how much did the construction site pay for the water?

$$\text{Volume of the Sphere} = \frac{\pi(10\ \text{ft})^3}{6} = \frac{3.14(1{,}000\ \text{ft}^3)}{6} = \frac{3{,}140\ \text{ft}^3}{6} = 523.33\ \text{ft}^3$$

$$\text{Volume of the Cylinder} = 0.785 \times D^2 \times H = 0.785 \times (10\ \text{ft})^2 \times 15\ \text{ft} = 1{,}177.5\ \text{ft}^3$$

$$\text{Total Volume} = 523.33\ \text{ft}^3 + 1{,}177.5\ \text{ft}^3 = 1{,}700.83\ \text{ft}^3 \times \frac{7.48\ \text{gal}}{1\ \text{ft}^3} = 12{,}722.2\ \text{gal}$$

$$12{,}722.2\ \text{gal} \times \frac{1\ \text{AF}}{325{,}829\ \text{gal}} \times \frac{\$352}{\text{AF}} \times 30\ \text{tank loads} = \$\ 412.32$$

5. A maintenance crew is replacing an 18” meter at a well. The specifications state that there needs to be 6.5 times the pipe diameter in feet of straight pipe before the meter and 4 times the pipe diameter in feet of straight pipe after the meter. How many feet of 18” pipe are needed?

$$\frac{18\ \cancel{\text{in}}}{1} \times \frac{1\ \text{ft}}{12\ \cancel{\text{in}}} = 1.5\ \text{ft}$$

$$\text{Before the Meter} = 6.5 \times 1.5\ \text{ft} = 9.75\ \text{ft}$$

$$\text{After the Meter} = 4 \times 1.5\ \text{ft} = 6\ \text{ft}$$

$$\text{Total Amount of Pipe Needed} = 9.75\ \text{ft} + 6\ \text{ft} = 15.75\ \text{ft}$$

6. A 1,200-foot section of a trapezoidal shaped aqueduct needs to be drained for maintenance. The aqueduct contains 5 AF of water, is 8 feet wide at the bottom, and is 14 feet wide at the water line. What is the water depth?

$$\text{Trapezoid Volume} = \frac{b_1 + b_2}{2} \times H \times L$$

$$\left(5\ \text{AF} \times \frac{325{,}829\ \text{gal}}{1\ \text{AF}} \times \frac{1\ \text{ft}^3}{7.48\ \text{gal}}\right) = \frac{14\ \text{ft} + 8\ \text{ft}}{2} \times \text{depth ft} \times 1{,}200\ \text{ft}$$

$$217{,}800.13\ ft^3 = \frac{22\ ft}{2} \times \text{ depth ft} \times 6{,}600\ ft$$

$$\text{depth ft} = \frac{217{,}800.13\ ft^3}{11\ ft \times 1{,}200\ ft} = \frac{217{,}800.13\ ft^3}{13{,}200\ ft^2} = 16.5\ ft$$

7. A water utility has installed 900 feet of 28” diameter pipe. They want to wrap a corrosion resistant sleeve around the pipe and fill the pipe to pressure test it. How many gallons of water will the pipe hold and how many square feet of corrosion resistant sleeve are required to cover the whole pipe?

$$\frac{28\ in}{1} \times \frac{1\ ft}{12\ in} = 2.33\ ft$$

$$\text{Circumference} = \pi \times 2.33\ ft = 3.14 \times 2.33\ ft = 7.3162\ ft = 7.3\ ft$$

$$\text{Pipe Surface Area} = L \times W = 900\ ft \times 7.3\ ft = 6{,}570\ ft^2$$

$$\text{Pipe Volume} = 0.785 \times D^2 \times H = 0.785 \times (2.33\ ft)^2 \text{ x } 900\ ft = 3{,}835.52\ ft^3$$

$$\frac{3{,}835.52\ ft^3}{1} \times \frac{7.48\ gal}{1\ ft^3} = 28{,}689.7\ gal$$

8. Which of the following tanks will provide storage for 50,000 gallons of water?
   a. A spherical tank with a 20-foot diameter.
   b. A rectangular tank that is 20 feet by 30 feet by 12 feet

$$\text{Sphere} = \frac{\pi(20\ ft)^3}{6} = \frac{3.14(8{,}000\ ft^3)}{6} = \frac{25{,}120\ ft^3}{6}$$

$$= 4{,}186.67\ ft^3 \times \frac{7.48\ gal}{1\ ft^3} = 31{,}316.3\ gal$$

$$\text{Rectangular Prism} = L \times W \times H = 20\ ft \times 30\ ft \text{ x } 12\ ft =$$

$$7{,}200\ ft^3 \times \frac{7.48\ gal}{1\ ft^3} = 53{,}856\ gal$$

The rectangular prism is large enough to provide the required storage.

Practice Problems 2.4

1. What is the flow rate in MGD of a 30" diameter pipe with a velocity of 5.5 fps?

$$\text{Flow Rate (cfs)} = \text{Area (ft}^2) \times \text{Velocity (ft/sec)}$$

$$\text{Area} = 0.785 \times (2.5\text{ ft})^2 = 4.90625\text{ ft}^2 = 4.9\text{ ft}^2$$

$$\text{Flow Rate (cfs)} = 4.9\text{ ft}^2 \times 5.5\text{ ft/sec} = 26.95\ \frac{\text{ft}^3}{\text{sec}} = 27\ \frac{\text{ft}^3}{\text{sec}}$$

$$\frac{27\text{ ft}^3}{\text{sec}} \times \frac{7.48\text{ gal}}{1\text{ ft}^3} \times \frac{60\text{ sec}}{1\text{ min}} \times \frac{1{,}440\text{ min}}{1\text{ day}} \times \frac{1\text{ MG}}{1{,}000{,}000} = 17.449344\text{ MGD} = 17.4\text{ MGD}$$

2. What is the velocity through a box culvert that is 8 feet wide and 5 feet deep if the daily flow is 44 AF?

$$Q = \frac{44\text{ AF}}{\text{day}} \times \frac{325{,}851\text{ gal}}{1\text{ AF}} \times \frac{1\text{ day}}{24\text{ hr}} \times \frac{1\text{ hr}}{60\text{ min}} \times \frac{1\text{ min}}{60\text{ sec}} \times \frac{1\text{ ft}^3}{7.48\text{ gal}} = 22.1848447\text{ cfs}$$

$$A = 8\text{ ft} \times 5\text{ ft} = 40\text{ ft}^2$$

$$\text{V (ft/sec)} = \frac{\text{Q (cfs)}}{\text{A (ft}^2)} = \frac{22.2\text{ cfs}}{40\text{ ft}^2} = 0.555\text{ fps} = 0.6\text{ fps}$$

3. What is the area of a pipe that flows 3.1 MGD and has a velocity of 9 fps?

$$Q = \frac{3{,}100{,}000\text{ gal}}{\text{day}} \times \frac{1\text{ day}}{24\text{ hr}} \times \frac{1\text{ hr}}{60\text{ min}} \times \frac{1\text{ min}}{60\text{ sec}} \times \frac{1\text{ ft}^3}{7.48\text{ gal}} = 4.7967419\text{ cfs}$$

$$\text{A (ft}^2) = \frac{\text{Q (cfs)}}{\text{V (ft/sec)}} = \frac{4.8\text{ cfs}}{9\text{ fps}} = 0.5333\text{ ft}^2 = 0.53\text{ ft}^2$$

4. What is the diameter of a pipe that flows 1,425 gpm with a velocity of approximately 2.7 fps?

$$\frac{1{,}425\text{ gpm}}{1} \times \frac{1\text{ cfs}}{448.8\text{ gpm}} = 3.17513\text{ cfs} = 3.18\text{ cfs}$$

$$A\ (ft^2) = \frac{Q\ (cfs)}{V\ (ft/sec)} = \frac{3.18\ cfs}{2.7\ fps} = 1.17777\ ft^2 = 1.2\ ft^2$$

$$\text{Area} = 0.785 \times D^2$$

$$D^2 = \frac{\text{Area}}{0.785} = \frac{1.2\ ft^2}{0.785} = 1.5286624\ ft^2$$

$$\sqrt{D^2} = \sqrt{1.5286624\ ft^2}$$

$$D = 1.236390\ ft \times \frac{12\ in}{1\ ft} = 14.8366\ in = 15\ in$$

5. A 20-mile aqueduct flows 22,200 AFY at an average velocity of 0.32 fps. If the distance across the top is 20 feet and the depth is 6 feet, what is the distance across the bottom?

$$Q = \frac{22{,}200\ AF}{year} \times \frac{325{,}851\ gal}{1\ AF} \times \frac{1\ year}{365\ day} \times \frac{1\ day}{24\ hr} \times \frac{1\ hr}{60\ min} \times \frac{1\ min}{60\ sec} \times \frac{1\ ft^3}{7.48\ gal} = 30.6664728\ cfs$$

$$A\ (ft^2) = \frac{Q\ (cfs)}{V\ (ft/sec)} = \frac{30.7\ cfs}{0.32\ fps} = 95.9375\ ft^2$$

$$\text{Trapezoid Area} = \frac{b_1 + b_2}{2} \times H$$

$$96\ ft^2 = \frac{20\ ft + ?\ ft}{2} \times 6\ ft$$

$$\frac{20\ ft + ?\ ft}{2} = \frac{96\ ft^2}{6\ ft} = 16\ ft$$

$$20\ ft + ?\ ft = (16\ ft)(2) = 32\ ft$$

$$?\ ft = 32\ ft - 20\ ft = 12\ ft$$

Practice Problems 3.1

1. Liquid sodium hypochlorite has a specific gravity of 1.69. What is the corresponding weight in pounds per gallon?

$$\frac{8.34 \text{ lbs/gal}}{1 \text{ SG}} \times 1.69 \text{ SG} = 14.0946 \frac{\text{lbs}}{\text{gal}} = 14.1 \frac{\text{lbs}}{\text{gal}}$$

2. Chlorine gas is cooled and pressurized into a liquid state. It weighs 17.31 lbs/gal. What is the specific gravity?

$$\frac{1 \text{ SG}}{8.34 \text{ lbs/gal}} \times 17.31 \text{ lbs/gal} = 2.07553 \text{ SG} = 2.08 \text{ SG}$$

3. What is the weight difference between 111 gallons of water and 61 gallons of sodium hypochlorite with a specific gravity of 1.37?

$$\text{Water: } 111 \text{ gal} \times \frac{8.34 \text{ lbs}}{\text{gal}} = 925.74 \text{ lbs}$$

$$\text{Sod. Hypo.: } 61 \text{ gal} \times \left(\frac{8.34 \text{ lbs/gal}}{1 \text{ SG}} \times 1.37 \text{ SG}\right) = 61 \text{ gal} \times \left(\frac{11.43 \text{ lbs}}{\text{gal}}\right) = 697.23 \text{ lbs}$$

Weight Difference = 925.74 lbs - 697.23 lbs = 228.51 lbs

4. A treatment operator has 75 gallons of 14.5% sodium hypochlorite. How many pounds of the 75 gallons are available chlorine?

$75 \text{ gal} \times 0.145 = 10.875$ gal of sodium hypochlorite

$$10.875 \text{ gal} \times \frac{8.34 \text{ lbs}}{\text{gal}} = 90.6975 \text{ lbs} = 90.7 \text{ lbs of sodium hypochlorite}$$

$$\text{Total Pounds: } 75 \text{ gal} \times \frac{8.34 \text{ lbs}}{\text{gal}} = 625.5 \text{ lbs}$$

5. The specific gravity of 25% Alum is 1.24. How much does 83 gallons of 25% Alum weigh?

$$\left(\frac{8.34\text{ lbs/gal}}{1\text{ SG}} \times 1.24\text{ SG}\right) \times 83\text{ gal} = \frac{10.3416\text{ lbs}}{\text{gal}} \times 83\text{ gal} = 858.3528\text{ lbs} = 858.4\text{ lbs}$$

6. Ferric chloride weighs 19.44 lbs/gal. What is the specific gravity?

$$\frac{19.44\text{ lbs}}{\text{gal}} \times \frac{\text{gal}}{8.34\text{ lbs}} = 2.33\text{ SG}$$

7. How many pounds of ferric chloride are in 92 gallons of 33% strength? (Assume the specific gravity is 1.52.)

$$\left(0.33 \times \frac{8.34\text{ lbs/gal}}{1\text{ SG}} \times 1.52\text{ SG}\right) \times 92\text{ gal} = \frac{4.18\text{ lbs}}{\text{gal}} \times 92\text{ gal} = 384.56\text{ lbs}$$

8. What is the weight in lbs/cf of a substance that has a specific gravity of 1.47?

$$\text{weight in lbs/gal} = \frac{8.34\text{ lbs/gal}}{1\text{ SG}} \times 1.47\text{ SG} = 12.2598\text{ lbs/gal} = 12.26\text{ lbs/gal}$$

$$\frac{12.26\text{ lbs}}{\text{gal}} \times \frac{7.48\text{ gal}}{1\text{ cf}} = 91.7048\text{ lbs/cf} = 91.7\text{ lbs/cf}$$

9. A shipment of crude oil has a specific gravity of 0.674. What is the weight in lbs/cf?

$$\text{weight in lbs/gal} = \frac{8.34\text{ lbs/gal}}{1\text{ SG}} \times 0.674\text{ SG} = 5.62116\text{ lbs/gal} = 5.6\text{ lbs/gal}$$

$$\frac{5.6\text{ lbs}}{\text{gal}} \times \frac{7.48\text{ gal}}{1\text{ cf}} = 41.888\text{ lbs/cf} = 41.9\text{ lbs/cf}$$

Practice Problems 3.2

1. An 87.5% chlorine solution has a ppm concentration of?

$$87.5 \times 10{,}000 = 875{,}000 \text{ ppm}$$

2. What is the percent concentration of a 471-ppm solution?

$$\% \times 10{,}000 = 471 \text{ ppm}$$

$$\% = \frac{471 \text{ ppm}}{10{,}000} = 0.0471\%$$

3. A water utility uses a 12.7% sodium hypochlorite solution to disinfect a well. What is the ppm concentration of the solution?

$$12.7 \times 10{,}000 = 127{,}000 \text{ ppm}$$

4. A container of liquid chlorine has a concentration of 390 ppm. What is the percent concentration of the solution?

$$\% \times 10{,}000 = 390 \text{ ppm}$$

$$\% = \frac{390 \text{ ppm}}{10{,}000} = 0.039\%$$

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

Constituent	ppm	ppb	ppt
Arsenic	0.051	51	51,000
Chromium	1.74	1,740	1,740,000
Nitrate (NO3)	112	112,000	112,000,000
Perchlorate	0.090832	90.832	90,832
Vinyl chloride	0.00075	0.75	750

To convert ppb to ppm, you divide ppb by 1,000.

$$\text{Arsenic: 51 ppb} \times \frac{1\text{ ppm}}{1{,}000\text{ ppb}} = 0.051\text{ ppm}$$

To convert ppb to ppt, you multiply ppb by 1,000.

$$\text{Arsenic: 51 ppb} \times \frac{1{,}000{,}000\text{ ppt}}{1{,}000\text{ ppb}} = 51\text{ ppb} \times \frac{1{,}000\text{ ppt}}{1\text{ ppb}} = 51{,}000\text{ ppt}$$

To convert ppm to ppb, you multiply ppm by 1,000.

$$\text{Chromium: 1.74 ppm} \times \frac{1{,}000\text{ ppb}}{1\text{ ppm}} = 1{,}740\text{ ppb}$$

To convert ppb to ppt, you multiply ppb by 1,000.

$$\text{Chromium: 1,740 ppb} \times \frac{1{,}000{,}000\text{ ppt}}{1{,}000\text{ ppb}} = 1{,}740\text{ ppb} \times \frac{1{,}000\text{ ppt}}{1\text{ ppb}} = 1{,}740{,}000\text{ ppt}$$

To convert ppm to ppb, you multiply ppm by 1,000.

$$\text{Nitrate } \left(NO_3\right): 112\text{ ppm} \times \frac{1{,}000\text{ ppb}}{1\text{ ppm}} = 112{,}000\text{ ppb}$$

To convert ppb to ppt, you multiply ppb by 1,000.

$$\text{Nitrate } \left(NO_3\right): 112{,}000\text{ ppb} \times \frac{1{,}000\text{ ppt}}{1\text{ ppb}} = 112{,}000{,}000\text{ ppt}$$

To convert ppt to ppb, you divide ppt by 1,000.

$$\text{Perchlorate}: 90{,}832\text{ ppt} \times \frac{1\text{ ppb}}{1{,}000\text{ ppt}} = 90.832\text{ ppb}$$

To convert ppb to ppm, you divide ppb by 1,000.

$$\text{Perchlorate}: 90.832\text{ ppb} \times \frac{1\text{ ppm}}{1{,}000\text{ ppb}} = 0.090832\text{ ppm}$$

To convert ppb to ppm, you divide ppb by 1,000.

$$\text{Vinyl chloride: 0.75 ppb} \times \frac{1\text{ ppm}}{1{,}000\text{ ppb}} = 0.00075\text{ ppm}$$

To convert ppb to ppt, you multiply ppb by 1,000.

$$\text{Vinyl chloride: } 0.75 \text{ ppb} \times \frac{1{,}000 \text{ ppt}}{1 \text{ ppb}} = 750 \text{ ppt}$$

Practice Problems 3.3

1. How many gallons are needed to dilute 30-gallons of 18.75% sodium hypochlorite solution to a 10% solution?

C_1 = 18.75% C_2 = 10 %
V_1 = 30 gal V_2 = ? gal

$$C_1V_1 = C_2V_2$$

$$(18.75\%)(30 \text{ gal}) = (10\%)V_2$$

$$V_2 = \frac{(0.1875)(30 \text{ gal})}{(0.10)} = 56.25 \text{ gal}$$

Total Diluted Volume = 56.25 gal

Gallons needed to dilute = 56.25 gal - 30 gal = 26.25 gal

2. If a 500-gallon container is 1/2 full of a 14% solution and is then completely filled with fresh water, what would the resulting ppm of the water be?

500 gal container that is 1/2 full: 500 gal (.50) = 250 gal

C_1 = 14% C_2 = ? %
V_1 = 250 gal V_2 = 500 gal

$$C_1V_1 = C_2V_2$$

$$(14\%)(250 \text{ gal}) = C_2(500 \text{ gal})$$

$$C_2 = \frac{(0.14)(250 \text{ gal})}{(500 \text{ gal})} = 0.07 \times 100 = 7\%$$

$7 \times 10{,}000 = 70{,}000$ ppm

3. A chlorine storage tank that is 6 ft high with a 3ft diameter contains 227 gallons of 30% chlorine solution. If the tank is filled up with water, what will the new diluted concentration be?

$$\text{Tank Volume} = 0.785 \times D^2 \times H = 0.785 \times (3\text{ ft})^2 \text{ x } 6\text{ ft} = 42.39\text{ ft}^3$$

$$42.39\text{ ft}^3 \times \frac{7.48\text{ gal}}{1\text{ ft}^3} = 317.0772\text{ gal} = 317\text{ gal}$$

C_1 = 30% $\qquad$ C_2 = ? %

V_1 = 227 gal $\qquad$ V_2 = 317 gal

$$C_1V_1 = C_2V_2$$

$$(30\%)(227\text{ gal}) = C_2(317\text{ gal})$$

$$C_2 = \frac{(0.30)(227\text{ gal})}{(317\text{ gal})} = 0.214826498 \times 100 = 21.48\% = 21.5\%$$

4. 45 gallons of a 223,000ppm solution are mixed with 100 gallons of water. What is the concentration of the diluted solution? (Express the answer as a percentage.)

$$\%\text{ concentration} = \frac{223{,}000\text{ ppm}}{10{,}000} = 22.3\%$$

Final water volume = 45 gal + 100 gal = 145 gal

C_1 = 22.3% $\qquad$ C_2 = ? %

V_1 = 45 gal $\qquad$ V_2 = 145 gal

$$C_1V_1 = C_2V_2$$

$$(22.3\%)(45\text{ gal}) = C_2(145\text{ gal})$$

$$C_2 = \frac{(0.223)(45\text{ gal})}{(145\text{ gal})} = 0.06920689 \times 100 = 6.9\%$$

Practice Problems 4.1

1. How many gallons of water can be treated with 325 pounds of 80% High Test Hypochlorite (HTH) to a dosage of 1.25 mg/L?

$$\text{Pound Formula} \rightarrow \frac{\text{MG} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \text{ppm}}{\%\text{ concentration}} = \text{lbs}$$

$$\frac{\text{MG} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times 1.25 \text{ ppm}}{80\%} = 325 \text{ lbs}$$

$$\text{MG} = \frac{325 \text{ lbs} \times 0.80}{\frac{8.34 \text{ lbs}}{\text{gal}} \times 1.25 \text{ ppm}} = \frac{260}{10.425} = 24.9 \text{ MG}$$

2. An operator added 85 pounds of 10% ferric chloride to a treatment flow of 4.1 MGD. What was the corresponding dosage?

$$\text{Pound Formula} \rightarrow \frac{\frac{\text{MG}}{\text{D}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \text{ppm}}{\%\text{ concentration}} = \frac{\text{lbs}}{\text{day}}$$

$$\text{Pound Formula} \rightarrow \frac{\frac{4.1 \text{ MG}}{\text{D}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \text{ppm}}{10\%} = \frac{85 \text{ lbs}}{\text{day}}$$

$$\frac{4.1 \text{ MG}}{\text{D}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \text{ppm} = \frac{85 \text{ lbs}}{\text{day}} \times 0.10$$

$$\text{ppm} = \frac{\frac{85 \text{ lbs}}{\text{day}} \times 0.10}{\frac{4.1 \text{ MG}}{\text{D}} \times \frac{8.34 \text{ lbs}}{\text{gal}}}$$

$$\text{ppm} = \frac{\frac{8.5 \text{ lbs}}{\text{day}}}{\frac{34.194 \text{ lbs}}{\text{day}}} = 0.24858 = 0.25$$

3. How many pounds of 24.5% sodium hypochlorite are needed to dose a well with a flow rate of 2,150 gpm to a dosage of 3.45 ppm? (Assume the well runs 10 hours a day).

$$\frac{2{,}150\text{ gal}}{\text{min}} \times \frac{60\text{ min}}{1\text{ hr}} \times \frac{10\text{ hr}}{1\text{ day}} \times \frac{1\text{ MG}}{1{,}000{,}000\text{ gal}} = 1.29\text{ MGD}$$

$$\text{Pound Formula} \rightarrow \frac{\frac{\text{MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}} \times \text{ppm}}{\%\text{ concentration}} = \frac{\text{lbs}}{\text{day}}$$

$$\frac{1.29\text{ MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}} \times 3.45\text{ ppm} = \frac{37.11717\text{ lbs}}{\text{day}}$$

$$\frac{\frac{37.11717\text{ lbs}}{\text{day}}}{\%\text{ concentration}} = \frac{\frac{37.11717\text{ lbs}}{\text{day}}}{24.5\%} = \frac{\frac{37.11717\text{ lbs}}{\text{day}}}{0.245} = \frac{151.498\text{ lbs}}{\text{day}} = \frac{151.50\text{ lbs}}{\text{day}}$$

4. In the above problem, how many gallons of chemical are needed per hour? (Assume the SG is 1.9).

$$\frac{8.34\text{ lbs/gal}}{1\text{ SG}} \times \frac{1.9\text{ SG}}{1} = 15.846 = 15.85\frac{\text{lbs}}{\text{gal}}$$

$$\frac{151.50\text{ lbs}}{\text{day}} \times \frac{\text{gal}}{15.85\text{ lbs}} = \frac{9.558\text{ gal}}{\text{day}} = \frac{9.6\text{ gal}}{\text{day}}$$

$$\frac{9.6\text{ gal}}{\text{day}} \times \frac{1\text{ day}}{10\text{ hours}} = \frac{0.96\text{ gal}}{\text{hour}} = \frac{1.0\text{ gal}}{\text{hour}}$$

5. A treatment operator has set a chemical pump to dose 145 gallons of NaOH (sodium hydroxide) per day for a flow rate of 6.35 MGD. What is the corresponding dosage? (Assume the SG is 2.41).

$$\frac{8.34\text{ lbs/gal}}{1\text{ SG}} \times \frac{2.41\text{ SG}}{1} = 20.0994 = 20.1\frac{\text{lbs}}{\text{gal}} \times 145\text{ gal} = 2{,}914.5\text{ lbs}$$

$$\text{Pound Formula} \rightarrow \frac{\text{MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}} \times \text{ppm} = \frac{\text{lbs}}{\text{day}}$$

$$\frac{6.35\text{ MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}} \times \text{ppm} = \frac{2{,}914.5\text{ lbs}}{\text{day}}$$

$$\text{ppm} = \frac{\frac{2{,}914.5\text{ lbs}}{\text{day}}}{\frac{6.35\text{ MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}}} = \frac{2{,}914.5}{52.959} = 55.033 = 55\text{ ppm}$$

6. 3 miles of 24" diameter main line needs to be dosed to 100 ppm. Answer the following questions.

   a. How many gallons of 15% (SG = 1.60) sodium hypochlorite are needed?

$$\text{Pipe Volume} = 0.785 \times \text{D}^2 \times \text{H}$$

$$\text{Pipe Volume} = 0.785 \times (2\text{ ft})^2 \text{ x } \left(3\text{ miles} \times \frac{5{,}280\text{ ft}}{\text{mile}}\right) =$$

$$\text{Pipe Volume} = 0.785 \times 4\text{ ft}^2 \text{ x } 15{,}840\text{ ft} = 49{,}737.6\text{ ft}^3$$

$$49{,}737.6\text{ ft}^3 \times \frac{7.48\text{ gal}}{1\text{ ft}^3} \times \frac{1\text{ MG}}{1{,}000{,}000\text{ gal}} = 0.372037\text{ MG} = 0.37\text{ MG}$$

$$\frac{0.37\text{ MG}}{\text{D}} \times \frac{8.34\text{ lbs}}{\text{gal}} \times 100\text{ ppm} = \frac{308.58\text{ lbs}}{\text{day}}$$

$$\frac{\frac{308.58\text{ lbs}}{\text{day}}}{\%\text{ concentration}} = \frac{\frac{308.58\text{ lbs}}{\text{day}}}{15\%} = \frac{\frac{308.58\text{ lbs}}{\text{day}}}{0.15} = \frac{2{,}057.2\text{ lbs}}{\text{day}}$$

$$\frac{8.34\text{ lbs/gal}}{1\text{ SG}} \times \frac{1.60\text{ SG}}{1} = 13.344 = 13.34\ \frac{\text{lbs}}{\text{gal}}$$

$$\frac{2{,}057.2\text{ lbs}}{\text{day}} \times \frac{\text{gal}}{13.34\text{ lbs}} = 154.2\text{ gal}$$

   b. How many pounds of 45% HTH are needed?

$$\text{Pound Formula} \rightarrow \frac{\text{MG} \times \frac{8.34\text{ lbs}}{\text{gal}} \times \text{ppm}}{\%\text{ concentration}} = \text{lbs}$$

$$\frac{0.37\text{ MG} \times \frac{8.34\text{ lbs}}{\text{gal}} \times 100\text{ ppm}}{45\%\text{ concentration}} = \frac{308.58}{0.45} = 685.73\text{ lbs}$$

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

i. Sodium hypochlorite = $2.75 per gallon

$$154.2\text{ gal} \times \frac{\$2.75}{\text{gal}} = \$424.05$$

ii. HTH = $1.35 per pound

$$685.73\text{ lbs} \times \frac{\$1.35}{\text{lbs}} = \$925.74$$

7. A water treatment operator adjusted the amount of 15% Alum dosage from 90 mg/L to 65 mg/L. Based on a treatment flow of 8 MGD, what is the cost savings if 15% Alum costs $1.20 per pound?

$$\frac{8\text{ MGD} \times \frac{8.34\text{ lbs}}{\text{gal}} \times 90\text{ ppm}}{15\%\text{ concentration}} = \frac{6{,}004.8}{0.15} = 40{,}032\text{ lbs per day}$$

$$40{,}032\text{ lbs} \times \frac{\$1.20}{\text{lbs}} = \$48{,}038.40\text{ per day}$$

$$\frac{8\text{ MGD} \times \frac{8.34\text{ lbs}}{\text{gal}} \times 65\text{ ppm}}{15\%\text{ concentration}} = \frac{4{,}336.8}{0.15} = 28{,}912\text{ lbs per day}$$

$$28{,}912\text{ lbs} \times \frac{\$1.20}{\text{lbs}} = \$34{,}694.4\text{ per day}$$

Cost Savings = $48,038.40 per day - $34,694.4 per day = $13,344 per day

8. A water utility produced 6,000 AF of water last year. The entire amount was dosed at an average rate of 0.6 ppm. If the chemical of choice was 35% HTH at a per pound cost of $2.43, what was the annual budget?

$$\frac{6{,}000 \text{ AF}}{\text{year}} \times \frac{325{,}851 \text{ gal}}{1 \text{ AF}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 1{,}955.11 = 1{,}955 \ \frac{\text{MG}}{\text{year}}$$

$$\frac{1{,}955 \text{ MG}}{\text{year}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times 0.6 \text{ ppm} = \frac{9{,}782.82 \text{ lbs}}{\text{year}} = \frac{9{,}783 \text{ lbs}}{\text{year}}$$

$$\frac{\frac{9{,}783 \text{ lbs}}{\text{year}}}{\% \text{ concentration}} = \frac{\frac{9{,}783 \text{ lbs}}{\text{year}}}{35\%} = \frac{\frac{9{,}783 \text{ lbs}}{\text{year}}}{0.35} = \frac{27{,}951.43 \text{ lbs}}{\text{year}}$$

$$\frac{27{,}951.43 \text{ lbs}}{\text{year}} \times \frac{\$2.43}{\text{lbs}} = \$67{,}921.97 \text{ per year}$$

9. Ferric chloride is used as the coagulant of choice at a 10.1 MGD rated capacity treatment plant. If the plant operated at the rated capacity for 60% of the year and operated at 30% of rated capacity for 40% of the year, how many pounds of the coagulant was needed to maintain a dosage of 65 mg/L?

60% of the year: 365 days $\times$ 0.60 = 219 days

40% of the year: 365 days $\times$ 0.40 = 146 days

Plant flow during 60% of the year.

$$\frac{10.1 \text{ MG}}{\text{D}} \times 219 \text{ days} = 2{,}211.9 \text{ MG}$$

$$2{,}211.9 \text{ MG} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times 65 \text{ ppm} = 1{,}199{,}070.99 \text{ lbs} = 1{,}199{,}071 \text{ lbs}$$

Plant flow during 40% of the year.

$$\frac{10.1 \text{ MG}}{\text{D}} \times 0.30 \times 146 \text{ days} = 442.38 \text{ MG}$$

$$442.38 \text{ MG} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times 65 \text{ ppm} = 239{,}814.198 \text{ lbs} = 239{,}814 \text{ lbs}$$

Total pounds used annually.

1,199,071 lbs + 238,814 lbs $=$ 1,437,885 lbs

10. A water softening treatment process uses 30% NaOH during 40% of the year and 40% NaOH for 60% of the year. Assuming a constant flow rate of 500 gpm and a dosage of 55 mg/L, what is the annual budget if the 30% NaOH (SG = 1.55) costs \$1.20 per gallon and the 40% NaOH (SG = 1.87) costs \$2.10 per gallon?

40% of the year: 365 days × 0.40 = 146 days

60% of the year: 365 days × 0.60 = 219 days

30% NaOH (SG = 1.55) in lbs per gallon.

$$\frac{8.34 \text{ lbs/gal}}{1 \text{ SG}} \times \frac{1.55 \text{ SG}}{1} = 12.927 = 12.9 \frac{\text{lbs}}{\text{gal}}$$

40% NaOH (SG = 1.87) in lbs per gallon.

$$\frac{8.34 \text{ lbs/gal}}{1 \text{ SG}} \times \frac{1.87 \text{ SG}}{1} = 15.5958 = 15.6 \frac{\text{lbs}}{\text{gal}}$$

Convert gpm to MGD

$$\frac{500 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{24 \text{ hr}}{1 \text{ day}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 0.72 \text{ MGD}$$

40% of the year

$$40\% \text{ of the year} = 146 \text{ days} \times \frac{0.72 \text{ MG}}{\text{D}} = 105.12 \text{ MG}$$

$$\frac{105.12 \text{ MG}}{\text{year}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times 55 \text{ ppm} = \frac{48{,}218.544 \text{ lbs}}{\text{year}}$$

$$\frac{\frac{48{,}218.544 \text{ lbs}}{\text{year}}}{\% \text{ concentration}} = \frac{\frac{48{,}218.544 \text{ lbs}}{\text{year}}}{30\%} = \frac{\frac{48{,}218.544 \text{ lbs}}{\text{year}}}{0.30} = \frac{160{,}728.48 \text{ lbs}}{\text{year}}$$

$$\frac{160{,}728.48 \text{ lbs}}{\text{year}} \times \frac{\text{gal}}{12.9 \text{ lbs}} \times \frac{\$1.20}{\text{gal}} = \$14{,}951.49 \text{ per year}$$

60% of the year

$$60\% \text{ of the year} = 219 \text{ days} \times \frac{0.72 \text{ MG}}{\text{D}} = 157.68 \text{ MG}$$

$$\frac{157.68 \text{ MG}}{\text{year}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times 55 \text{ ppm} = \frac{72{,}327.816 \text{ lbs}}{\text{year}}$$

$$\frac{\frac{72,327.816 \text{ lbs}}{\text{year}}}{\% \text{ concentration}} = \frac{\frac{72,327.816 \text{ lbs}}{\text{year}}}{40\%} = \frac{\frac{72,327.816 \text{ lbs}}{\text{year}}}{0.40} = \frac{180,819.54 \text{ lbs}}{\text{year}}$$

$$\frac{180,819.54 \text{ lbs}}{\text{year}} \times \frac{\text{gal}}{15.6 \text{ lbs}} \times \frac{\$2.10}{\text{gal}} = \$24,341.09 \text{ per year}$$

Total cost annually.

$$\$14,951.49 \text{ per year} + \$24,341.09 \text{ per year} = \$39,292.58 \text{ per year}$$

11. An operator added 422 gallons of 15% sodium hypochlorite (SG=1.57) in to 5,340 ft of 3 feet diameter pipe. After 36 hours, the residual was measured at 122.65 ppm. What was the demand?

$$\text{Pipe Volume} = 0.785 \times D^2 \times H = 0.785 \times (3 \text{ ft})^2 \text{ x } 5,340 \text{ ft} = 37,727.1 \text{ ft}^3$$

$$37,727.1 \text{ ft}^3 \times \frac{7.48 \text{ gal}}{1 \text{ ft}^3} \times \frac{1 \text{ MG}}{1,000,000 \text{ gal}} = 0.282198708 \text{ MG} = 0.28 \text{ MG}$$

$$\frac{8.34 \text{ lbs/gal}}{1 \text{ SG}} \times \frac{1.57 \text{ SG}}{1} = 13.0938 = 13.1 \frac{\text{lbs}}{\text{gal}}$$

$$13.1 \frac{\text{lbs}}{\text{gal}} \times 422 \text{ gal} = 5,528.2 \text{ lbs}$$

$$\frac{0.28 \text{ MG} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \text{ppm}}{15\%} = 5,528.2 \text{ lbs}$$

$$\frac{2.3352 \times \text{ppm}}{0.15} = 5,528.2 \text{ lbs} \qquad 15.568 \times \text{ppm} = 5,528.2 \text{ lbs}$$

$$\text{ppm} = \frac{5,528.2 \text{ lbs}}{15.568} = 355.10$$

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

$$\text{demand} = \text{dosage} - \text{residual} = 355.10 - 122.65 = 232.45$$

Practice Problems 5.1

1. What is the weir overflow rate through a 3.2 MGD treatment plant if the weir is 18 feet long? (Express your answer in MGD/ft and gpm/ft).

$$\text{Weir Overflow Rate (MGD/ft)} = \frac{3.2\ \text{MGD}}{18\ \text{ft}} = 0.1778\ \text{MGD/ft}$$

Convert the MGD/ft solution previously calculated to gpm/ft.

$$\frac{\frac{0.177778\ \text{MG}}{\text{D}} \times \frac{1{,}000{,}000\ \text{gal}}{1\ \text{MG}} \times \frac{1\ \text{day}}{24\ \text{hour}} \times \frac{1\ \text{hour}}{60\ \text{min}}}{\text{ft}} = \frac{123.46\ \text{gpm}}{\text{ft}}$$

Or convert the treatment plant flow rate provided from MGD to gpm first.

$$\frac{3.2\ \text{MG}}{\text{D}} \times \frac{1{,}000{,}000\ \text{gal}}{1\ \text{MG}} \times \frac{1\ \text{day}}{24\ \text{hour}} \times \frac{1\ \text{hour}}{60\ \text{min}} = 2{,}222.22\ \text{gpm}$$

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{2{,}222.22\ \text{gpm}}{18\ \text{ft}} = \frac{123.46\ \text{gpm}}{\text{ft}}$$

2. A drainage channel has a 210-foot weir and a weir overflow rate of 28 gpm/ft. What is the daily flow expressed in MGD?

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{?\ \text{gpm}}{210\ \text{ft}} = 28\ \text{gpm/ft}$$

$$?\ \text{gpm} = \frac{28\ \text{gpm}}{\text{ft}} \times 210\ \text{ft} = 5{,}880\ \text{gpm}$$

$$\frac{5{,}880\ \text{gal}}{\text{min}} \times \frac{1\ \text{MG}}{1{,}000{,}000\ \text{gal}} \times \frac{24\ \text{hour}}{1\ \text{day}} \times \frac{60\ \text{min}}{1\ \text{hour}} = 8.4672\ \text{MGD} = 8.5\ \text{MGD}$$

3. What is the length of a weir if the daily flow is 6.9 MG and the weir overflow rate is 41 gpm/ft?

Converting 6.9 MGD to gpm.

$$\frac{6.9\ \text{MG}}{\text{D}} \times \frac{1{,}000{,}000\ \text{gal}}{1\ \text{MG}} \times \frac{1\ \text{day}}{24\ \text{hour}} \times \frac{1\ \text{hour}}{60\ \text{min}} = 4{,}791.67\ \text{gpm}$$

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{4{,}791.67\ \text{gpm}}{?\ \text{ft}} = 41\ \text{gpm/ft}$$

$$\text{Weir Length (ft)} = \frac{4{,}791.67 \text{ gpm}}{41 \text{ gpm/ft}} = 116.87 \text{ ft} = 116.9 \text{ ft}$$

Converting 41 gpm/ft to MGD/ft.

$$\frac{\frac{41 \text{ gal}}{\text{min}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} \times \frac{24 \text{ hour}}{1 \text{ day}} \times \frac{60 \text{ min}}{1 \text{ hour}}}{\text{ft}} = \frac{0.05904 \text{ MGD}}{\text{ft}}$$

$$\text{Weir Overflow Rate (MGD/ft)} = \frac{6.9 \text{ MGD}}{? \text{ ft}} = 0.05904 \text{ MGD/ft}$$

$$\text{Weir Length (ft)} = \frac{6.9 \text{ MGD}}{0.05904 \text{ MGD/ft}} = 116.87 \text{ ft} = 116.9 \text{ ft}$$

4. A 37 ft diameter circular clarifier has a weir overflow rate of 25 gpm/ft. What is the daily flow in MGD?

$$\text{Circumference} = \pi \times 37 \text{ ft} = 116.18 \text{ ft}$$

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{? \text{ gpm}}{116.18 \text{ ft}} = 25 \text{ gpm/ft}$$

$$? \text{ gpm} = \frac{25 \text{ gpm}}{\text{ft}} \times 116.18 \text{ ft} = 2{,}904.5 \text{ gpm}$$

$$\frac{2{,}904.5 \text{ gal}}{\text{min}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} \times \frac{24 \text{ hour}}{1 \text{ day}} \times \frac{60 \text{ min}}{1 \text{ hour}} = 4.18248 \text{ MGD} = 4.2 \text{ MGD}$$

5. A treatment plant processes 8.4 MGD. The weir overflow rate through a circular clarifier is 17.6 gpm/ft. What is the diameter of the clarifier?

$$\frac{\frac{17.6 \text{ gal}}{\text{min}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} \times \frac{24 \text{ hour}}{1 \text{ day}} \times \frac{60 \text{ min}}{1 \text{ hour}}}{\text{ft}} = \frac{0.025344 \text{ MGD}}{\text{ft}}$$

$$\text{Weir Overflow Rate (MGD/ft)} = \frac{8.4 \text{ MGD}}{? \text{ ft}} = 0.025344 \text{ MGD/ft}$$

$$\text{Weir Length (ft)} = \frac{8.4 \text{ MGD}}{0.025344 \text{ MGD/ft}} = 331.44 \text{ ft}$$

$$\text{Circumference} = \pi \times D = 331.44 \text{ ft}$$

$$D = \frac{331.44 \text{ ft}}{3.14} = 105.55 \text{ ft} = 105.6 \text{ ft}$$

6. An aqueduct that flowed 44,500 acre-feet of water last year has a weir overflow structure to control the flow. If the weir is 315 feet long, what was the average weir overflow rate in gpm/ft?

$$\frac{44{,}500 \text{ AF}}{\text{year}} \times \frac{325{,}851 \text{ gal}}{1 \text{ AF}} \times \frac{1 \text{ year}}{365 \text{ day}} \times \frac{1 \text{ day}}{24 \text{ hour}} \times \frac{1 \text{ hour}}{60 \text{ min}} = 27{,}588.22 \text{ gpm}$$

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{27{,}588.22 \text{ gpm}}{315 \text{ ft}} = 87.58 = 87.6 \text{ gpm/ft}$$

7. An aqueduct is being reconstructed to widen the width across the top. The width across the bottom is 25 feet and the average water depth is 40 feet. The aqueduct must maintain a constant weir overflow rate of 15 gpm per foot with a daily flow of 0.88 MGD. What is the length of the weir?

Converting 0.88 MGD to gpm.

$$\frac{0.88 \text{ MG}}{\text{D}} \times \frac{1{,}000{,}000 \text{ gal}}{1 \text{ MG}} \times \frac{1 \text{ day}}{24 \text{ hour}} \times \frac{1 \text{ hour}}{60 \text{ min}} = 611.1 \text{ gpm}$$

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{611.1 \text{ gpm}}{? \text{ ft}} = 15 \text{ gpm/ft}$$

$$\text{Weir Length (ft)} = \frac{611.1 \text{ gpm}}{15 \text{ gpm/ft}} = 40.74 \text{ ft}$$

Converting 15 gpm/ft to MGD/ft.

$$\frac{\frac{15 \text{ gal}}{\text{min}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} \times \frac{24 \text{ hour}}{1 \text{ day}} \times \frac{60 \text{ min}}{1 \text{ hour}}}{\text{ft}} = \frac{0.0216 \text{ MGD}}{\text{ft}}$$

$$\text{Weir Overflow Rate (MGD/ft)} = \frac{0.88 \text{ MGD}}{? \text{ ft}} = 0.0216 \text{ MGD/ft}$$

$$\text{Weir Length (ft)} = \frac{0.88 \text{ MGD}}{0.0216 \text{ MGD/ft}} = 40.74 \text{ ft}$$

8. An engineering report determined that a minimum weir overflow rate of 25 gpm per foot and a maximum weir overflow rate of 30 gpm per foot were needed to meet the water

quality objectives of a certain treatment plant. The existing weir is 120 feet long. What is the daily treatment flow range of the plant?

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{?\ \text{gpm}}{120\ \text{ft}} = 25\ \text{gpm/ft}$$

$$?\ \text{gpm} = \frac{25\ \text{gpm}}{\text{ft}} \times 120\ \text{ft} = 3{,}000\ \text{gpm}$$

$$\frac{3{,}000\ \text{gal}}{\text{min}} \times \frac{1\ \text{MG}}{1{,}000{,}000\ \text{gal}} \times \frac{24\ \text{hour}}{1\ \text{day}} \times \frac{60\ \text{min}}{1\ \text{hour}} = 4.32\ \text{MGD} = 4.3\ \text{MGD}$$

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{?\ \text{gpm}}{120\ \text{ft}} = 30\ \text{gpm/ft}$$

$$?\ \text{gpm} = \frac{30\ \text{gpm}}{\text{ft}} \times 120\ \text{ft} = 3{,}600\ \text{gpm}$$

$$\frac{3{,}600\ \text{gal}}{\text{min}} \times \frac{1\ \text{MG}}{1{,}000{,}000\ \text{gal}} \times \frac{24\ \text{hour}}{1\ \text{day}} \times \frac{60\ \text{min}}{1\ \text{hour}} = 5.184\ \text{MGD} = 5.2\ \text{MGD}$$

Practice Problems 6.1

1. What is the detention time in hours of a 300 ft by 50 ft by 25 ft sedimentation basin with a flow of 8.1 MGD?

$$\text{Volume} = 300 \text{ ft} \times 50 \text{ ft} \times 25 \text{ ft} = 375{,}000 \text{ ft}^3$$

$$375{,}000 \text{ ft}^3 \times \frac{7.48 \text{ gal}}{1 \text{ cf}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 2.805 \text{ MG}$$

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{2.805 \text{ MG}}{8.1 \text{ MGD}} = 0.346296 \text{ days} \times \frac{24 \text{ hour}}{1 \text{ day}} \times \frac{60 \text{ min}}{1 \text{ hour}} = 498.7 \text{ min}$$

2. What is the detention time in a circular clarifier with a depth of 65 ft and a 95 ft diameter if the daily flow is 7.3 MG. (Express your answer in hours:minutes.)

$$\text{Tank Volume} = 0.785 \times D^2 \times H = 0.785 \times (95 \text{ ft})^2 \text{ x } 65 \text{ ft} = 460{,}500.63 \text{ ft}^3$$

$$460{,}500.63 \text{ ft}^3 \times \frac{7.48 \text{ gal}}{1 \text{ cf}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 3.44454 \text{ MG}$$

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{3.44454 \text{ MG}}{7.3 \text{ MGD}} = 0.471855 \text{ days} \times \frac{24 \text{ hour}}{1 \text{ day}} = 11.32453 \text{ hours}$$

$$0.32453 \text{ hours} \times \frac{60 \text{ min}}{1 \text{ hour}} = 19.5 \text{ min}$$

$$D_t = 11 \text{ hours } 19.5 \text{ minutes} = 11{:}19.5$$

3. A water utility engineer is designing a sedimentation basin to treat 12 MGD and maintain a minimum detention time of 3 hours 30 minutes. The basin cannot be longer than 100 feet and wider than 65 feet. Under this scenario, how deep must the basin be?

Convert detention time to mins

$$\left(3 \text{ hours} \times \frac{60 \text{ min}}{1 \text{ hour}}\right) + 30 \text{ min} = 210 \text{ min}$$

Convert flow from MGD to gpm

$$\frac{12\text{ MG}}{\text{D}} \times \frac{1{,}000{,}000\text{ gal}}{1\text{ MG}} \times \frac{1\text{ day}}{24\text{ hour}} \times \frac{1\text{ hour}}{60\text{ min}} = 8{,}333.33\text{ gpm}$$

$$\text{Volume} = D_t \times \text{Flow} = 210\text{ min} \times \frac{8{,}333.33\text{ gal}}{\text{min}} = 1{,}749{,}999.3\text{ gal}$$

$$\text{Volume} = 1{,}749{,}999.3\text{ gal} \times \frac{1\text{ cf}}{7.48\text{ gal}} = 233{,}957.13\text{ cf}$$

$$\text{Volume} = 100\text{ ft} \times 65\text{ ft} \times \text{Depth} = 233{,}957.13\text{ ft}^3$$

$$\text{Depth} = \frac{233{,}957.13\text{ ft}^3}{100\text{ ft} \times 65\text{ ft}} = \frac{233{,}957.13\text{ ft}^3}{6500\text{ ft}^2} = 35.99\text{ ft} = 36\text{ ft}$$

4. A water utility is designing a transmission pipeline collection system in order to achieve a chlorine contact time of 75 minutes once a 3,400 gpm well is chlorinated. How many feet of 36" diameter pipe are needed?

$$\text{Volume} = D_t \times \text{Flow} = 75\text{ min} \times \frac{3{,}400\text{ gal}}{\text{min}} = 255{,}000\text{ gal}$$

$$\text{Volume} = 255{,}000\text{ gal} \times \frac{1\text{ cf}}{7.48\text{ gal}} = 34{,}090.909\text{ cf} = 34{,}090.9\text{ cf}$$

$$\text{Pipe Volume} = 0.785 \times D^2 \times H = 0.785 \times (3\text{ ft})^2 \text{ x Length} = 34{,}090.9\text{ ft}^3$$

$$\text{Length} = \frac{34{,}090.9\text{ ft}^3}{0.785 \times (3\text{ ft})^2} = \frac{34{,}090.9\text{ ft}^3}{7.065\text{ ft}^2} = 4{,}825.3\text{ ft} = 4{,}825\text{ ft}$$

5. The chlorine residual decay rate is 0.7 mg/L per 3/4 hour in a 4 MG water storage tank. If the storage tank needs to maintain a minimum chlorine residual of 6.5 mg/L what is the required dosage if the tank is filling at a rate of 900 gpm until the tank is full?

$$4\text{ MG} \times \frac{1{,}000{,}000\text{ gal}}{1\text{ MG}} = 4{,}000{,}000\text{ gal}$$

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{4{,}000{,}000\text{ gal}}{900\text{ gpm}} = 4{,}444.44\text{ min}$$

$$4{,}444.44\text{ min} \times \frac{0.7\text{ mg/L}}{45\text{ min}} = 69.14\text{ mg/L} + 6.5\text{ mg/L} = 75.6\text{ mg/L}$$

6. A 44-foot-tall water storage tank is disinfected with chloramines through an onsite disinfection system. The average constant effluent from the tank is 680 gpm through a 20-inch diameter pipe. If the first customer that receives water from the tank is 4,972 feet from the tank, would the required 30-minute contact time be achieved?

$$\text{Pipe Volume} = 0.785 \times D^2 \times H = 0.785 \times (1.67\text{ ft})^2 \text{ x } 4{,}972\text{ ft} = 10{,}885.13\text{ ft}^3$$

$$10{,}885.13\text{ ft}^3 \times \frac{7.48\text{ gal}}{1\text{ cf}} = 81{,}420.8\text{ gal}$$

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{81{,}420.8\text{ gal}}{680\text{ gpm}} = 119.74\text{ min} \quad \text{YES!}$$

7. A 70-foot diameter, 35 foot deep clarifier maintains a constant weir overflow rate of 22.6 gpm/ft. What is the detention time in hours:min?

$$\text{Circumference} = \pi \times 70\text{ ft} = 219.8\text{ ft}$$

$$\text{Weir Overflow Rate (gpm/ft)} = \frac{?\text{ gpm}}{219.8\text{ ft}} = 22.6\text{ gpm/ft}$$

$$?\text{ gpm} = \frac{22.6\text{ gpm}}{\text{ft}} \times 219.8\text{ ft} = 4{,}967.48\text{ gpm}$$

$$\text{Tank Volume} = 0.785 \times D^2 \times H = 0.785 \times (70\text{ ft})^2 \text{ x } 35\text{ ft} = 134{,}627.5\text{ ft}^3$$

$$134{,}627.5\text{ ft}^3 \times \frac{7.48\text{ gal}}{1\text{ cf}} = 1{,}007{,}013.7\text{ gal}$$

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{1{,}007{,}013.7\text{ gal}}{4{,}967.48\text{ gpm}} = 202.72\text{ min}$$

$$202.72\text{ min} \times \frac{1\text{ hour}}{60\text{ min}} = 3.378667\text{ hour}$$

$$0.378667\text{ hour} \times \frac{60\text{ min}}{1\text{ hour}} = 22.72\text{ min} = 23\text{ min}$$

$$D_t = 3\text{ hours }23\text{ minutes} = 3{:}23$$

8. A circular clarifier processes 9.5 MGD with a detention time of 3.7 hours. If the clarifier is 45 feet deep, what is the diameter?

$$\frac{9.5 \text{ MG}}{\text{D}} \times \frac{1{,}000{,}000 \text{ gal}}{1 \text{ MG}} \times \frac{1 \text{ day}}{24 \text{ hour}} = 395{,}833.33 \text{ gph}$$

$$\text{Volume} = D_t \times \text{Flow} = 3.7 \text{ hours} \times \frac{395{,}833.33 \text{ gal}}{\text{hour}} = 1{,}464{,}583.33 \text{ gal}$$

$$1{,}464{,}583.33 \text{ gal} \times \frac{1 \text{ cf}}{7.48 \text{ gal}} = 195{,}799.91 \text{ ft}^3$$

$$\text{Pipe Volume} = 0.785 \times D^2 \times H = 0.785 \times (D)^2 \text{ x } 45 \text{ ft} = 195{,}799.91 \text{ ft}^3$$

$$(D)^2 = \frac{195{,}799.91 \text{ ft}^3}{0.785 \times 45 \text{ ft}} = \frac{195{,}799.91 \text{ ft}^3}{35.325 \text{ ft}} = 5{,}542.81 \text{ ft}^2$$

$$\sqrt{D^2} = \sqrt{5{,}542.81 \text{ ft}^2}$$

$$D = \sqrt{5{,}542.81 \text{ ft}^2} = 74.45 \text{ ft} = 74.5 \text{ ft}$$

Practice Problems 6.2

1. A water treatment plant processes 15.2 MGD. What is the required filter bed area needed to maintain a filtration rate of 2.80 gpm/ft^2?

$$\frac{15.2 \text{ MG}}{\text{D}} \times \frac{1{,}000{,}000 \text{ gal}}{1 \text{ MG}} \times \frac{1 \text{ day}}{24 \text{ hour}} \times \frac{1 \text{ hour}}{60 \text{ min}} = 10{,}555.56 \text{ gpm}$$

$$\text{Filtration Rate (gpm/ft}^2\text{)} = \frac{10{,}555.56 \text{ gpm}}{? \text{ ft}^2} = 2.80 \text{ gpm/ft}^2$$

$$? \text{ ft}^2 = \frac{10{,}555.56 \text{ gpm}}{2.80 \text{ gpm/ft}^2} = 3{,}769.8428 \text{ ft}^2 = 3{,}770 \text{ ft}^2$$

2. A 30 ft by 35 ft filter needs to be back washed at a rate of 25 gpm/ft^2 for a minimum of 22 minutes. How many gallons are used during the backwashing process?

$$\text{Surface Area} = 30 \text{ ft} \times 35 \text{ ft} = 1{,}050 \text{ ft}^2$$

$$\text{Filtration Rate (gpm/ft}^2\text{)} = \frac{? \text{ gpm}}{1{,}050 \text{ ft}^2} = 25 \text{ gpm/ft}^2$$

$$? \text{ gpm} = 25 \text{ gpm/ft}^2 \times 1{,}050 \text{ ft}^2 = 26{,}250 \text{ gpm}$$

$$\frac{26{,}250 \text{ gal}}{\text{min}} \times 22 \text{ min} = 577{,}500 \text{ gal}$$

3. In order to properly back wash a certain filter a back wash rate of 15 inches per minute rise is needed. If the filter is 40 ft by 30 ft, what is the backwash flow rate in gpm?

$$15 \text{ in/min} \times \frac{1 \text{ gpm/sqft}}{1.6 \text{ in/min}} = 9.375 \text{ gpm/sqft}$$

$$\text{Surface Area} = 40 \text{ ft} \times 30 \text{ ft} = 1{,}200 \text{ ft}^2$$

$$\text{Filtration Rate (gpm/ft}^2\text{)} = \frac{? \text{ gpm}}{1{,}200 \text{ ft}^2} = 9.375 \text{ gpm/ft}^2$$

$$? \text{ gpm} = 9.375 \text{ gpm/ft}^2 \times 1{,}200 \text{ ft}^2 = 11{,}250 \text{ gpm}$$

4. A water treatment plant processes a maximum of 7.50 MGD. The plant has 3 filters measuring 28 ft by 33 ft each. Assuming that each filter receives an equal amount of flow what is the filtration rate in gpm/ft^2?

$$\frac{7.5\text{ MG}}{\text{D}} \times \frac{1{,}000{,}000\text{ gal}}{1\text{ MG}} \times \frac{1\text{ day}}{1{,}440\text{ min}} = 5{,}208.33\text{ gpm}$$

$$\text{Surface Area of each filter} = 28\text{ ft} \times 33\text{ ft} = 924\text{ ft}^2$$

$$\text{Total Area of 6 Filters} = 3 \times 924\text{ ft}^2 = 2{,}772\text{ ft}^2$$

$$\text{Filtration Rate (gpm/ft}^2\text{)} = \frac{5{,}208.33\text{ gpm}}{2{,}772\text{ ft}^2} = 1.8789\text{ gpm/ft}^2 = 1.9\text{ gpm/ft}^2$$

5. A water treatment plant processes 10.3 MGD through a 50 ft by 50 ft filter. What is the corresponding inches per minute through the filter?

$$\frac{10.3\text{ MG}}{\text{D}} \times \frac{1{,}000{,}000\text{ gal}}{1\text{ MG}} \times \frac{1\text{ day}}{1{,}440\text{ min}} = 7{,}152.78\text{ gpm}$$

$$\text{Surface Area of the filter} = 50\text{ ft} \times 50\text{ ft} = 2{,}500\text{ ft}^2$$

$$\text{Filtration Rate (gpm/ft}^2\text{)} = \frac{7{,}152.78\text{ gpm}}{2{,}500\text{ ft}^2} = 2.861\text{ gpm/ft}^2 = 2.9\text{ gpm/ft}^2$$

$$\text{Filtration Rate} = 2.9\text{ gpm/ft}^2 \times \frac{1.6\text{ in/min}}{1\text{ gpm/sqft}} = 4.64\text{ in/min} = 4.6\text{ in/min}$$

6. A filter is backwashed at a rate of 27.0 inches per minute for 17 minutes. If the filter is 225 ft^2, how many gallons were used?

$$27.0\text{ in/min} \times \frac{1\text{ gpm/sqft}}{1.6\text{ in/min}} = 16.875\text{ gpm/sqft}$$

$$\text{Filtration Rate (gpm/ft}^2\text{)} = \frac{?\text{ gpm}}{225\text{ ft}^2} = 16.875\text{ gpm/ft}^2$$

$$?\text{ gpm} = 16.875\text{ gpm/ft}^2 \times 225\text{ ft}^2 = 3{,}796.875\text{ gpm}$$

$$\frac{3{,}796.875\text{ gal}}{\text{min}} \times 17\text{ min} = 64{,}546.875\text{ gal} = 64{,}547\text{ gal}$$

7. An Engineer is designing a circular filter to handle 2.14 MGD and maintain a filtration rate of 1.25 inches per minute. What will the diameter be?

$$1.25 \text{ in/min} \times \frac{1 \text{ gpm/sqft}}{1.6 \text{ in/min}} = 0.78125 \text{ gpm/sqft} = 0.78 \text{ gpm/sqft}$$

$$\frac{2.14 \text{ MG}}{\text{D}} \times \frac{1{,}000{,}000 \text{ gal}}{1 \text{ MG}} \times \frac{1 \text{ day}}{1{,}440 \text{ min}} = 1{,}486.1 \text{ gpm}$$

$$\text{Filtration Rate (gpm/ft}^2\text{)} = \frac{1{,}486.1 \text{ gpm}}{? \text{ ft}^2} = 0.78 \text{ gpm/ft}^2$$

$$? \text{ ft}^2 = \frac{1{,}486.1 \text{ gpm}}{0.78 \text{ gpm/ft}^2} = 1{,}905.26 \text{ ft}^2$$

$$\text{Area of the Pipe: } = 0.785 \times (\text{D ft})^2 = 1{,}905.26 \text{ ft}^2$$

$$\text{D}^2 = \frac{1{,}905.26 \text{ ft}^2}{0.785} = 2{,}427.08 \text{ ft}^2$$

$$\sqrt{\text{D}^2} = \sqrt{2{,}427.08 \text{ ft}^2}$$

D = 49.2654 ft = 49.3 ft

8. A filter needs to be backwashed when the fall rate exceeds 6.3 inches per minute. It was determined that this rate is reached after 4.7 MG flows through a 27 ft by 28 ft filter. How often does the filter need backwashing? Give your answer in the most logical time unit.

$$6.3 \text{ in/min} \times \frac{1 \text{ gpm/sqft}}{1.6 \text{ in/min}} = 3.9375 \text{ gpm/sqft} = 4.0 \text{ gpm/sqft}$$

$$\text{Filter Surface Area} = 27 \text{ ft} \times 28 \text{ ft} = 756 \text{ ft}^2$$

$$\text{Filtration Rate (gpm/ft}^2\text{)} = \frac{? \text{ gpm}}{756 \text{ ft}^2} = 4.0 \text{ gpm/ft}^2$$

$$? \text{ gpm} = 4.0 \text{ gpm/ft}^2 \times 756 \text{ ft}^2 = 3{,}024 \text{ gpm}$$

$$\frac{3{,}024 \text{ gal}}{\text{min}} \times ? \text{ min} = 4{,}700{,}000 \text{ gal}$$

$$? \text{ min} = \frac{4{,}700{,}000 \text{ gal}}{3{,}024 \text{ gpm}} = 1{,}554.23 \text{ min} \times \frac{1 \text{ day}}{1{,}440 \text{ min}} = 1.0793 \text{ days} = 1.1 \text{ days}$$

Practice Problems 7.1

1. What is the required CT inactivation in a conventional filtration plant for Giardia by free chlorine at 20°C with a pH of 8.0 and a chlorine concentration of 2.0 mg/L? (Look up value in the CT tables and remember to apply any credits.)

   From Table 7.2 Treatment Credits and Log Inactivation Requirements you can see that:
   3 Log (Required) - 2.5 Log (Credit) = 0.5 Log (Remaining)

   Now look at Table C-5 Inactivation of Giardia Cysts by Free Chlorine at 20°C. In the pH 8.0 section look down the 0.5 Log Inactivation column until it intersects with the 2.0 mg/L row.

   15 mg/L min CT is required.

2. What is the required CT inactivation for viruses with chlorine dioxide, a pH of 9.0, and a temperature of 10°C?

   From Table 7.2 Treatment Credits and Log Inactivation Requirements you can see that 4 log removal is required.

   Now look at Table C-9 Values for Inactivation of Viruses by Chlorine Dioxide, pH 6.0 - 9.0. The solution is where the 10°C column intersects with the 4 Log Inactivation row.

   25.1 mg/L min CT is required.

3. What is the required CT inactivation in a direct filtration plant for Giardia by free chlorine at 15°C with a pH of 7.0 and a chlorine concentration of 2.8 mg/L?

   From Table 7.2 Treatment Credits and Log Inactivation Requirements you can see that:
   3 Log (Required) - 2 Log (Credit) = 1 Log (Remaining)

   Now look at Table C-4 Inactivation of Giardia Cysts by Free Chlorine at 15°C. In the pH 7.0 section look down the 1 Log Inactivation column until it intersects with the 2.8 mg/L row.

   30 mg/L min CT is required.

4. A conventional water treatment plant is fed from a reservoir 1.5 miles away through a 7-foot diameter pipe. Disinfection is provided from the supply reservoir to the plant influent at a free chlorine residual of 0.6 mg/L. The daily flow is a constant 40 MGD. And the water is 10°C and has a pH of 8.5. The treatment plant maintains a chloramines residual of 2.0 mg/L. Tracer studies have shown the contact time (T_{10}) for the treatment plant at the rated capacity of 40 MGD to be 22 minutes. Does this plant meet compliance for CT inactivation for *Giardia*?

Pipeline:
From Table 7.2 Treatment Credits and Log Inactivation Requirements you can see that:
3 Log (Required) - 2.5 Log (Credit) = 0.5 Log (Remaining)

Now look at Table C-3 Inactivation of Giardia Cysts by Free Chlorine at 10°C. In the pH 8.5 section look down the 0.5 Log Inactivation column until it intersects with the 0.6 mg/L row.

31 mg/L min CT is **required**.

Treatment Plant:
From Table 7.2 Treatment Credits and Log Inactivation Requirements you can see that:
3 Log (Required) - 2.5 Log (Credit) = 0.5 Log (Remaining)

Now look at Table C-10 Inactivation of Giardia Cysts by Chloramine, pH 6.0-9.0. The solution is where the 10°C column intersects with the 0.5 Log Inactivation row.

310 mg/L min CT is **required**.

Location and Type of Disinfection	Actual CT	Required CT	CT Ratio
Pipeline		31 mg/L · min	
Treatment Plant		310 mg/L · min	

Pipeline Actual CT:
Now calculate the actual CT using the formula for detention time.

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

First determine the volume in the pipe in gallons.

$$\text{Pipe Volume} = 0.785 \times D^2 \times L$$

$$0.785 \times (7\text{ ft})^2 \text{ x } \left(1.5\text{ miles} \times \frac{5{,}280\text{ ft}}{1\text{ mile}}\right) = 304{,}642.8\text{ ft}^3 = 304{,}643\text{ ft}^3$$

Convert the volume to gallons.

$$304{,}643\ \text{ft}^3 \times \frac{7.48\ \text{gal}}{\text{ft}^3} = 2{,}278{,}729.64\ \text{gal} = 2{,}278{,}730\ \text{gal}$$

Convert the flow rate to gallons per minute.

$$\frac{40{,}000{,}000\ \text{gallons}}{1\ \text{day}} \times \frac{1\ \text{day}}{1{,}440\ \text{minutes}} = 27{,}777.7778\ \text{gpm} = 27{,}778\ \text{gpm}$$

Now you can calculate the detention time.

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{2{,}278{,}730\ \text{gal}}{27{,}778\ \text{gpm}} = 82.03362\ \text{mins} = 82\ \text{mins}$$

Now you multiply the detention time by the concentration, and you get CT through the pipeline.

$$0.6\ \text{mg/L} \times 82\ \text{min} = 49.2\ \text{mg/L}\ \text{min}$$

<u>Treatment Plant Actual CT:</u>

$$2.0\ \text{mg/L} \times 22\ \text{min} = 44\ \text{mg/L}\ \text{min}$$

Now you can finish populating the table and calculating the CT Ratios.

$$\frac{\text{Actual CT}}{\text{Required CT}} = \frac{49.2\ \text{mg/L min}}{31\ \text{mg/L min}} = 1.587 = 1.6$$

$$\frac{\text{Actual CT}}{\text{Required CT}} = \frac{44\ \text{mg/L min}}{310\ \text{mg/L min}} = 0.1419 = 0.1$$

Location and Type of Disinfection	Actual CT	Required CT	CT Ratio
Pipeline	49.2 mg/L · min	31 mg/L · min	1.6
Treatment Plant	44 mg/L · min	310 mg/L · min	0.1
		Total:	1.7

Yes! This plant does meet compliance for CT inactivation of Giardia.

5. A conventional water treatment plant is fed from a reservoir 4 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 0.1 mg/L. The daily flow is a constant 25 MGD. The water is 10°C and has a pH of 7.0. The treatment plant maintains a chloramines residual of 1.5 mg/L. Tracer studies have shown the contact time (T_{10}) for the treatment plant at the rated capacity of 25 MGD to be 55 minutes. Does this plant meet compliance for CT inactivation for viruses?

   <u>Pipeline:</u>

   From Table 7.2 Treatment Credits and Log Inactivation Requirements you can see that:

   4 Log (Required) - 2 Log (Credit) = 2 Log (Remaining)

Now look at Table C-7 Inactivation of Viruses by Free Chlorine, pH 6.0 – 9.0. The solution is where the 10°C column intersects with the 2 Log Inactivation row.
3.0 mg/L min CT is **required**.

Treatment Plant:
From Table 7.2 Treatment Credits and Log Inactivation Requirements you can see that:
4 Log (Required) - 2 Log (Credit) =   2 Log (Remaining)

Now look at Table C-11 Inactivation of Viruses by Chloramine. The solution is where the 10°C column intersects with the 2 Log Inactivation row.

643 mg/L min CT is **required**.

Location and Type of Disinfection	Actual CT	Required CT	CT Ratio
Pipeline		3.0 mg/L · min	
Treatment Plant		643 mg/L · min	

Pipeline Actual CT:
Now calculate the actual CT using the formula for detention time.

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

First determine the volume in the pipe in gallons.

$$\text{Pipe Volume } = 0.785 \times D^2 \times L$$

$$0.785 \times (4\text{ ft})^2 \text{ x } \left(4\text{ miles} \times \frac{5{,}280\text{ ft}}{1\text{ mile}}\right) = 265{,}267.2\text{ ft}^3 = 265{,}267\text{ ft}^3$$

Convert the volume to gallons.

$$265{,}267\text{ ft}^3 \times \frac{7.48\text{ gal}}{\text{ft}^3} = 1{,}984{,}197.16\text{ gal} = 1{,}984{,}197\text{ gal}$$

Convert the flow rate to gallons per minute.

$$\frac{25{,}000{,}000\text{ gallons}}{1\text{ day}} \times \frac{1\text{ day}}{1{,}440\text{ minutes}} = 17{,}361.111\text{ gpm} = 17{,}361\text{ gpm}$$

Now you can calculate the detention time.

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{1{,}984{,}197\text{ gal}}{17{,}361\text{ gpm}} = 114.29047\text{ mins} = 114\text{ mins}$$

Now you multiply the detention time by the concentration, and you get CT through the pipeline.

$$0.1\text{ mg/L} \times 114\text{ min} = 11.4\text{ mg/L min}$$

Treatment Plant Actual CT:

$$1.5\ \text{mg/L} \times 55\ \text{min} = 82.5\ \text{mg/L min}$$

Now you can finish populating the table and calculating the CT Ratios.

$$\frac{\text{Actual CT}}{\text{Required CT}} = \frac{11.4\ \text{mg/L min}}{3.0\ \text{mg/L min}} = 3.8$$

$$\frac{\text{Actual CT}}{\text{Required CT}} = \frac{82.5\ \text{mg/L min}}{643\ \text{mg/L min}} = 0.1283 = 0.1$$

Location and Type of Disinfection	Actual CT	Required CT	CT Ratio
Pipeline	11.4 mg/L · min	3.0 mg/L · min	3.8
Treatment Plant	82.5 mg/L · min	643 mg/L · min	0.1
		Total:	3.9

Yes! This plant does meets compliance for CT inactivation of viruses.

6. A direct filtration water treatment plant is fed from a reservoir .5 miles away through a 3-foot diameter pipe. Disinfection is provided from the supply reservoir to the plant influent at a free chlorine residual of 0.6 mg/L. The daily flow is a constant 15 MGD. The water is 15°C and has a pH of 7.0. The treatment plant maintains a chloramines residual of 0.4 mg/L. Tracer studies have shown the contact time (T_{10}) for the treatment plant at the rated capacity of 15 MGD to be 30 minutes. Does this plant meet compliance for CT inactivation for *Giardia*?

   <u>Pipeline:</u>
   From Table 7.2 Treatment Credits and Log Inactivation Requirements you can see that:
   3 Log (Required) - 2.0 Log (Credit) = 1.0 Log (Remaining)

   Now look at Table C-4 Inactivation of Giardia Cysts by Free Chlorine at 15°C. In the pH 7.0 section look down the 1.0 Log Inactivation column until it intersects with the 0.6 mg/L row.

   24 mg/L min CT is **required**.

   <u>Treatment Plant:</u>
   From Table 7.2 Treatment Credits and Log Inactivation Requirements you can see that:
   3 Log (Required) - 2.0 Log (Credit) = 1.0 Log (Remaining)

   Now look at Table C-10 Inactivation of Giardia Cysts by Chloramine, pH 6.0-9.0. The solution is where the 15°C column intersects with the 1.0 Log Inactivation row.

500 mg/L min CT is **required**.

Location and Type of Disinfection	Actual CT	Required CT	CT Ratio
Pipeline		24 mg/L · min	
Treatment Plant		500 mg/L · min	

Pipeline Actual CT:

Now calculate the actual CT using the formula for detention time.

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

First determine the volume in the pipe in gallons.

$$\text{Pipe Volume} = 0.785 \times D^2 \times L$$

$$0.785 \times (3\text{ ft})^2 \text{ x } \left(0.5\text{ miles} \times \frac{5{,}280\text{ ft}}{1\text{ mile}}\right) = 18{,}651.6\ \text{ft}^3 = 18{,}652\ \text{ft}^3$$

Convert the volume to gallons.

$$18{,}652\ \text{ft}^3 \times \frac{7.48\text{ gal}}{\text{ft}^3} = 139{,}516.96\text{ gal} = 139{,}517\text{ gal}$$

Convert the flow rate to gallons per minute.

$$\frac{15{,}000{,}000\text{ gallons}}{1\text{ day}} \times \frac{1\text{ day}}{1{,}440\text{ minutes}} = 10{,}416.6667\text{ gpm} = 10{,}417\text{ gpm}$$

Now you can calculate the detention time.

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{139{,}517\text{ gal}}{10{,}417\text{ gpm}} = 13.3932\text{ mins} = 13.4\text{ mins}$$

Now you multiply the detention time by the concentration, and you get CT through the pipeline.

$$0.6\text{ mg/L} \times 13.4\text{ min} = 8.04\text{ mg/L min} = 8.0\text{ mg/L min}$$

Treatment Plant Actual CT:

$$0.4\text{ mg/L} \times 30\text{ min} = 12\text{ mg/L min}$$

Now you can finish populating the table and calculating the CT Ratios.

$$\frac{\text{Actual CT}}{\text{Required CT}} = \frac{8.0\text{ mg/L min}}{39\text{ mg/L min}} = 0.2051 = 0.2$$

$$\frac{\text{Actual CT}}{\text{Required CT}} = \frac{12\text{ mg/L min}}{500\text{ mg/L min}} = 0.024 = 0.0$$

Location and Type of Disinfection	Actual CT	Required CT	CT Ratio
Pipeline	8.0 mg/L · min	39 mg/L · min	0.2
Treatment Plant	12 mg/L · min	500 mg/L · min	0.0
		Total:	0.2

No! This plant does NOT meet compliance for CT inactivation of Giardia.

7. A direct filtration plant is operated at a designed flow of 20 MGD with a contact time of 35 minutes. A free chlorine dose of 1.2 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 0.4 mg/L through a pipeline with a contact time of 12 minutes into a 650,000-gallon reservoir. The pH of the water is 8.5 and has a temperature of 15°C. Does this treatment process meet compliance for CT inactivation for viruses?

<u>Treatment Plant:</u>
From Table 7.2 Treatment Credits and Log Inactivation Requirements you can see that:
4 Log (Required) - 1 Log (Credit) = 3 Log (Remaining)

Now look at Table C-7 Inactivation of Viruses by Free Chlorine, pH 6.0 – 9.0. The solution is where the 15°C column intersects with the 3 Log Inactivation row.

3.0 mg/L min CT is **required**.

<u>Pipeline:</u>
From Table 7.2 Treatment Credits and Log Inactivation Requirements you can see that:
4 Log (Required) - 1 Log (Credit) = 3 Log (Remaining)

Now look at Table C-11 Inactivation of Viruses by Chloramine. The solution is where the 15°C column intersects with the 3 Log Inactivation row.

712 mg/L min CT is **required**.

Location and Type of Disinfection	Actual CT	Required CT	CT Ratio
Treatment Plant		3.0 mg/L · min	
Pipeline		712 mg/L · min	

Treatment Plant Actual CT:

$$1.2 \text{ mg/L} \times 35 \text{ min} = 42 \text{ mg/L min}$$

Pipeline Actual CT:

$$0.4 \text{ mg/L} \times 12 \text{ min} = 4.8 \text{ mg/L min}$$

Now you can finish populating the table and calculating the CT Ratios.

$$\frac{\text{Actual CT}}{\text{Required CT}} = \frac{42 \text{ mg/L min}}{3.0 \text{ mg/L min}} = 14$$

$$\frac{\text{Actual CT}}{\text{Required CT}} = \frac{4.8 \text{ mg/L min}}{712 \text{ mg/L min}} = 0.00674 = 0.0$$

Location and Type of Disinfection	Actual CT	Required CT	CT Ratio
Treatment Plant	42 mg/L · min	3.0 mg/L · min	14
Pipeline	4.8 mg/L · min	712 mg/L · min	0.0
		Total:	14.0

Yes! This plant does meets compliance for CT inactivation of viruses.

8. Does a water utility meet CT for viruses by disinfection if only the free chlorine concentration is 0.5 ppm through 200 ft of 24” diameter pipe at a flow rate of 730 gpm? Assume the water is 15°C and has a pH of 8.0.

Pipeline:
From Table 7.2 Treatment Credits and Log Inactivation Requirements you can see that:
4 Log (Required) Pipeline Only – No credits

Now look at Table C-7 Inactivation of Viruses by Free Chlorine. The solution is where the 15°C column intersects with the 4 Log Inactivation row.

4.0 mg/L min CT is **required**.

Location and Type of Disinfection	Actual CT	Required CT	CT Ratio
Pipeline		4.0 mg/L · min	

Now calculate the actual CT using the formula for detention time.

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

First determine the volume in the pipe in gallons.

$$\text{Pipe Volume} = 0.785 \times D^2 \times L$$

$$0.785 \times \left(24 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}}\right)^2 \text{ x } 200 \text{ ft} = 628 \text{ ft}^3$$

Convert the volume to gallons.

$$628 \text{ ft}^3 \times \frac{7.48 \text{ gal}}{\text{ft}^3} = 4{,}697.44 \text{ gal} = 4{,}697 \text{ gal}$$

Now you can calculate the detention time.

$$D_t = \frac{\text{Volume}}{\text{Flow}} = \frac{4{,}697 \text{ gal}}{730 \text{ gpm}} = 6.43424 \text{ mins} = 6.4 \text{ mins}$$

Now you multiply the detention time by the concentration, and you get CT through the pipeline.

$$0.5 \text{ ppm} \times 6.4 \text{ min} = 3.2 \text{ mg/L min}$$

$$\frac{\text{Actual CT}}{\text{Required CT}} = \frac{3.2 \text{ mg/L min}}{4.0 \text{ mg/L min}} = 0.75$$

Location and Type of Disinfection	Actual CT	Required CT	CT Ratio
Pipeline	3.2 mg/L · min	4.0 mg/L · min	0.75

No! The water utility does NOT meet compliance for CT inactivation of viruses.

Practice Problems 8.1

1. What is the pressure at the bottom of a 65-ft tank if the tank is half full?

$$\text{Tank is half full} = \frac{65\text{ ft}}{2} = 32.5\text{ ft}$$

$$\text{Pressure} = \frac{32.5\text{ ft}}{1} \times \frac{1\text{ psi}}{2.31\text{ ft}} = 14.06926\text{ psi} = 14.1\text{ psi}$$

$$\text{Pressure} = \frac{32.5\text{ ft}}{1} \times \frac{0.433\text{ psi}}{1\text{ ft}} = 14.0725\text{ psi} = 14.1\text{ psi}$$

2. A 50-foot tall tank sits on a 120-foot-tall hill. Assuming the tank is full, what is the pressure at the bottom of the hill?

$$\text{Total height} = 50\text{ ft} + 120\text{ ft} = 170\text{ ft}$$

$$\text{Pressure} = \frac{170\text{ ft}}{1} \times \frac{1\text{ psi}}{2.31\text{ ft}} = 73.59307\text{ psi} = 73.6\text{ psi}$$

$$\text{Pressure} = \frac{170\text{ ft}}{1} \times \frac{0.433\text{ psi}}{1\text{ ft}} = 73.61\text{ psi} = 73.6\text{ psi}$$

3. The opening of a 3.7” fire hydrant nozzle has a pressure of 212 psi. What is the corresponding force in pounds?

$$\text{Area of a Circle} = 0.785 \times D^2$$

$$\text{Area} = 0.785 \times (3.7\text{ in})^2 = 10.74665\text{ in}^2$$

$$\text{Force} = 212\text{ psi} \times 10.74665\text{ in}^2 = 2{,}278.2898\text{ lbs} = 2{,}278.3\text{ lbs}$$

4. A home sits at an elevation of 900 ft above sea level. The base of a water tank that serves the home sits at an elevation of 1,281 ft above sea level. The tank is 20 feet tall and ¾ full. What is the pressure in psi at the home?

$$\text{Tank is 3/4 full} = 20\text{ ft} \times 0.75 = 15\text{ ft}$$

$$\text{Water Elevation} = 15\text{ ft} + 1{,}281\text{ ft} = 1{,}296\text{ ft}$$

$$\text{Water Elevation at the home} = 1{,}296\text{ ft} - 900\text{ ft} = 396\text{ ft}$$

$$\text{Pressure} = \frac{396\text{ ft}}{1} \times \frac{1\text{ psi}}{2.31\text{ ft}} = 171.42857\text{ psi} = 171.4\text{ psi}$$

$$\text{Pressure} = \frac{396 \text{ ft}}{1} \times \frac{0.433 \text{ psi}}{1 \text{ ft}} = 171.468 \text{ psi} = 171.5 \text{ psi}$$

5. Two houses are served by a nearby water storage tank. House A is 108 ft above House B which sits at 432 ft above sea level. The base of the tank sits at 705 ft above sea level. The low water level in the tank is at 2.0 ft. At the low level, will House A meet the minimum pressure requirements of 60 psi?

Water Elevation = 705 ft + 2 ft = 707 ft

Elevation at home A = 432 ft + 108 ft = 540 ft

Water Elevation at the home = 707 ft - 540 ft = 167 ft

$$\text{Pressure} = \frac{167 \text{ ft}}{1} \times \frac{1 \text{ psi}}{2.31 \text{ ft}} = 72.29437 \text{ psi} = 72.3 \text{ psi}$$

$$\text{Pressure} = \frac{167 \text{ ft}}{1} \times \frac{0.433 \text{ psi}}{1 \text{ ft}} = 72.311 \text{ psi} = 72.3 \text{ psi}$$

YES!

6. House A sits at an elevation of 1,300 ft. Another house (B) needs to be built 125 ft below House A. At what elevation should the tank be built in order to give House B the maximum pressure of 210 psi?

$$\text{Pressure} = \frac{? \text{ ft}}{1} \times \frac{1 \text{ psi}}{2.31 \text{ ft}} = 210 \text{ psi}$$

$$? \text{ ft} = 210 \text{ psi} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 485.1 \text{ ft}$$

Tank Elevation = 1,175 ft + 485.1 ft = 1,660.1 ft = 1,660 ft

7. A flowing pipeline has a pressure of 65 psi and a corresponding force of 2,398 pounds. What is the diameter of the pipe?

Force = Pressure $\times$ Area

$$65 \text{ psi} \times \text{Area} = 2{,}398 \text{ lbs}$$

$$\text{Area} = \frac{2{,}398 \text{ lbs}}{65 \text{ psi}} = 36.8923 \text{ in}^2 \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 0.2561965 \text{ ft}^2 = 0.26 \text{ ft}^2$$

Area of a Circle/Pipe = $0.785 \times D^2$

$$D^2 = \frac{\text{Area}}{0.785} = \frac{0.26 \text{ ft}^2}{0.785} = 0.33121019 \text{ ft}^2$$

$$\sqrt{D^2} = \sqrt{0.33121019 \text{ ft}^2}$$

$$D = 0.5755086 \text{ ft} \times \frac{12 \text{ in}}{1 \text{ ft}} = 6.906 \text{ in} = 7.0 \text{ in}$$

Practice Problems 8.2

1. A well pumps directly to a 60-foot tall water tank that sits 500 feet above the elevation of the well. If the total head loss in the piping up to the tank is 14 feet, what is the total pressure in psi on the discharge side of the well?

Assuming that the water tank is full -

Height of water + Head Loss = 500 ft + 60 ft + 14 ft = 574 ft

$$\text{Pressure} = \frac{574 \text{ ft}}{1} \times \frac{1 \text{ psi}}{2.31 \text{ ft}} = 248.4848 \text{ psi} = 248.5 \text{ psi}$$

$$\text{Pressure} = \frac{574 \text{ ft}}{1} \times \frac{0.433 \text{ psi}}{1 \text{ ft}} = 248.542 \text{ psi} = 248.5 \text{ psi}$$

2. A booster pump receives water from a tank that is 120 feet above the pump and discharges to a tank that is 450 feet above the pump. What is the total head (TH)?

450 ft - 120 ft (Suction Head) = 330 ft of total head

3. A well located at 200 feet above sea level has a below ground surface water depth of 50 ft and pumps to a water tank at an elevation of 840 ft above sea level. The water main from the well to the tank has a total head loss of 6 psi. What is the TH in feet?

$$\frac{6 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 13.86 \text{ ft} = 13.9 \text{ ft}$$

Total Head = 840 ft - (200 ft - 50 ft) + 13.9 = 703.9 ft

4. A housing tract is located at an approximate average elevation of 5,000 ft above sea level and is served from a storage tank that is at 5,160 ft. The average head loss from the tank to the housing tract is 20.3 psi. What is the minimum water level in the tank to maintain a minimum pressure 30 psi?

$$\frac{30 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 69.3 \text{ ft}$$

$$\frac{20.3 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 46.893 \text{ ft} = 46.9 \text{ ft}$$

5,160 ft - 5,000 ft = 160 ft - 46.9 ft = 113.1 ft

113.1 ft - 69.3 ft = 43.8 ft is the minimum water level

5. A water utility has two different pressure zones (1 and 2.) The zone 1 Tank is 15 ft tall and sits at an elevation of 625 ft and the zone 2 Tank is 50 feet tall and sits at 1,300 ft. The booster pump from zone 1 to 2 sits at an elevation of 700 ft. The head loss is 11 psi. Tank 1 is full, and Tank 2 needs to be 1/2 full. What is the TH?

$$\frac{11 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 25.41 \text{ ft} = 25.4 \text{ ft}$$

Zone 1: 625 ft + 15 ft = 640 ft

Zone 2: 1,300 ft + 25 ft = 1,325 ft

1,325 ft - 640 ft = 685 ft + 25.4 ft = 710.4 ft = 710 ft

Add HL because the pump needs to pump against this additional pressure.

Practice Problems 9.1

1. A well has a static water level of 77 ft bgs and a pumping level of 111 ft bgs. What is the drawdown?

   Drawdown = Pumping Water Level - Static Water Level

   Drawdown = 111 ft - 77 ft = 34 ft

2. A groundwater well has a base elevation of 982 ft above sea level. If the drawdown on this well is 31 ft and the pumping level is 75 ft bgs, what is the static water elevation above sea level?

   Static Water Level = Pumping Water Level - Drawdown

   Static Water Level = 75 ft - 31 ft = 44 ft
   Elevation Above Sea Level = 982 ft - 44 ft = 938 ft

3. A deep well has a static water level of 148 ft bgs. A drawdown has been calculated out to be 83 ft. What is the pumping level of the well?

   Pumping Water Level = Drawdown + Static Water Level

   Pumping Water Level = 83 ft + 148 ft = 231 ft

4. A well has an hour meter attached to a water meter totalizer. After 5 hours of operation, the well produced 374,000 gallons. Water is the well yield in gpm?

$$\frac{374{,}000\text{ gal}}{5\text{ hr}} \times \frac{1\text{ hr}}{60\text{ min}} = \frac{1{,}246.6667\text{ gal}}{\text{min}} = \frac{1{,}246.7\text{ gal}}{\text{min}}$$

5. When a well was first constructed it was pumping 1,237 gpm. The efficiency of the well has dropped 42%. In addition, the drawdown has decreased by 22%. If the original drawdown was 66 ft what is the current specific capacity?

   1,237 gpm x 0.42 = 519.54 gpm
   Reduced efficiency: 1,237 gpm - 519.54 gpm = 717.46 gpm= 717.5 gpm
   66 ft x 0.22 = 14.52 ft
   Reduced drawdown: 66 ft - 14.52 ft = 51.48 ft = 51.5 ft

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

$$\text{Specific Capacity} = \frac{717.5 \text{ gpm}}{51.5 \text{ ft}} = \frac{13.932 \text{ gpm}}{\text{ft}} = \frac{13.9 \text{ gpm}}{\text{ft}}$$

6. A well pumped 468 AF over a one-year period averaging 14 hours of operation per day. For half the year the static water level was 41 ft bgs and half the year 30 ft bgs. The pumping level averaged 72 ft bgs for half the year and 83 ft bgs the other half. What was the average specific capacity for the year?

$$\frac{468 \text{ AF}}{\text{year}} \times \frac{325{,}851 \text{ gal}}{1 \text{ AF}} \times \frac{1 \text{ year}}{365 \text{ day}} \times \frac{1 \text{ day}}{14 \text{ hour}} \times \frac{1 \text{ hour}}{60 \text{ min}} = 497.385 \text{ gpm}$$

1st Half of the Year:

Drawdown = 72 ft - 41 ft = 31 ft

$$\text{Specific Capacity} = \frac{497.4 \text{ gpm}}{31 \text{ ft}} = \frac{16.05 \text{ gpm}}{\text{ft}} = \frac{16.0 \text{ gpm}}{\text{ft}}$$

2nd Half of the Year:

Drawdown = 83 ft - 30 ft = 53 ft

$$\text{Specific Capacity} = \frac{497.4 \text{ gpm}}{53 \text{ ft}} = \frac{9.384 \text{ gpm}}{\text{ft}} = \frac{9.4 \text{ gpm}}{\text{ft}}$$

7. A well has a specific capacity of 63 gpm per foot. The well operates at a constant 2,350 gpm. What is the drawdown?

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

$$\text{Drawdown} = \frac{2{,}350 \text{ gpm}}{63 \text{ gpm/ft}} = 37.301 \text{ ft} = 37.3 \text{ ft}$$

8. A well has a calculated specific capacity of 18 gpm per foot and operates at a flow rate of 0.85 MGD. If the static water level is 56 ft bgs, what is the pumping level?

$$\frac{0.85 \text{ MG}}{\text{D}} \times \frac{1{,}000{,}000 \text{ gal}}{1 \text{ MG}} \times \frac{1 \text{ day}}{1{,}440 \text{ min}} = 590.2778 \text{ gpm} = 590.3 \text{ gpm}$$

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

$$\text{Drawdown} = \frac{590.3 \text{ gpm}}{18 \text{ gpm/ft}} = 32.7944 \text{ ft} = 32.8 \text{ ft}$$

Pumping Water Level = Drawdown + Static Water Level

Pumping Water Level = 32.8 ft + 56 ft = 88.8 ft

Practice Problems 10.1

1. What is the required water horsepower for 213 gpm and a total head pressure of 72 ft?

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

$$\text{Water hp} = \frac{(213\text{ gpm})(72\text{ ft})}{3{,}960} = \frac{15{,}336}{3{,}960} = 3.8727\text{ hp} = 3.9\text{ hp}$$

2. What is the water horsepower needed for a well that pumps 1,845 gpm against a pressure of 232 psi?

$$\frac{232\text{ psi}}{1} \times \frac{2.31\text{ ft}}{1\text{ psi}} = 535.92\text{ ft} = 536\text{ ft}$$

$$\text{Water hp} = \frac{(1{,}845\text{ gpm})(536\text{ ft})}{3{,}960} = \frac{988{,}920}{3{,}960} = 249.7272\text{ hp} = 249.7\text{ hp}$$

3. It has been determined that the wire-to-water efficiency at a pump station is 33%. If the pump station lifts 345 gpm to a tank 128 feet above, what is the motor horsepower needed?

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

$$\text{Motor hp} = \frac{(345\text{ gpm})(128\text{ ft})}{(3{,}960)(33\ \%)}$$

$$\text{Motor hp} = \frac{(345\text{ gpm})(128\text{ ft})}{(3{,}960)(0.33)}$$

$$\text{Motor hp} = \frac{44{,}160}{1{,}306.8} = 33.79247 = 33.8\text{ hp}$$

4. What is the motor horsepower needed to pump 4,643 AF of water over a year with an average daily pumping operation of 6 hours? Assume the pump is pumping against 70 psi and has a pump efficiency of 90% and a motor efficiency of 75%.

$$\frac{4{,}643\text{ AF}}{\text{year}} \times \frac{325{,}851\text{ gal}}{1\text{ AF}} \times \frac{1\text{ year}}{365\text{ day}} \times \frac{1\text{ day}}{6\text{ hour}} \times \frac{1\text{ hour}}{60\text{ min}} = 11{,}513.897\text{ gpm} = 11{,}514\text{ gpm}$$

$$\frac{70\text{ psi}}{1} \times \frac{2.31\text{ ft}}{1\text{ psi}} = 161.7\text{ ft} = 162\text{ ft}$$

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

$$\text{Motor hp} = \frac{(11{,}514\text{ gpm})(162\text{ ft})}{(3{,}960)(75\ \%)(90\ \%)} = \frac{(11{,}514\text{ gpm})(162\text{ ft})}{(3{,}960)(0.75)(0.90)}$$

$$\text{Motor hp} = \frac{1{,}865{,}268}{2{,}673} = 697.8181 = 698\text{ hp}$$

Practice Problems 10.2

1. A well is pumping water from an aquifer with a water table 55 feet below ground surface (bgs) to a tank 190 feet above the well. If the well flows 870 gpm, what is the required horsepower? (Assume the wire-to-water efficiency is 88%.)

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

$$\text{Motor hp} = \frac{\text{(870 gpm)(190 ft + 55 ft)}}{\text{(3,960)(88 \%)}}$$

$$\text{Motor hp} = \frac{\text{(870 gpm)(245 ft)}}{\text{(3,960)(0.88)}}$$

$$\text{Motor hp} = \frac{213{,}150}{3{,}484.8} = 61.16563 = 61 \text{ hp}$$

2. A booster pump station is pumping water from Zone 1 at an elevation of 1,537 ft above sea level to Zone 2 which is at 1,745 ft above sea level. The pump station is located at an elevation of 1,124 ft above sea level. The pump was recently tested and the efficiencies for the pump and motor were 76% and 88% respectively. The losses through the piping and appurtenances equate to a total of 15 ft. If the pump flows 1,500 gpm, what is the required motor horsepower?

Calculate total head in feet:

$$(1{,}745 \text{ ft} - 1{,}124 \text{ ft}) - (1{,}537 \text{ ft} - 1{,}124) + 15 \text{ ft} =$$

$$621 \text{ ft} - 413 \text{ ft} + 15 \text{ ft} = 223 \text{ ft}$$

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

$$\text{Motor hp} = \frac{\text{(1,500 gpm)(223 ft)}}{\text{(3,960)(76 \%)(88 \%)}} = \frac{\text{(1,500 gpm)(223 ft)}}{\text{(3,960)(0.76)(0.88)}}$$

$$\text{Motor hp} = \frac{334{,}500}{2{,}648.448} = 126.300 = 126 \text{ hp}$$

3. A well with pumps located 46 ft bgs pumps against a discharge head pressure of 140 psi to a tank located at an elevation 278 ft above the well. The well pumps at a rate of 1,260 gpm. What is the level of water in the tank and what is the required water horsepower? (Assume the wire-to-water efficiency is 70%.)

Calculate feet of water in the tank:

$$\frac{140 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 323.4 \text{ ft} = 323 \text{ ft}$$

323 ft - 278 ft = 45 ft in the tank

Total head in feet:

323 ft + 46 ft = 369 ft

Calculate the horsepower:

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

$$\text{Water hp} = \frac{(1{,}260 \text{ gpm})(369 \text{ ft})}{(3{,}960)(70\ \%)} = \frac{(1{,}260 \text{ gpm})(369 \text{ ft})}{(3{,}960)(0.70)}$$

$$\text{Water hp} = \frac{464{,}940}{2{,}772} = 167.7272 = 168 \text{ hp}$$

4. A 430 hp booster pump is pulling water from a 50-foot tall tank that is 85 feet below the pump line. It is then pumping against a discharge head pressure of 150 psi. What is the flow rate in gpm? Assume the wire-to-water efficiency is 92% and the tank is full.

$$\frac{150 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 346.5 \text{ ft} = 347 \text{ ft}$$

85 ft - 50 ft = 35 ft

Total head in feet:

347 ft + 35 ft = 382 ft

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

$$430 \text{ hp} = \frac{(? \text{ gpm})(382 \text{ ft})}{(3{,}960)(92\ \%)} = \frac{(? \text{ gpm})(382 \text{ ft})}{(3{,}960)(0.92)}$$

$$(? \text{ gpm})(382 \text{ ft}) = (430 \text{ hp})(3{,}960)(0.92)$$

$$? \text{ gpm} = \frac{(430 \text{ hp})(3{,}960)(0.92)}{(382 \text{ ft})} = \frac{1{,}566{,}576}{382} = 4{,}100.9843 \text{ gpm} = 4{,}101 \text{ gpm}$$

Practice Problems 10.3

1. A well flows an estimated 4,500 gpm against a discharge head pressure of 212 psi. What is the corresponding hp and kW if the pump has an efficiency of 55% and the motor 71%?

$$\frac{212 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 489.72 \text{ ft} = 490 \text{ ft}$$

   Calculate the horsepower:

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

$$\text{Water hp} = \frac{\text{(4,500 gpm)(490 ft)}}{\text{(3,960)(55 \%)(71 \%)}} = \frac{\text{(4,500 gpm)(490 ft)}}{\text{(3,960)(0.55)(0.71)}}$$

$$\text{Water hp} = \frac{2{,}205{,}000}{1{,}546.38} = 1{,}425.91 = 1{,}426 \text{ hp}$$

$$\frac{1{,}426 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 1{,}063.796 \text{ kW} = 1{,}064 \text{ kW}$$

2. Based on the above question, how much would the electrical costs be if the rate is \$0.15 per kW-Hr and the pump runs for 6 hours a day?

$$\frac{1{,}064 \text{ kW}}{1} \times \frac{\$\, 0.15}{1 \text{ kW-hr}} \times \frac{6 \text{ hr}}{1 \text{ day}} = \$\, 957.60 \text{ per day}$$

3. A utility has 3 pumps that run at different flow rates and supply water to an 800,000 gallon storage tank. Assume that only one pump runs per day. The TDH for the pumps is 130 ft. The utility needs to fill the tank daily and power costs are to be calculated at a rate of \$0.10 per kW-Hr. Complete the table below.

Pump	Flow Rate (gpm)	hp	Efficiency	Run Time (hr)	Total Cost
1	630	65	32%	21.16	\$103
2	1,150	95	40%	11.59	\$82
3	2,440	375	21%	5.46	\$153

PUMP 1

First Calculate Efficiency:

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

$$65 \text{ hp} = \frac{(630 \text{ gpm})(130 \text{ ft})}{(3{,}960)(?\ \%)}$$

$$(?\ \%) = \frac{(630 \text{ gpm})(130 \text{ ft})}{(3{,}960)65 \text{ hp}}$$

$$(?\ \%) = \frac{81{,}900}{257{,}400} = 0.31818 \times 100 = 32\%$$

Run Time to fill the 800,000-gallon tank.

$$800{,}000 \text{ gal} \times \frac{\text{min}}{630 \text{ gal}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 21.1640 \text{ hr} = 21.16 \text{ hr}$$

Total Cost to fill the tank.

$$\frac{65 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 48.49 \text{ kW} = 48.5 \text{ kW}$$

$$\frac{48.5 \text{ kW}}{1} \times \frac{\$\,0.10}{1 \text{ kW-hr}} \times \frac{21.16 \text{ hr}}{1 \text{ day}} = \$\,102.626 \text{ per day} = \$\,103 \text{ per day}$$

PUMP 2

First Calculate Efficiency:

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

$$95 \text{ hp} = \frac{(1{,}150 \text{ gpm})(130 \text{ ft})}{(3{,}960)(?\ \%)}$$

$$(?\ \%) = \frac{(1{,}150 \text{ gpm})(130 \text{ ft})}{(3{,}960)95 \text{ hp}}$$

$$(?\ \%) = \frac{149{,}500}{376{,}200} = 0.397395 \times 100 = 39.7\% = 40\%$$

Run Time to fill the 800,000-gallon tank.

$$800{,}000 \text{ gal} \times \frac{\text{min}}{1{,}150 \text{ gal}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 11.5942 \text{ hr} = 11.59 \text{ hr}$$

Total Cost to fill the tank.

$$\frac{95 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 70.87 \text{ kW}$$

$$\frac{70.87 \text{ kW}}{1} \times \frac{\$\,0.10}{1 \text{ kW-hr}} \times \frac{11.59 \text{ hr}}{1 \text{ day}} = \$\,82.13833 \text{ per day} = \$\,82 \text{ per day}$$

PUMP 3

First Calculate Efficiency:

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

$$375 \text{ hp} = \frac{(2{,}440 \text{ gpm})(130 \text{ ft})}{(3{,}960)(?\ \%)}$$

$$(?\ \%) = \frac{(2{,}440 \text{ gpm})(130 \text{ ft})}{(3{,}960)375 \text{ hp}}$$

$$(?\ \%) = \frac{317{,}200}{1{,}485{,}000} = 0.2136 \times 100 = 21.36\% = 21\%$$

Run Time to fill the 800,000-gallon tank.

$$800{,}000 \text{ gal} \times \frac{\text{min}}{2{,}440 \text{ gal}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 5.46448 \text{ hr} = 5.46 \text{ hr}$$

Total Cost to fill the tank.

$$\frac{375 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 279.75 \text{ kW}$$

$$\frac{279.75 \text{ kW}}{1} \times \frac{\$\,0.10}{1 \text{ kW-hr}} \times \frac{5.46 \text{ hr}}{1 \text{ day}} = \$\,152.7435 \text{ per day} = \$\,153 \text{ per day}$$

4. A well draws water from an aquifer that has an average water level of 100 ft bgs and pumps to a tank 300 ft above it. Friction loss to the tank is approximately 28 psi. If the well pumps at a rate of 1,900 gpm and has a wire-to-water efficiency of 45% how much will it cost to run this well 10 hours per day. Assume the electrical rate is $0.22 per kW-Hr.

$$\frac{28 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 64.68 \text{ ft} = 65 \text{ ft}$$

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

$$\text{hp} = \frac{(1{,}900 \text{ gpm})(100 \text{ ft} + 300 \text{ ft} + 65 \text{ ft})}{(3{,}960)(45\ \%)} = \frac{(1{,}900 \text{ gpm})(465 \text{ ft})}{(3{,}960)(0.45)}$$

$$\text{hp} = \frac{883{,}500}{1{,}782} = 495.79 \text{ hp} = 496 \text{ hp}$$

$$\frac{496 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 370.016 \text{ kW} = 370 \text{ kW}$$

$$\frac{370 \text{ kW}}{1} \times \frac{\$\,0.13}{1 \text{ kW-hr}} \times \frac{14 \text{ hr}}{1 \text{ day}} = \$\,542.36 \text{ per day}$$

5. A utility manager is trying to determine which hp motor to purchase for a pump station. A 500 hp motor with a wire-to-water efficiency of 70% can pump 3,300 gpm. Similarly, a 300 hp motor with a wire-to-water efficiency of 80% can pump 2,500 gpm. With an

electrical rate of $0.111 per kW-Hr, how much would it cost to run each motor to achieve a daily flow of 1.5 MG? Which one is less expensive to run?

PUMP 1

$$\frac{1{,}500{,}000 \text{ gal}}{1} \times \frac{\text{min}}{3{,}300 \text{ gal}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 7.5757 \text{ hr} = 7.6 \text{ hr}$$

$$\frac{500 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 373 \text{ kW}$$

$$\frac{373 \text{ kW}}{1} \times \frac{\$\,0.111}{1 \text{ kW-hr}} \times \frac{7.6 \text{ hr}}{1 \text{ day}} = \$\,314.66 \text{ per day}$$

PUMP 2

$$\frac{1{,}500{,}000 \text{ gal}}{1} \times \frac{\text{min}}{2{,}500 \text{ gal}} \times \frac{1 \text{ hr}}{60 \text{ min}} = 10 \text{ hr}$$

$$\frac{300 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 223.8 \text{ kW}$$

$$\frac{223.8 \text{ kW}}{1} \times \frac{\$\,0.111}{1 \text{ kW-hr}} \times \frac{10 \text{ hr}}{1 \text{ day}} = \$\,248.42 \text{ per day}$$

6. Approximately 170 kW of power are needed to run a certain booster pump. If the booster has a wire-to-water efficiency of 81% and is pumping against 205 psi of head pressure, what is the corresponding flow in gpm?

$$\frac{170 \text{ kW}}{1} \times \frac{1 \text{ hp}}{0.746 \text{ kW}} = 227.8820 \text{ hp} = 228 \text{ hp}$$

$$\frac{205 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 473.55 \text{ ft} = 474 \text{ ft}$$

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

$$228 \text{ hp} = \frac{(?\text{ gpm})(474 \text{ ft})}{(3{,}960)(81\ \%)}$$

$$(?\text{ gpm})(474 \text{ ft}) = (228 \text{ hp})(3{,}960)(81\ \%)$$

$$(?\text{ gpm}) = \frac{(228 \text{ hp})(3{,}960)(0.81)}{(474 \text{ ft})} = \frac{731{,}332.8}{474} = 1{,}542.8962 \text{ gpm} = 1{,}543 \text{ gpm}$$

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 ($) @ $0.12/kW-Hr
A	900	12	60%	150	131	$51,509
B	1,550	19	78%	50	58	$35,785
C	3,375	8	69%	110	314	$81,994

WELL A

$$\frac{150 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 346.5 \text{ ft} = 347 \text{ ft}$$

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

$$\text{hp} = \frac{(900 \text{ gpm})(347 \text{ ft})}{(3{,}960)(60\ \%)} = \frac{(900 \text{ gpm})(347 \text{ ft})}{(3{,}960)(0.60)}$$

$$\text{hp} = \frac{312{,}300}{2{,}376} = 131.43939 = 131 \text{ hp}$$

$$\frac{131 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 97.726 \text{ kW} = 98 \text{ kW}$$

$$\frac{98 \text{ kW}}{1} \times \frac{\$\,0.12}{1 \text{ kW-hr}} \times \frac{12 \text{ hr}}{1 \text{ day}} \times \frac{365 \text{ day}}{1 \text{ yr}} = \$\,51{,}508.80 \text{ per year}$$

WELL B

$$\frac{50 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 115.5 \text{ ft} = 116 \text{ ft}$$

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

$$\text{hp} = \frac{(1{,}550 \text{ gpm})(116 \text{ ft})}{(3{,}960)(78\ \%)} = \frac{(1{,}550 \text{ gpm})(116 \text{ ft})}{(3{,}960)(0.78)}$$

$$\text{hp} = \frac{179{,}800}{3{,}088.8} = 58.2103 = 58 \text{ hp}$$

$$\frac{58 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 43.268 \text{ kW} = 43 \text{ kW}$$

$$\frac{43 \text{ kW}}{1} \times \frac{\$\,0.12}{1 \text{ kW-hr}} \times \frac{19 \text{ hr}}{1 \text{ day}} \times \frac{365 \text{ day}}{1 \text{ yr}} = \$\,35{,}784.60 \text{ per year}$$

WELL C

$$\frac{110 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 254.1 \text{ ft} = 254 \text{ ft}$$

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

$$\text{hp} = \frac{\text{(3,375 gpm)(254 ft)}}{\text{(3,960)(69 \%)}} = \frac{\text{(3,375 gpm)(254 ft)}}{\text{(3,960)(0.69)}}$$

$$\text{hp} = \frac{857{,}250}{2{,}732.4} = 313.7351 = 314 \text{ hp}$$

$$\frac{314 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 234.244 \text{ kW} = 234 \text{ kW}$$

$$\frac{234 \text{ kW}}{1} \times \frac{\$\,0.12}{1 \text{ kW-hr}} \times \frac{8 \text{ hr}}{1 \text{ day}} \times \frac{365 \text{ day}}{1 \text{ yr}} = \$\,81{,}993.60 \text{ per year}$$

8. It costs $103.61 in electricity to run a well for 10 hours a day. The well has a TDH of 167 psi and an overall efficiency of 82.3%. The cost per kW-Hr is $0.156. What is the cost of the water per gallon?

First convert the cost to kW.

$$\frac{\$103.61}{1} \times \frac{1 \text{ kW-hr}}{\$\,0.156} \times \frac{1 \text{ day}}{10 \text{ hr}} = 66.4166 \text{ kW} = 66 \text{ kW}$$

Next convert the kW to hp.

$$\frac{66 \text{ kW}}{1} \times \frac{1 \text{ hp}}{0.746 \text{ kW}} = 88.4718 \text{ hp} = 88 \text{ hp}$$

Use the hp to determine the flow rate in gpm.

$$\frac{167 \text{ psi}}{1} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 385.77 \text{ ft} = 386 \text{ ft}$$

$$88 \text{ hp} = \frac{\text{(? gpm)(386 ft)}}{\text{(3,960)(82.3 \%)}}$$

$$\text{(? gpm)(386 ft)} = \text{(88 hp)(3,960)(82.3 \%)}$$

$$\text{(? gpm)} = \frac{\text{(88 hp)(3,960)(0.823)}}{\text{(386 ft)}} = \frac{286{,}799.04}{386} = 743.00269 \text{ gpm} = 743 \text{ gpm}$$

Use the flow rate gpm to calculate the total gallons per day.

$$\frac{743 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{10 \text{ hr}}{1 \text{ day}} = \frac{445{,}800 \text{ gal}}{\text{day}}$$

Use the total gallons per day to calculate the cost per gallon.

$$\frac{\$103.61}{\text{day}} \times \frac{\text{day}}{445{,}800 \text{ gal}} = \$\,0.0002324 \text{ per gal}$$

Practice Problems 11.1

1. What is the average GPCD of a small community of 4,761 people that use approximately 605,000 gallons per day?

$$\frac{\frac{605{,}000 \text{ gal}}{\text{day}}}{4{,}761 \text{ people}} = 127.074 \text{ gpcd} = 127 \text{ gpcd}$$

2. A water utility produced 23,000 acre-feet of water last year that supplied a population of 68,437. What was the GPCD for this community?

$$\frac{23{,}000 \text{ AF}}{\text{year}} \times \frac{325{,}851 \text{ gal}}{1 \text{ AF}} \times \frac{1 \text{ year}}{365 \text{ days}} = 20{,}533{,}076.7123 \ \frac{\text{gal}}{\text{day}}$$

$$\frac{\frac{20{,}533{,}076.7123 \text{ gal}}{\text{day}}}{68{,}437 \text{ people}} = 300.0288 \text{ gpcd} = 300 \text{ gpcd}$$

3. A water utility in northern California has 71% of its 41,000 acre-feet of water used by the residential sector. If the total population is 37,500, what is the R-GPCD?

$$\frac{41{,}000 \text{ AF}}{\text{year}} \times 0.71 = 29{,}110 \ \frac{\text{AF}}{\text{year}}$$

$$\frac{29{,}110 \text{ AF}}{\text{year}} \times \frac{325{,}851 \text{ gal}}{1 \text{ AF}} = 9{,}485{,}522{,}610 \ \frac{\text{gal}}{\text{year}}$$

$$\frac{9{,}485{,}522{,}610 \ \frac{\text{gal}}{\text{year}}}{37{,}500 \text{ people}} = 252{,}947.2696 \text{ gal per person per year}$$

$$\frac{252{,}947 \text{ gal per person}}{\text{year}} \times \frac{1 \text{ year}}{365 \text{ days}} = 693.0054 \text{ R-GPCD} = 693 \text{ R-GPCD}$$

4. How much water would a family of six save over ten years from replacing three toilets from 1993 with three toilets purchased in 2020. Assume each person flushes each toilet twice a day.

$$\frac{1.6 \text{ gallons}}{\text{flush}} - \frac{1.28 \text{ gallons}}{\text{flush}} = \frac{0.32 \text{ gallons}}{\text{flush}}$$

$$6 \text{ family members} \times 3 \text{ toilets} \times \frac{2 \text{ flushes per family member}}{\text{toilet}} = 36 \text{ flushes}$$

$$\frac{36 \text{ flushes}}{\text{day}} \times \frac{0.32 \text{ gallons}}{\text{flush}} = \frac{11.52 \text{ gallons}}{\text{day}}$$

$$\frac{11.52 \text{ gallons}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} = \frac{4{,}204.8 \text{ gallons}}{\text{year}} = \frac{4{,}205 \text{ gallons}}{\text{year}}$$

$$\frac{4{,}205 \text{ gallons}}{\text{year}} \times 10 \text{ years} = 42{,}050 \text{ gallons saved}$$

5. A small water system has one well that pumps 130 gpm. This well serves a population of 633 with an average gpcd of 210. How many hours per day must this well run to meet the demand?

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

$$210 = \frac{\text{water used (gpd)}}{633}$$

$$\text{water used (gpd)} = (210)(633) = 132{,}930 \text{ gpd}$$

$$\frac{132{,}930 \text{ gallon}}{\text{day}} \times \frac{\text{min}}{130 \text{ gallon}} = \frac{1{,}022.538 \text{ min}}{\text{day}} \times \frac{1 \text{ hour}}{60 \text{ min}} = \frac{17.0423 \text{ hrs}}{\text{day}} = \frac{17 \text{ hrs}}{\text{day}}$$

6. What is the GPCD of a community with 6,000,000 people if the annual water used is 372,000 AF?

$$\frac{372{,}000 \text{ AF}}{\text{year}} \times \frac{325{,}851 \text{ gal}}{1 \text{ AF}} \times \frac{1 \text{ year}}{365 \text{ days}} = 332{,}100{,}197.26 \frac{\text{gal}}{\text{day}}$$

$$\frac{332{,}100{,}197 \frac{\text{gal}}{\text{day}}}{6{,}000{,}000 \text{ people}} = 55.350 \text{ GPCD} = 55 \text{ GPCD}$$

7. A water district has a goal of 125 gpcd and an annual water projection of 28,640 AF. What is the population that can be served?

$$\frac{28{,}640 \text{ AF}}{\text{year}} \times \frac{325{,}851 \text{ gal}}{1 \text{ AF}} \times \frac{1 \text{ year}}{365 \text{ days}} = 25{,}568{,}144.2192 \frac{\text{gal}}{\text{day}}$$

$$125 \text{ GPCD} = \frac{25{,}568{,}144 \frac{\text{gal}}{\text{day}}}{? \text{ people}}$$

$$? \text{ people} = \frac{25{,}568{,}144 \ \frac{\text{gal}}{\text{day}}}{125 \text{ GPCD}} = 204{,}545.152 \text{ people} = 204{,}545 \text{ people}$$

8. A house of 5 people used 42 CCF of water in 45 days. What is their gpcd within their household?

$$\frac{42 \text{ CCF}}{1} \times \frac{748 \text{ gal}}{1 \text{ CCF}} = 31{,}416 \text{ gal}$$

$$\frac{31{,}416 \text{ gal}}{45 \text{ days}} = 698.1333 \text{ gpd} = 698 \text{ gpd}$$

$$\frac{\frac{698 \text{ gal}}{\text{day}}}{5 \text{ people}} = 139.6 \text{ gpcd} = 140 \text{ gpcd}$$

9. In question 8, what would the gpcd be if you took out 70% of the usage and classified it as outdoor usage?

$$140 \text{ gpcd} \times 0.70 = 98 \text{ gpcd outdoor usage}$$

$$140 \text{ gpcd} \times 0.30 = 42 \text{ gpcd indoor usage}$$

Practice Problems 12.1

1. A well has a nitrate level that exceeds the MCL of 63 mg/L. Over the last 4 sample results it has averaged 71 mg/L. A nearby well has a nitrate level of 40 mg/L. If both wells combined pump up to 1,575 gpm, how much flow is required from each well to achieve a nitrate level of 50 mg/L?

   Well A – 71 mg/L Well B – 40 mg/L Desired result "C" – 50 mg/L
   To determine the percentage of Source A required for the blend, the desired result minus the low result is divided by the high result minus the low result.

   $$\frac{C - B}{A - B} =$$

   $$\frac{50 \text{ mg/L} - 40 \text{ mg/L}}{71 \text{ mg/L} - 40 \text{ mg/L}} = \frac{10 \text{ mg/L}}{31 \text{ mg/L}} = 0.3225$$

   This says that 32% of Well A is needed to achieve the desired blended result.
   To determine the percentage of Source B required for the blend, the high result minus the desired result is divided by the high result minus the low result.

   $$\frac{A - C}{A - B} =$$

   $$\frac{71 \text{ mg/L} - 50 \text{ mg/L}}{71 \text{ mg/L} - 40 \text{ mg/L}} = \frac{21 \text{ mg/L}}{31 \text{ mg/L}} = 0.6774$$

   This says that 68% of Well B is needed to achieve the desired blended result.
   Well A:
   $1{,}575 \text{ gpm} \times 0.32 = 504 \text{ gpm}$
   Well B:
   $1{,}575 \text{ gpm} \times 0.68 = 1{,}071 \text{ gpm}$

2. A well (A) has shown quarterly arsenic levels above the MCL over the last year, of 16 ug/L, 22 ug/L, 20 ug/L and 10 ug/L. A utility wants to blend this well to a level of 6.0 ug/L with a well (B) that has a level of 2.1 ug/L. The total production needed from both of these wells is 4,100 gpm. How much can each well produce?

   Remember that it is best to take the highest result when calculating blend volumes.

   Well A: 22 ug/L Well B: 2.1 ug/L Desired result: 6.0 ug/L

   Well A:

   $$\frac{C - B}{A - B} =$$

   $$\frac{6 \text{ ug/L} - 2.1 \text{ ug/L}}{22 \text{ ug/L} - 2.1 \text{ ug/L}} = \frac{3.9 \text{ ug/L}}{19.9 \text{ ug/L}} = 0.19597$$

Well B:

$$\frac{A - C}{A - B} =$$

$$\frac{22 \text{ ug/L} - 6 \text{ ug/L}}{22 \text{ ug/L} - 2.1 \text{ ug/L}} = \frac{16 \text{ ug/L}}{19.9 \text{ ug/L}} = 0.804020$$

Well A:

$$4{,}100 \text{ gpm} \times 0.20 = 820 \text{ gpm}$$

Well B:

$$4{,}100 \text{ gpm} \times 0.80 = 3{,}280 \text{ gpm}$$

3. A well with a PCE level of 12.4 ug/L is supplying approximately 65% of total water demand. It is being blended with a well that has a PCE level of 1.5 ug/L. Will this blended supply meet the MCL for PCE of 7.0 ug/L?

Well A: 12.4 ug/L Well B: 1.5 ug/L Desired result: ? ug/L

Well A:

$$\frac{? \text{ ug/L} - 1.5 \text{ ug/L}}{12.4 \text{ ug/L} - 1.5 \text{ ug/L}} = 0.65$$

$$\frac{? \text{ ug/L} - 1.5 \text{ ug/L}}{10.9 \text{ ug/L}} = 0.65$$

$$? \text{ ug/L} - 1.5 \text{ ug/L} = (0.65)(10.9 \text{ ug/L})$$

$$? \text{ ug/L} = 7.085 \text{ ug/L} + 1.5 \text{ ug/L} = 8.585 \text{ ug/L} = 8.6 \text{ ug/L} \quad \text{NO!}$$

4. Well A has a total dissolved solids (TDS) level of 625 mg/L. It is pumping 2,300 gpm, which is 50% of the total production from two wells. The other well (B) blends with well A to achieve a TDS level of 450 mg/L. What is the TDS level for Well B?

Well A – 625 mg/L Well B – ? mg/L Desired result – 450 mg/L

Well B

$$\frac{A - C}{A - B} =$$

$$\frac{625 \text{ mg/L} - 450 \text{ mg/L}}{625 \text{ mg/L} - ? \text{ mg/L}} = \frac{175 \text{ mg/L}}{625 \text{ mg/L} - ? \text{ mg/L}} = 0.50$$

$$175 \text{ mg/L} = 0.50(625 \text{ mg/L} - ? \text{ mg/L})$$

$$175 \text{ mg/L} = 312.5 \text{ mg/L} - (0.50)(? \text{ mg/L})$$

$$175 \text{ mg/L} - 312.5 \text{ mg/L} = -(0.50)(? \text{ mg/L})$$

$$? \text{ mg/L} = \frac{-137.5 \text{ mg/L}}{-(0.50)} = 275 \text{ mg/L}$$

OR

Well A

$$\frac{C - B}{A - B} =$$

$$\frac{450 \text{ mg/L} - ? \text{ mg/L}}{625 \text{ mg/L} - ? \text{ mg/L}} = 0.5$$

$$450 \text{ mg/L} - ? \text{ mg/L} = 0.5(625 \text{ mg/L} - ? \text{ mg/L})$$

$$450 \text{ mg/L} - ? \text{ mg/L} = 312.5 \text{ mg/L} - (0.5)(? \text{ mg/L})$$

$$450 \text{ mg/L} - 312.5 \text{ mg/L} = ? \text{ mg/L} - (0.5)(? \text{ mg/L})$$

$$0.5(? \text{ mg/L}) = 137.5 \text{ mg/L}$$

$$? \text{ mg/L} = \frac{137.5 \text{ mg/L}}{0.5} = 275 \text{ mg/L}$$

5. Two wells need to achieve a daily flow of 2.1 MG and a total hardness level of 110 mg/L as calcium carbonate ($CaCO_3$.) Well #1 has a total hardness level of 390 mg/L as $CaCO_3$ and Well #2 has a level of 63 mg/L as $CaCO_3$. What is the gpm that each well must pump?

Well 1 – 390 mg/L Well 2 – 63 mg/L Desired result – 110 mg/L

Well 1

$$\frac{C - B}{A - B} =$$

$$\frac{110 \text{ mg/L} - 63 \text{ mg/L}}{390 \text{ mg/L} - 63 \text{ mg/L}} = \frac{47 \text{ mg/L}}{327 \text{ mg/L}} = 0.1437$$

Well 2

$$\frac{A - C}{A - B} =$$

$$\frac{390 \text{ mg/L} - 110 \text{ mg/L}}{390 \text{ mg/L} - 63 \text{ mg/L}} = \frac{280 \text{ mg/L}}{327 \text{ mg/L}} = 0.8562$$

$$\frac{2{,}100{,}000 \text{ gal}}{\text{day}} \times \frac{1 \text{ day}}{1{,}440 \text{ min}} = 1{,}458.3333 \text{ gpm} = 1{,}458 \text{ gpm}$$

Well 1:

$$1{,}458 \text{ gpm} \times 0.14 = 204.12 \text{ gpm} = 204 \text{ gpm}$$

Well 2:

$$1{,}458 \text{ gpm} \times 0.86 = 1{,}253.88 \text{ gpm} = 1{,}254 \text{ gpm}$$

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 480 mg/L. The utility needs to purchase the water to blend with the well. The purchased water has a sulfate level of 55 mg/L. They need to bring the sulfate levels down to 225 mg/L and supply a demand of 2.0 MGD. The purchased water costs $475/AF. How much will the purchased water cost for the entire year?

Well A – 480 mg/L Well B – 55 mg/L Desired result – 225 mg/L

Well A

$$\frac{C - B}{A - B} =$$

$$\frac{225 \text{ mg/L} - 55 \text{ mg/L}}{480 \text{ mg/L} - 55 \text{ mg/L}} = \frac{170 \text{ mg/L}}{425 \text{ mg/L}} = 0.4$$

Well B

$$\frac{A - C}{A - B} =$$

$$\frac{480 \text{ mg/L} - 225 \text{ mg/L}}{480 \text{ mg/L} - 55 \text{ mg/L}} = \frac{255 \text{ mg/L}}{425 \text{ mg/L}} = 0.6$$

$$\frac{2{,}000{,}000 \text{ gal}}{\text{day}} \times \frac{1 \text{ day}}{1{,}440 \text{ min}} = 1{,}388.8889 \text{ gpm}$$

Well A:

$$1{,}389 \text{ gpm} \times 0.4 = 555.6 \text{ gpm} = 556 \text{ gpm}$$

Well B:

$$1{,}389 \text{ gpm} \times 0.6 = 833.4 \text{ gpm} = 833 \text{ gpm}$$

$$\frac{833 \text{ gal}}{\text{min}} \times \frac{1{,}440 \text{ min}}{1 \text{ day}} \times \frac{365 \text{ day}}{1 \text{ year}} \times \frac{1 \text{ AF}}{325{,}851 \text{ gal}} = 1{,}343.63497 \text{ AF/year}$$

$$\frac{1{,}344 \text{ AF}}{\text{year}} \times \frac{\$475}{\text{AF}} = \$\,638{,}400 \text{ per year}$$

Practice Problems 13.1

1. A 4-20 mA signal is being used to measure the water level in a water storage tank. The tank is 50 feet tall and the low-level signal is set at 0 feet and the high level at 50 feet. What is the level in the tank with a 17 mA reading?

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

$$\frac{17 \text{ mA } - 4 \text{ mA}}{(20 \text{ mA} - 4 \text{ mA})} = \frac{13 \text{ mA}}{16 \text{ mA}} = 0.8125$$

$$0.81 \times 50 \text{ ft} = 40.5 \text{ ft} = 41 \text{ ft}$$

2. A 48 ft tall water tank uses a 4-20 mA signal for calculating the water level. If the 4 mA level is set at 5 feet from the bottom and the 20 mA is set at 5 feet from the top, what is the level in the tank with a 9 mA reading?

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

$$\frac{9 \text{ mA } - 4 \text{ mA}}{(20 \text{ mA} - 4 \text{ mA})} = \frac{5 \text{ mA}}{16 \text{ mA}} = 0.3125$$

Since the 4 mA level is set 5 feet from the bottom of the tank and the 20 mA level is set 5 feet from the top of the tank, the actual measured tank height is 38 feet.

$$48 \text{ ft } - 5 \text{ ft } - 5 \text{ ft } = 38 \text{ ft}$$

$$0.31 \times 38 \text{ ft} = 11.78 \text{ ft} = 12 \text{ ft}$$

$$12 \text{ ft} + 5 \text{ ft} = 17 \text{ ft}$$

This accounts for the 5 feet from the bottom of the tank to the start of the measuring point.

3. A chlorine analyzer uses a 4-20 mA signal to monitor the chlorine residual. The 4-20 mA range is 0.8 mg/L – 4.6 mg/L respectively. If the reading is 10 mA, what is the corresponding residual in mg/L?

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

$$\frac{10 \text{ mA } - 4 \text{ mA}}{(20 \text{ mA} - 4 \text{ mA})} = \frac{6 \text{ mA}}{16 \text{ mA}} = 0.375$$

$$4.6 \text{ mg/L} - 0.8 \text{ mg/L} = 3.8 \text{ mg/L}$$

$$0.375 \times 3.8 \text{ mg/L} = 1.425 \text{ mg/L}$$

$$1.425 \text{ mg/L} + 0.8 \text{ mg/L} = 2.225 \text{ mg/L} = 2.2 \text{ mg/L}$$

4. A water tank is 52 ft tall and has 41 ft of water in it. If the 4-20 mA set points are at 4 ft and 50 ft respectively, what is the mA reading?

$$\text{Range} = 52 \text{ ft} - 2 \text{ ft} - 4 \text{ ft} = 46 \text{ ft}$$

$$\text{Water height during the reading} = 41 \text{ ft} - 4 \text{ ft} = 37 \text{ ft}$$

$$\text{Percentage being measured} = \frac{37 \text{ ft}}{46 \text{ ft}} = 0.8043$$

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

$$\frac{? \text{ mA} - 4 \text{ mA}}{(20 \text{ mA} - 4 \text{ mA})} = \frac{? \text{ mA} - 4 \text{ mA}}{16 \text{ mA}} = 0.80$$

$$? \text{ mA} - 4 \text{ mA} = (0.80)16 \text{ mA}$$

$$? \text{ mA} = 12.8 \text{ mA} + 4 \text{ mA} = 16.8 \text{ mA} = 17 \text{ mA}$$

5. A water tank with a 75 ft diameter is 25 ft tall. The 4-20 mA set points are 2 ft and 22 ft respectively. If the current level reading is 12 mA, how many gallons of water are in the tank?

$$\text{Range} = 25 \text{ ft} - (25 \text{ ft} - 22 \text{ ft}) - 2 \text{ ft} = 25 \text{ ft} - 3 \text{ ft} - 2 \text{ ft} = 20 \text{ ft}$$

$$\frac{12 \text{ mA} - 4 \text{ mA}}{(20 \text{ mA} - 4 \text{ mA})} = \frac{8 \text{ mA}}{16 \text{ mA}} = 0.5$$

$$0.5 \times 20 \text{ ft} = 10 \text{ ft}$$

$$10 \text{ ft} + 2 \text{ ft} = 12 \text{ ft}$$

$$\text{Tank Volume} = 0.785 \times D^2 \times H = 0.785 \times (75 \text{ ft})^2 \text{ x } 12 \text{ ft} = 52{,}987.5 \text{ ft}^3$$

$$52{,}988 \text{ ft}^3 \times \frac{7.48 \text{ gal}}{1 \text{ cf}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 0.39635 \text{ MG} = 0.40 \text{ MG}$$

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 205 psi bgs and the 4 mA signal at 15 psi bgs. If the reading is 14 mA, what is the water level in feet?

$$\text{Range} = 205 \text{ psi} - 15 \text{ psi} = 190 \text{ psi}$$

$$\frac{14 \text{ mA} - 4 \text{ mA}}{(20 \text{ mA} - 4 \text{ mA})} = \frac{10 \text{ mA}}{16 \text{ mA}} = 0.625$$

$$0.625 \times 190 \text{ psi} = 118.75 \text{ psi} = 118.8 \text{ psi}$$

$$118.8 \text{ psi} \times \frac{2.31 \text{ ft}}{1 \text{ psi}} = 274.428 \text{ ft} = 274.4 \text{ ft}$$

$$\left(15 \text{ psi} \times \frac{2.31 \text{ ft}}{1 \text{ psi}}\right) + 274.4 \text{ ft} = 34.7 \text{ ft} + 274.4 \text{ ft} = 309.1 \text{ ft bgs}$$

7. A water utility uses a 4-20 mA signal to determine groundwater elevations in a well. The set points are based on actual elevations above the mean sea level (MSL). The ground surface elevation at this well is 1,400 ft and this is where the 4 mA signal is set. The 20 mA signal is set at 740 ft. What is the elevation and the feet bgs with an 11 mA reading?

$$\text{Range} = 1{,}400 \text{ ft} - 740 \text{ ft} = 660 \text{ ft}$$

$$\frac{11 \text{ mA} - 4 \text{ mA}}{(20 \text{ mA} - 4 \text{ mA})} = \frac{7 \text{ mA}}{16 \text{ mA}} = 0.4375$$

$$0.438 \times 660 \text{ ft} = 289.08 \text{ ft} = 289 \text{ ft}$$

$$1{,}400 \text{ ft} - 289 \text{ ft} = 1{,}111 \text{ ft}$$

8. A chemical injection system is monitored with a 4-20 mA signal. The reading is 9 mA at 4.71 mg/L and the 4 mA set point is at 1.0 mg/L. What is the 20 mA set point?

$$\frac{9 \text{ mA} - 4 \text{ mA}}{(20 \text{ mA} - 4 \text{ mA})} = \frac{5 \text{ mA}}{16 \text{ mA}} = 0.3125$$

$$\text{Range} = x \text{ mg/L} - 1.0 \text{ mg/L}$$

$$0.3125 \times (\text{Range}) = 4.71 \text{ mg/L}$$

$$0.3125 \times (x \text{ mg/L} - 1.0 \text{ mg/L}) = 4.71 \text{ mg/L}$$

$$x \text{ mg/L} - 1.0 \text{ mg/L} = \frac{4.71 \text{ mg/L}}{0.3125}$$

$$x \text{ mg/L} - 1.0 \text{ mg/L} = 15.072 \text{ mg/L}$$

$$x \text{ mg/L} = 15.072 \text{ mg/L} + 1.0 \text{ mg/L} = 16.072 \text{ mg/L} = 16.07 \text{ mg/L}$$

Practice Problems 14.1

1. A utility vehicle costs on average \$730 per year for maintenance. A replacement vehicle would cost \$32,000. The utility has a vehicle policy that states all vehicles with 155,000 miles or more shall be replaced. The policy also states that once maintenance costs exceed 50% of the cost of a replacement vehicle, the vehicle shall be replaced. This particular vehicle averages 22,000 miles per year.

    a. Will the vehicle cost more than 50% of a new vehicle cost before reaching 155,000 miles?

    $$0.50 \times \$32{,}000 = \$16{,}000$$
    $$\$16{,}000 \times \frac{1 \text{ year}}{\$750} = 21.3 \text{ years}$$
    $$155{,}000 \text{ miles} \times \frac{1 \text{ year}}{22{,}000 \text{ miles}} = 7.0 \text{ years}$$

    NO. The vehicle will reach 155,000 miles in 7 years and it will take more than 21 years for the annual maintenance cost to be 50% of the cost of a new vehicle.

    b. What is the total maintenance cost if the vehicle reaches 155,000 miles?

    $$7.0 \text{ years} \times \frac{\$750}{\text{year}} = \$5{,}250$$

2. A pump that has been in operation for 15 years pumps a constant 450 gpm through 65 feet of dynamic head. The pump uses 6,537 kW-Hr of electricity per month at a cost of \$0.095 per kW-Hr. The old pump efficiency has dropped to 50%. Assuming a new pump that operates at 90% efficiency is available for \$10,270, how long would it take to pay for replacing the old pump?

    OLD PUMP:

    $$\text{Motor hp} = \frac{(450 \text{ gpm})(65 \text{ ft})}{(3{,}960)(0.50)}$$
    $$\text{Motor hp} = \frac{29{,}250}{1{,}980} = 14.772727 = 14.8 \text{ hp}$$
    $$\frac{14.8 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 11.0408 \text{ kW} = 11.04 \text{ kW}$$
    $$\frac{6{,}537 \text{ kW-hr}}{\text{month}} \times \frac{1}{11.04 \text{ kW}} = 592.1195 \text{ hrs/month} = 592 \text{ hours per month}$$

NEW PUMP:

$$\text{Motor hp} = \frac{(450\text{ gpm})(65\text{ ft})}{(3{,}960)(0.90)}$$

$$\text{Motor hp} = \frac{29{,}250}{3{,}564} = 8.20707 = 8.2\text{ hp}$$

$$\frac{8.2\text{ hp}}{1} \times \frac{0.746\text{ kW}}{1\text{ hp}} = 6.1172\text{ kW} = 6.12\text{ kW}$$

$$6.12\text{ kW} \times \frac{592\text{ hours}}{\text{month}} = 3{,}623.04\text{ kW-hr/month} = 3{,}623\text{ kW-hr/month}$$

Difference in kW-hrs per month between the pumps:

$$6{,}537\text{ kW-hr/month} - 3{,}623\text{ kW-hr/month} = 2{,}914\text{ kW-hr/month}$$

$$\frac{2{,}914\text{ kW-hr}}{\text{month}} \times \frac{\$0.095}{\text{kW-hr}} = \$276.83\text{ per month savings}$$

Payback period:

$$\$10{,}270 \times \frac{\text{month}}{\$276.83} = 37.09858\text{ month} = 37.1\text{ months}$$

$$37.1\text{ months} \times \frac{1\text{ year}}{12\text{ month}} = 3.09167\text{ years} = 3.1\text{ years}$$

3. A utility has annual operating expenses of \$4.7 million and a need for \$2.1 million in capital improvements. The current water rate is \$1.30 per CCF. Last year the utility sold 7270 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.)

Total cost of operation and capital requirements.

$$\$4.7\text{ M} + \$2.1\text{ M} = \$6.8\text{ M}$$

Convert AF sold to CCF.

$$7{,}270\text{ AF} \times \frac{325{,}851\text{ gal}}{1\text{ AF}} \times \frac{1\text{ CCF}}{748\text{ gal}} = 3{,}167{,}027.76738\text{ CCF} = 3{,}167{,}027.8\text{ CCF}$$

Calculate revenue.

$$3{,}167{,}027.8\text{ CCF} \times \frac{\$1.30}{\text{CCF}} = \$4{,}117{,}136.14$$

Difference between revenue and total costs. (Shortfall)

$$\$6{,}800{,}000 - \$4{,}117{,}136.14 = \$2{,}682{,}863.86$$

Calculate rate required to cover total costs.

$$3{,}167{,}027.8\text{ CCF} \times \frac{\$?}{\text{CCF}} = \$6{,}800{,}000$$

$$\frac{\$?}{\text{CCF}} = \frac{\$6{,}800{,}000}{3{,}167{,}027.8\text{ CCF}} = \$2.1471\text{ per CCF} = \$2.15\text{ per CCF}$$

Calculate rate increase.

$$\$2.15 \text{ per CCF} - \$1.30 \text{ per CCF} = \$0.85 \text{ per CCF}$$

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 $400K to a reserve account?

$$3{,}167{,}027.8 \text{ CCF} \times \frac{\$?}{\text{CCF}} = \$7{,}200{,}000$$

$$\frac{\$?}{\text{CCF}} = \frac{\$7{,}200{,}000}{3{,}167{,}027.8 \text{ CCF}} = \$2.2734 \text{ per CCF} = \$2.27 \text{ per CCF}$$

Calculate rate increase.

$$\$2.27 \text{ per CCF} - \$1.30 \text{ per CCF} = \$0.97 \text{ per CCF}$$

5. A 300 hp well operates 6 hours a day and flows 1,700 gpm. The electricity cost is $0.118 per kW-Hr. The well is also dosed with a 55% calcium hypochlorite tablet chlorinator to a dosage of 1.65 ppm. The tablets cost $1.20 per pound. The labor burden associated with the well maintenance is $60 per day. What is the total operating expense for this well in one year?

Cost of the tablets per day.

$$\frac{1{,}700 \text{ gal}}{\text{min}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{6 \text{ hr}}{1 \text{ day}} \times \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gal}} = 0.612 \text{ MGD}$$

$$\text{Pound Formula} \rightarrow \frac{\frac{\text{MG}}{\text{D}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \text{ppm}}{\%\text{ concentration}} = \frac{\text{lbs}}{\text{day}}$$

$$\frac{0.612 \text{ MG}}{\text{D}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times 1.65 \text{ ppm} = \frac{8.421732 \text{ lbs}}{\text{day}}$$

$$\frac{\frac{8.421732 \text{ lbs}}{\text{day}}}{\%\text{ concentration}} = \frac{\frac{8.421732 \text{ lbs}}{\text{day}}}{55\%} = \frac{\frac{8.421732 \text{ lbs}}{\text{day}}}{0.55} = \frac{15.31224 \text{ lbs}}{\text{day}}$$

$$\frac{15.31224 \text{ lbs}}{\text{day}} \times \frac{\$1.20}{\text{lb}} = \frac{\$18.374688}{\text{day}} = \frac{\$18.37}{\text{day}}$$

Cost of electricity per day.

$$\frac{300 \text{ hp}}{1} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 223.8 \text{ kW}$$

$$\frac{223.8 \text{ kW}}{1} \times \frac{\$\,0.118}{1 \text{ kW-hr}} \times \frac{6 \text{ hr}}{1 \text{ day}} = \$\,158.4504 \text{ per day} = \$\,158.45 \text{ per day}$$

Total operational cost per day.

$$\$18.37 + \$60 + \$\,158.45 = \$236.82 \text{ per day}$$

Total operational cost per year.

$$\frac{\$236.82}{\text{day}} \times \frac{365\ \text{days}}{\text{year}} = \$86{,}439.30 \text{ per year}$$

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

$$\frac{0.612\ \text{MG}}{\text{day}} \times \frac{1{,}000{,}000\ \text{gal}}{1\ \text{MG}} \times \frac{1\ \text{AF}}{325{,}851\ \text{gal}} \times \frac{365\ \text{day}}{\text{year}} = \frac{685.52804\ \text{AF}}{\text{year}} = \frac{686\ \text{AF}}{\text{year}}$$

$$\frac{\$86{,}439.30}{\text{year}} \times \frac{\text{year}}{686\ \text{AF}} = \frac{\$126.00}{\text{AF}}$$

7. A small water company has a total operating budget of $950,000. Salaries and benefits account for approximately 85% of this budget. The company has 9 employees. What is the average annual salary?

$$\$950{,}000 \times 0.85 = \$807{,}500$$

$$\frac{\$807{,}500}{9} = \$89{,}722.22$$

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 $3.40 per pound and salt is $0.50 per pound. It takes approximately 4 pounds of salt to create 1 gallon of 1.75% chlorine with a specific gravity of 1.20. Assuming that the plant is dosing 12.5 MGD to a dosage of 2.75, what would be the annual cost of each? Which one is more cost effective?

Cost of the gas chlorine.

$$\frac{12.5\ \text{MG}}{\text{D}} \times \frac{8.34\ \text{lbs}}{\text{gal}} \times 2.75\ \text{ppm} = \frac{286.6875\ \text{lbs}}{\text{day}}$$

$$\frac{286.6875\ \text{lbs}}{\text{day}} \times \frac{\$3.40}{\text{lb}} = \frac{\$974.74\ \text{lbs}}{\text{day}}$$

Cost of the salt.

$$\frac{\frac{286.6875\ \text{lbs}}{\text{day}}}{0.0175} = \frac{16{,}382.1428\ \text{lbs}}{\text{day}} = \frac{16{,}382\ \text{lbs}}{\text{day}}$$

$$\frac{8.34\ \text{lbs/gal}}{1\ \text{SG}} \times \frac{1.20\ \text{SG}}{1} = 10.008 = 10.0\ \frac{\text{lbs}}{\text{gal}}$$

$$\frac{16{,}382 \text{ lbs}}{\text{day}} \times \frac{\text{gal}}{10.0 \text{ lbs}} = \frac{1{,}638.2 \text{ gal}}{\text{day}}$$

$$\frac{1{,}638 \text{ gal}}{\text{day}} \times \frac{4 \text{ lbs}}{\text{gal}} = \frac{6{,}552 \text{ lbs}}{\text{day}}$$

$$\frac{6{,}552 \text{ lbs}}{\text{day}} \times \frac{\$0.50}{\text{lb}} = \frac{\$3{,}276}{\text{day}}$$

APPENDIX

CT TABLES

Table C-1. CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 0.5°C or Lower

CHLORINE CONCENTRATION	pH<=6 Log Inactivation						pH=6.5 Log Inactivation					
(mg/L)	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	23	46	69	91	114	137	27	54	82	109	136	163
0.6	24	47	71	94	118	141	28	56	84	112	140	169
0.8	24	48	73	97	121	145	29	57	86	115	143	172
1	25	49	74	99	123	148	29	59	88	117	147	176
1.2	25	51	76	101	127	152	30	60	90	120	150	180
1.4	26	52	78	103	129	155	31	61	92	123	153	184
1.6	26	52	79	105	131	157	32	63	95	126	155	189
1.8	27	54	81	108	135	162	32	64	97	129	161	193
2	28	55	83	110	138	165	33	66	99	131	164	197
2.2	28	56	85	113	141	169	34	67	101	134	169	201
2.4	29	57	86	115	143	172	34	68	103	137	171	205
2.6	29	58	88	117	146	175	35	70	105	139	174	209
2.8	30	59	89	119	148	178	36	71	107	142	178	213
3	30	60	91	121	151	181	36	72	109	145	181	217

CHLORINE CONCENTRATION	pH=7.0 Log Inactivation						pH=7.5 Log Inactivation					
(mg/L)	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	33	65	98	130	163	195	40	79	119	158	198	237
0.6	33	67	100	133	167	200	40	80	120	159	199	239
0.8	34	68	103	137	171	205	41	82	123	164	205	246
1	35	70	105	140	175	210	42	84	127	169	211	253
1.2	36	72	108	143	179	215	43	86	130	173	216	259
1.4	37	74	111	147	184	221	44	89	133	177	222	266
1.6	38	75	113	151	188	226	46	91	137	182	228	273
1.8	39	77	116	154	193	231	47	93	140	186	233	279
2	39	79	118	157	197	236	48	95	143	191	238	286
2.2	40	81	121	161	202	242	50	99	149	198	248	297
2.4	41	82	124	165	206	247	50	99	149	199	248	298
2.6	42	84	126	168	210	252	51	101	152	203	253	304
2.8	43	86	129	171	214	257	52	103	155	207	258	310
3	44	87	131	174	218	261	53	105	158	211	263	316

CHLORINE CONCENTRATION	pH=8.0 Log Inactivation						pH=8.5 Log Inactivation					
(mg/L)	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	46	92	139	185	231	277	55	110	165	219	274	329
0.6	48	95	143	191	238	286	57	114	171	228	285	342
0.8	49	98	148	197	246	295	59	113	177	236	295	354
1	51	101	152	203	253	304	61	122	183	243	304	365
1.2	52	104	157	209	261	313	63	125	188	251	313	376
1.4	54	107	161	214	268	321	65	129	194	258	323	387
1.6	55	110	165	219	274	329	66	132	199	265	331	397
1.8	56	113	169	225	282	338	68	136	204	271	339	407
2	55	115	173	231	288	346	70	139	209	278	348	417
2.2	59	118	177	235	294	353	71	142	213	284	355	426
2.4	60	120	181	241	301	361	73	145	218	290	363	435
2.6	61	123	184	245	307	368	74	148	222	296	370	444
2.8	63	125	188	250	313	375	75	151	226	301	377	452
3	64	127	191	255	318	382	77	153	230	307	383	460

CHLORINE CONCENTRATION	pH=9.0 Log Inactivation					
(mg/L)	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	65	130	195	260	325	390
0.6	68	136	204	271	339	407
0.8	70	141	211	281	352	422
1	73	146	219	291	364	437
1.2	75	150	226	301	376	451
1.4	77	155	232	309	387	464
1.6	80	159	239	318	398	477
1.8	82	163	245	326	408	489
2	83	167	250	333	417	500
2.2	85	170	256	341	426	511
2.4	87	174	261	348	435	522
2.6	89	178	267	355	444	533
2.8	91	181	272	362	453	543
3	92	184	276	369	460	552

Source: AWWA, 1991.

Table C-2. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 5°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	16	32	49	65	81	97	20	39	59	78	98	117	23	46	70	93	116	139	28	55	83	111	138	166
0.6	17	33	50	67	83	100	20	40	60	80	100	120	24	49	72	95	119	143	29	57	86	114	143	171
0.8	17	34	52	69	86	103	20	41	61	81	102	122	24	49	73	97	122	146	29	58	88	117	146	175
1	18	35	53	70	88	105	21	42	63	83	104	125	25	50	75	99	124	149	30	60	90	119	149	179
1.2	18	36	54	71	89	107	21	42	64	85	106	127	25	51	76	101	127	152	31	61	92	122	153	183
1.4	18	36	55	73	91	109	22	43	65	97	108	130	26	52	78	103	129	155	31	62	94	125	156	187
1.6	19	37	56	74	93	111	22	44	66	88	110	132	26	53	79	105	132	158	32	64	96	128	160	192
1.8	19	38	57	76	95	114	23	45	69	90	113	135	27	54	81	108	135	162	33	65	98	131	163	196
2	19	39	58	77	97	116	23	46	69	92	115	138	28	55	83	110	138	165	33	67	100	133	167	200
2.2	20	39	59	79	98	118	23	47	70	93	117	140	28	56	85	113	141	169	34	68	102	136	170	204
2.4	20	40	60	80	100	120	24	48	72	95	119	143	29	57	86	115	143	172	35	70	105	139	174	209
2.6	20	41	61	81	102	122	24	49	73	97	122	146	29	58	88	117	146	175	36	71	107	142	178	213
2.8	21	41	62	83	103	124	25	49	74	99	123	148	30	59	89	119	148	178	36	72	109	145	181	217
3	21	42	63	84	105	126	25	50	76	101	126	151	30	61	91	121	152	182	37	74	111	147	184	221

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	33	66	99	132	165	198	39	79	118	157	197	236	47	93	140	186	233	279
0.6	34	68	102	136	170	204	41	81	122	163	203	244	49	97	146	194	243	291
0.8	35	70	105	140	175	210	42	84	126	168	210	252	50	100	151	201	251	301
1	36	72	108	144	180	216	43	87	130	173	217	260	52	104	156	208	260	312
1.2	37	74	111	147	184	221	45	89	134	178	223	267	53	107	160	213	267	320
1.4	38	76	114	151	189	227	46	91	137	183	228	274	55	110	165	219	274	329
1.6	39	77	116	155	193	232	47	94	141	197	234	281	56	112	169	225	281	337
1.8	40	79	119	159	198	238	48	96	144	191	239	287	58	115	173	230	288	345
2	41	81	122	162	203	243	49	98	147	196	245	294	59	118	177	235	294	353
2.2	41	83	124	165	207	248	50	100	150	200	250	300	60	120	181	241	301	361
2.4	42	84	127	169	211	253	51	102	153	204	255	306	61	123	184	245	307	368
2.6	43	86	129	172	215	258	52	104	156	208	260	312	63	125	189	250	313	375
2.8	44	88	132	175	219	263	53	106	159	212	265	318	64	127	191	255	318	382
3	45	89	134	179	223	268	54	108	162	216	270	324	65	130	195	259	324	389

Source: AWWA, 1991.

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.

Table C-4. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 15°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	8	16	25	33	41	49	10	20	30	39	49	59	12	23	35	47	58	70	14	28	42	55	69	83
0.6	8	17	25	33	42	50	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86
0.8	9	17	26	35	43	52	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88
1	9	18	27	35	44	53	11	21	32	42	53	63	13	25	38	50	63	75	15	30	45	60	75	90
1.2	9	18	27	36	45	54	11	21	32	43	53	64	13	25	38	51	63	76	15	31	46	61	77	92
1.4	9	18	28	37	46	55	11	22	33	43	54	65	13	26	39	52	65	78	16	31	47	63	78	94
1.6	9	19	28	37	47	56	11	22	33	44	55	66	13	26	40	53	66	79	16	32	48	64	80	96
1.8	10	19	29	38	48	57	11	23	34	45	57	68	14	27	41	54	68	81	16	33	49	65	82	98
2	10	19	29	39	48	58	12	23	35	46	58	69	14	28	42	55	69	83	17	33	50	67	83	100
2.2	10	20	30	39	49	59	12	23	35	47	58	70	14	28	43	57	71	85	17	34	51	68	85	102
2.4	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86	18	35	53	70	88	105
2.6	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88	18	36	54	71	89	107
2.8	10	21	31	41	52	62	12	25	37	49	62	74	15	30	45	59	74	89	18	36	55	73	91	109
3	11	21	32	42	53	63	13	25	38	51	63	76	15	30	46	61	76	91	19	37	56	74	93	111

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	17	33	50	66	83	99	20	39	59	79	98	118	23	47	70	93	117	140
0.6	17	34	51	68	85	102	20	41	61	81	102	122	24	49	73	97	122	146
0.8	18	35	53	70	88	105	21	42	63	84	105	126	25	50	76	101	126	151
1	18	36	54	72	90	108	22	43	65	87	108	130	26	52	78	104	130	156
1.2	19	37	56	74	93	111	22	45	67	89	112	134	27	53	80	107	133	160
1.4	19	38	57	76	95	114	23	46	69	91	114	137	28	55	83	110	138	165
1.6	19	39	58	77	97	116	24	47	71	94	118	141	28	56	85	113	141	169
1.8	20	40	60	79	99	119	24	48	72	96	120	144	29	59	87	115	144	173
2	20	41	61	81	102	122	25	49	74	98	123	147	30	59	89	118	148	177
2.2	21	41	62	83	103	124	25	50	75	100	125	150	30	60	91	121	151	181
2.4	21	42	64	85	106	127	26	51	77	102	128	153	31	61	92	123	153	184
2.6	22	43	65	86	108	129	26	52	78	104	130	156	31	63	94	125	157	188
2.8	22	44	66	88	110	132	27	53	80	106	133	159	32	64	96	127	159	191
3	22	45	67	89	112	134	27	54	81	109	135	162	33	65	98	130	163	195

Source: AWWA, 1991.

Table C-5. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 20°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	6	12	18	24	30	36	7	15	22	29	37	44	9	17	26	35	43	52	10	21	31	41	52	62
0.6	6	13	19	25	32	38	8	15	23	30	38	45	9	18	27	36	45	54	11	21	32	43	53	64
0.8	7	13	20	26	33	39	8	15	23	31	38	46	9	18	28	37	46	55	11	22	33	44	55	66
1	7	13	20	26	33	39	8	16	24	31	39	47	9	19	28	37	47	56	11	22	34	45	56	67
1.2	7	13	20	27	33	40	8	16	24	32	40	48	10	19	29	38	48	57	12	23	35	46	58	69
1.4	7	14	21	27	34	41	8	16	25	33	41	49	10	19	29	39	48	58	12	23	35	47	58	70
1.6	7	14	21	28	35	42	8	17	25	33	42	50	10	20	30	39	49	59	12	24	36	48	60	72
1.8	7	14	22	29	36	43	9	17	26	34	43	51	10	20	31	41	51	61	12	25	37	49	62	74
2	7	15	22	29	37	44	9	17	26	35	43	52	10	21	31	41	52	62	13	25	38	50	63	75
2.2	7	15	22	29	37	44	9	18	27	35	44	53	11	21	32	42	53	63	13	26	39	51	64	77
2.4	8	15	23	30	38	45	9	18	27	36	45	54	11	22	33	43	54	65	13	26	39	52	65	78
2.6	8	15	23	31	38	46	9	18	28	37	46	55	11	22	33	44	55	66	13	27	40	53	67	80
2.8	8	16	24	31	39	47	9	19	28	37	47	56	11	22	34	45	56	67	14	27	41	54	68	81
3	9	16	24	31	39	47	10	19	29	38	48	57	11	23	34	45	57	68	14	28	42	55	69	83

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	12	25	37	49	62	74	15	30	45	59	74	89	19	35	53	70	88	105
0.6	13	26	39	51	64	77	15	31	46	61	77	92	18	36	55	73	91	109
0.8	13	26	40	53	66	79	16	32	48	63	79	95	19	38	57	75	94	113
1	14	27	41	54	68	81	16	33	49	65	82	98	20	39	59	78	98	117
1.2	14	28	42	55	69	83	17	33	50	67	83	100	20	40	60	80	100	120
1.4	14	28	43	57	71	85	17	34	52	69	86	103	21	41	62	82	103	123
1.6	15	29	44	58	73	87	18	35	53	70	88	105	21	42	63	84	105	126
1.8	15	30	45	59	74	89	18	36	54	72	90	108	22	43	65	86	108	129
2	15	30	46	61	76	91	18	37	55	73	92	110	22	44	66	88	110	132
2.2	16	31	47	62	78	93	19	38	57	75	94	113	23	45	68	90	113	135
2.4	16	32	48	63	79	95	19	38	58	77	96	115	23	46	69	92	115	139
2.6	16	32	49	65	81	97	20	39	59	78	98	117	24	47	71	94	117	141
2.8	17	33	50	66	83	99	20	40	60	79	99	119	24	48	72	95	119	143
3	17	34	51	67	84	101	20	41	61	81	102	122	24	49	73	97	122	146

Source: AWWA, 1991.

Table C-6. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 25°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	4	8	12	16	20	24	5	10	15	19	24	29	6	12	18	23	29	35	7	14	21	28	35	42
0.6	4	8	13	17	21	25	5	10	15	20	25	30	6	12	18	24	30	36	7	14	22	29	36	43
0.8	4	9	13	17	22	26	5	10	16	21	26	31	6	12	19	25	31	37	7	15	22	29	37	44
1	4	9	13	17	22	26	5	10	16	21	26	31	6	12	19	25	31	37	8	15	23	30	38	45
1.2	5	9	14	18	23	27	5	11	16	21	27	32	6	13	19	25	32	38	8	15	23	31	38	46
1.4	5	9	14	18	23	27	6	11	17	22	28	33	7	13	20	26	33	39	8	16	24	31	39	47
1.6	5	9	14	19	23	28	6	11	17	22	28	33	7	13	20	27	33	40	8	16	24	32	40	48
1.8	5	10	15	19	24	29	6	11	17	23	28	34	7	14	21	27	34	41	8	16	25	33	41	49
2	5	10	15	19	24	29	6	12	13	23	29	35	7	14	21	27	34	41	8	17	25	33	42	50
2.2	5	10	15	20	25	30	6	12	18	23	29	35	7	14	21	28	35	42	9	17	26	34	43	51
2.4	5	10	15	20	25	30	6	12	19	24	30	36	7	14	22	29	36	43	9	17	26	35	43	52
2.6	5	10	16	21	26	31	6	12	19	25	31	37	7	15	22	29	37	44	9	18	27	35	44	53
2.8	5	10	16	21	26	31	6	12	19	25	31	37	8	15	23	30	38	45	9	18	27	36	45	54
3	5	11	16	21	27	32	6	13	19	25	32	38	8	15	23	31	38	46	9	18	28	37	46	55

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	8	17	25	33	42	50	10	20	30	39	49	59	12	23	35	47	58	70
0.6	9	17	26	34	43	51	10	20	31	41	51	61	12	24	37	49	61	73
0.8	9	18	27	35	44	53	11	21	32	42	53	63	13	25	38	50	63	75
1	9	19	27	36	45	54	11	22	33	43	54	65	13	26	39	52	65	78
1.2	9	18	28	37	46	55	11	22	34	45	56	67	13	27	40	53	67	80
1.4	10	19	29	38	48	57	12	23	35	46	58	69	14	27	41	55	68	82
1.6	10	19	29	39	48	58	12	23	35	47	58	70	14	28	42	56	70	84
1.8	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86
2	10	20	31	41	51	61	12	25	37	49	62	74	15	29	44	59	73	89
2.2	10	21	31	41	52	62	13	25	38	50	63	75	15	30	45	60	75	90
2.4	11	21	32	42	53	63	13	26	39	51	64	77	15	31	46	61	77	92
2.6	11	22	33	43	54	65	13	26	39	52	65	78	16	31	47	63	78	94
2.8	11	22	33	44	55	66	13	27	40	53	67	80	16	32	48	64	80	96
3	11	22	34	45	56	67	14	27	41	54	68	81	16	32	49	65	81	97

Source: AWWA, 1991.

Table C-7. CT Values for Inactivation of Viruses by Free Chlorine, pH 6.0-9.0

	Temperature (°C)																									
Inactivation (log)	0.5	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2	6.0	5.8	5.3	4.9	4.4	4.0	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0	1.0	1.0	1.0	1.0	1.0
3	9.0	8.7	8.0	7.3	6.7	6.0	5.6	5.2	4.8	4.4	4.0	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
4	12.0	11.6	10.7	9.8	8.9	8.0	7.6	7.2	6.8	6.4	6.0	5.6	5.2	4.8	4.4	4.0	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.2	2.0

Source: AWWA, 1991. Modified by linear interpolation between 5°C increments.

Table C-8. CT Values for Inactivation of Giardia Cysts by Chlorine Dioxide, pH 6.0-9.0

	Temperature (°C)																								
Inactivation (log)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0.5	10.0	8.6	7.2	5.7	4.3	4.2	4.2	4.1	4.1	4.0	3.8	3.7	3.5	3.4	3.2	3.1	2.9	2.8	2.6	2.5	2.4	2.3	2.2	2.1	2.0
1	21.0	17.9	14.9	11.8	8.7	8.5	8.3	8.1	7.9	7.7	7.4	7.1	6.9	6.6	6.3	6.0	5.8	5.5	5.3	5.0	4.7	4.5	4.2	4.0	3.7
1.5	32.0	27.3	22.5	17.8	13.0	12.8	12.6	12.4	12.2	12.0	11.6	11.2	10.8	10.4	10.0	9.5	9.0	8.5	8.0	7.5	7.1	6.7	6.3	5.9	5.5
2	42.0	35.8	29.5	23.3	17.0	16.6	16.2	15.8	15.4	15.0	14.6	14.2	13.8	13.4	13.0	12.4	11.8	11.2	10.6	10.0	9.5	8.9	8.4	7.8	7.3
2.5	52.0	44.5	37.0	29.5	22.0	21.4	20.8	20.2	19.6	19.0	18.4	17.8	17.2	16.6	16.0	15.4	14.8	14.2	13.6	13.0	12.2	11.4	10.6	9.8	9.0
3	63.0	53.8	44.5	35.3	26.0	25.4	24.8	24.2	23.6	23.0	22.2	21.4	20.6	19.8	19.0	18.2	17.4	16.6	15.8	15.0	14.2	13.4	12.6	11.8	11.0

Source: AWWA, 1991. Modified by linear interpolation between 5°C increments.

Table C-9. CT Values for Inactivation of Viruses by Chlorine Dioxide, pH 6.0-9.0

	Temperature (°C)																								
Inactivation (log)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2	8.4	7.7	7.0	6.3	5.6	5.3	5.0	4.8	4.5	4.2	3.9	3.6	3.4	3.1	2.8	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.5	1.4
3	25.6	23.5	21.4	19.2	17.1	16.2	15.4	14.5	13.7	12.8	12.0	11.1	10.3	9.4	8.6	8.2	7.7	7.3	6.8	6.4	6.0	5.6	5.1	4.7	4.3
4	50.1	45.9	41.8	37.6	33.4	31.7	30.1	28.4	26.8	25.1	23.4	21.7	20.1	18.4	16.7	15.9	15.0	14.2	13.3	12.5	11.7	10.9	10.0	9.2	8.4

Source: AWWA, 1991. Modified by linear interpolation between 5°C increments.

Table C-10. CT Values for Inactivation of Giardia Cysts by Chloramine, pH 6.0-9.0

	Temperature (°C)																								
Inactivation (log)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
0.5	635	568	500	433	365	354	343	332	321	310	298	286	274	262	250	237	224	211	198	185	173	161	149	137	125
1	1,270	1,136	1,003	869	735	711	687	663	639	615	592	569	546	523	500	474	448	422	396	370	346	322	298	274	250
1.5	1,900	1,700	1,500	1,300	1,100	1,066	1,032	998	964	930	894	858	822	786	750	710	670	630	590	550	515	480	445	410	375
2	2,535	2,269	2,003	1,736	1,470	1,422	1,374	1,326	1,278	1,230	1,184	1,138	1,092	1,046	1,000	947	894	841	788	735	688	641	594	547	500
2.5	3,170	2,835	2,500	2,165	1,830	1,772	1,714	1,656	1,598	1,540	1,482	1,424	1,366	1,308	1,250	1,183	1,116	1,049	982	915	857	799	741	683	625
3	3,800	3,400	3,000	2,600	2,200	2,130	2,060	1,990	1,920	1,850	1,780	1,710	1,640	1,570	1,500	1,420	1,340	1,260	1,180	1,100	1,030	960	890	820	750

Source: AWWA, 1991. Modified by linear interpolation between 5°C increments.

Table C-11. CT Values for Inactivation of Viruses by Chloramine

	Temperature (°C)																								
Inactivation (log)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
2	1,243	1,147	1,050	954	857	814	771	729	686	643	600	557	514	471	428	407	385	364	342	321	300	278	257	235	214
3	2,063	1,903	1,743	1,583	1,423	1,352	1,281	1,209	1,138	1,067	996	925	854	783	712	676	641	605	570	534	498	463	427	392	356
4	2,883	2,659	2,436	2,212	1,988	1,889	1,789	1,690	1,590	1,491	1,392	1,292	1,193	1,093	994	944	895	845	796	746	696	646	597	547	497

Source: AWWA, 1991. Modified by linear interpolation between 5°C increments.

Table C-12. CT Values for Inactivation of Giardia Cysts by Ozone

Inactivation (log)	Temperature (°C)																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0.5	0.48	0.44	0.40	0.36	0.32	0.30	0.28	0.27	0.25	0.23	0.22	0.20	0.19	0.17	0.16	0.15	0.14	0.14	0.13	0.12	0.11	0.10	0.10	0.09	0.08
1.0	0.97	0.89	0.80	0.72	0.63	0.60	0.57	0.54	0.51	0.48	0.45	0.42	0.38	0.35	0.32	0.30	0.29	0.27	0.26	0.24	0.22	0.21	0.19	0.18	0.16
1.5	1.50	1.36	1.23	1.09	0.95	0.90	0.86	0.81	0.77	0.72	0.67	0.62	0.58	0.53	0.48	0.46	0.43	0.41	0.38	0.36	0.34	0.31	0.29	0.26	0.24
2.0	1.90	1.75	1.60	1.45	1.30	1.23	1.16	1.09	1.02	0.95	0.89	0.82	0.76	0.69	0.63	0.60	0.57	0.54	0.51	0.48	0.45	0.42	0.38	0.35	0.32
2.5	2.40	2.20	2.00	1.80	1.60	1.52	1.44	1.36	1.28	1.20	1.12	1.04	0.95	0.87	0.79	0.75	0.71	0.68	0.64	0.60	0.56	0.52	0.48	0.44	0.40
3.0	2.90	2.65	2.40	2.15	1.90	1.81	1.71	1.62	1.52	1.43	1.33	1.24	1.14	1.05	0.95	0.90	0.86	0.81	0.77	0.72	0.67	0.62	0.58	0.53	0.48

Source: AWWA, 1991. Modified by linear interpolation between 5°C increments.

Table C-13. CT Values for Inactivation of Viruses by Ozone

Inactivation (log)	Temperature (°C)																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2	0.90	0.83	0.75	0.68	0.60	0.58	0.56	0.54	0.52	0.50	0.46	0.42	0.38	0.34	0.30	0.29	0.28	0.27	0.26	0.25	0.23	0.21	0.19	0.17	0.15
3	1.40	1.28	1.15	1.03	0.90	0.88	0.86	0.84	0.82	0.80	0.74	0.68	0.62	0.56	0.50	0.48	0.46	0.44	0.42	0.40	0.37	0.34	0.31	0.28	0.25
4	1.80	1.65	1.50	1.35	1.20	1.16	1.12	1.08	1.04	1.00	0.92	0.84	0.76	0.68	0.60	0.58	0.56	0.54	0.52	0.50	0.46	0.42	0.38	0.34	0.30

Source: AWWA, 1991. Modified by linear interpolation between 5°C increments

STATE WATER RESOURCES CONTROL BOARD EXAM FORMULA SHEETS

The following pages include the State Water Resources Control Board exam formula sheets for the Treatment, Distribution, and Wastewater exams. They are included so you can use them to solve the problems in this text. They will be provided to you when you take your state exams. Being familiar with them and using them to solve problems now will help you later on the exam.

CALIFORNIA
Water Boards

State Water Resources Control Board

EDMUND G. BROWN JR.
GOVERNOR

MATTHEW RODRIQUEZ
SECRETARY FOR
ENVIRONMENTAL PROTECTION

UNITS AND CONVERSION FACTORS

1 cubic foot of water weighs 62.3832 lb
1 gallon of water weighs 8.34 lb
1 liter of water weighs 1,000 gm
1 mg/L = 1 part per million (ppm)
1% = 10,000 ppm
ft^2 = square feet and ft^3 = cubic feet
1 mile = 5,280 feet (ft)
1 yd^3 = 27ft^3 and 1 yard = 3 feet
1 acre (a) = 43,560 square feet (ft^2)
1 acre foot = 325,851 gallons
1 cubic foot (ft^3) = 7.48 gallons (gal)
1 gal = 3.785 liters (L)
1 L = 1,000 milliliters (ml)
1 pound (lb) = 454 grams (gm)
1 lb = 7,000 grains (gr)
1 grain per gallon (gpg) = 17.1 mg/L
1 gm = 1,000 milligrams (mg)
1 day = 24 hr = 1,440 min = 86,400 sec
1,000,000 gal/day ÷ 86,400 sec/day ÷ 7.48 gal/cu ft = 1.55 cu ft/sec/MGD

CHLORINATION

Dosage, mg/l = (Demand, mg/l) + (Residual, mg/l)

(Gas) lbs = Vol, MG x ppm or mg/L x 8.34 lbs/gal

HTH Solid (lbs) =

$$\frac{\text{(Vol. MG) x (ppm or mg/L) x 8.34 lbs/gal}}{\text{(\% Strength / 100)}}$$

Liquid (gal) = $\frac{\text{(Vol. MG) x (ppm or mg/L) x 8.34 lbs/gal}}{\text{(\% Strength /100) x Chemical Wt. (lbs/gal)}}$

PRESSURE

PSI = $\frac{\text{(Head, ft.)}}{\text{2.31ft./psi}}$ **PSI =** Head, ft. x 0.433 PSI/ft.

lbs Force = (0.785) (D, ft.)^2 x 144 in^2/ft^2 x PSI.

VOLUME

Rectangular Basin, Volume, gal =
(Length, ft) x (Width, ft) x (Height, ft) x 7.48 gal/cu. ft.

Cylinder , Volume, gal =
(0.785) x (Dia, ft)^2 x (Height, Depth, or Length in ft.) x 7.48 gal/ft^3

Time, Hrs. = $\frac{\text{Volume, gallons}}{\text{(Pumping Rate, GPM, x 60 Min/Hr)}}$

Supply, Hrs. = $\frac{\text{Storage Volume, Gals}}{\text{(Flow In, GPM - Flow Out, GPM) x 60 Min/Hr)}}$

SOLUTIONS

Lbs/Gal = $\frac{\text{(Solution \%)}}{100}$ x 8.34 lbs/gal x Specific Gravity

Lbs Chemical =
Specific Gravity x 8.34 lbs/gallons x Solution(gal)

Specific Gravity = $\frac{\text{Chemical Wt. (lbs/gal)}}{\text{8.34 (lbs/gal)}}$

% of Chemical in Solution = $\frac{\text{(Dry Chemical, lbs) x 100}}{\text{(Dry Wt. Chemical, lbs)+(Water, lbs)}}$

GPD = $\frac{\text{(MGD) x (ppm or mg/L) x 8.34 lbs/gal}}{\text{(\% purity) x Chemical Wt.(lbs/gal)}}$

GPD = $\frac{\text{(Feed, ml/min. x 1,440 min/day)}}{\text{(1,000 ml/L x 3.785 L/gal)}}$

Two-Normal Equations:
a) $C_1V_1 = C_2V_2$ $\frac{Q_1}{V_1} = \frac{Q_2}{V_2}$

b) $C_1V_1 + C_2V_2 = C_3V_3$

C = Concentration V = Volume Q = Flow

PUMPING

1 horsepower (Hp) = 746 watts = 0.746 kw = 3,960 gal/min/ft

Water Hp = $\frac{\text{(GPM) x (Total Head, ft)}}{\text{(3,960 gal/min/ft)}}$

Brake Hp = $\frac{\text{(GPM) x (Total Head, ft)}}{\text{(3,960) x (Pump \% Efficiency)}}$

Motor Hp = $\frac{\text{(GPM) x (Total Head, ft)}}{\text{(3,960) x Pump \% Eff. x Motor \% Eff.}}$

"Wire-to-Water" Efficiency
= (Motor, % Efficiency x Pump % Efficiency)

Cost, $ =
(Hp) x (0.746 Kw/Hp) x (Operating Hrs.) x cents/Kw-Hr

Flow, velocity, area

Q = A x V Quantity = Area x Velocity

Flow (ft^3/sec) = Area(ft^2) x Velocity (ft/sec)

$\frac{\text{MGD x 1.55 cuft/sec/MGD}}{\text{.785 x pipe diameter ft x pipe diameter ft}}$ = $\frac{\text{cu ft/sec}}{\text{sqft}}$ = ft/sec

General

($)Cost/day = lbs/day x ($)Cost/lb

Removal, Percent = $\frac{\text{(In - Out)}}{\text{In}}$ x 100

Specific Capacity, GPM/ft. = $\frac{\text{Well Yield, GPM}}{\text{Drawdown, ft.}}$

Gals/Day = (Population) x (Gals/Capita/Day)

GPD = $\frac{\text{(Meter Read 2 - Meter Read 1)}}{\text{(Number of Days)}}$

Volume, Gals = GPM x Time, minutes

SCADA = 4 mA to 20 mA analog signal

$\frac{\text{(live signal mA - 4 mA offset) x process unit and range}}{\text{(16 mA span)}}$

4 mA = 0 20 mA full-range

FILTRATION

sq. ft. = square feet

Filtration Rate (GPM/sq.ft) $= \dfrac{\text{Filter Production (gallons per day)}}{\text{(Filter area sq. ft.)} \times \text{(1,440 min/day)}}$

Loading Rate (GPM/ sq. ft.) $= \dfrac{\text{(Flow Rate, GPM)}}{\text{(Filter Area, sq. ft.)}}$

Daily Filter Production (GPD) = (Filter Area, sq. ft.) x (GPM/sq. ft. x 1,440 min/day)

Backwash Pumping Rate (GPM) = (Filter Area, sq. ft.) x (Backwash Rate, GPM/sq. ft.)

Backwash Volume (Gallons) =
(Filter Area, sq. ft.) x (Backwash Rate, GPM/sq. ft.) x (Time, min)

Backwash Rate, GPM/ sq. ft. $= \dfrac{\text{(Backwash Volume, gallons)}}{\text{(Filter Area, sq. ft.)} \times \text{(Time, min)}}$

Rate of Rise (inches per min.) $= \dfrac{\text{(Backwash Rate gpm/sq.ft.)} \times \text{12 inches /ft}}{\text{7.48 gal/cu.ft.}}$

Unit Filter Run Volume, (UFRV) $= \dfrac{\text{(gallons produced in a filter run)}}{\text{(Filter Area sq. ft.)}}$

C• T CALCULATIONS

C• t = (Chlorine Residual, mg/L) x (Time, minutes)

Time, minutes $= \dfrac{\text{(C• t)}}{\text{(Chlorine Residual, mg/L)}}$

Chlorine Residual (mg/L) $= \dfrac{\text{(C• t)}}{\text{(Time, minutes)}}$

Inactivation Ratio $= \dfrac{\text{(Actual System C• t)}}{\text{(Table "E" C• t)}}$

C• t Calculated =
T_{10} Value, minutes x Chlorine Residual, mg/L

Log Removal $= 1.0 - \dfrac{\text{\% Removal}}{100} \times \text{Log key} \times (-1)$

CHEMICAL DOSAGE CALCULATIONS

Note: (% purity) and (% commercial purity) used in decimal form

Lbs/day gas feed dry = MGD x (ppm or mg/L) x 8.34 lbs/gal

Lbs/day $= \dfrac{\text{MGD} \times \text{(ppm or mg/L)} \times \text{8.34 lbs/gal}}{\text{\% purity}}$

GPD $= \dfrac{\text{MGD} \times \text{(ppm or mg/L)} \times \text{8.34 lbs/gal}}{\text{(\% purity)} \times \text{lbs/gal}}$

GPD $= \dfrac{\text{MGD} \times \text{(ppm or mg/L)} \times \text{8.34 lbs/gal}}{\text{(commercial purity \%)} \times \text{(ion purity \%)} \times \text{(lbs/gal)}}$

ppm or mg/l $= \dfrac{\text{lbs/day}}{\text{MGD} \times \text{8.34 lbs/gal}}$ or $\dfrac{\text{gallons} \times \text{\% purity} \times \text{lbs/gal}}{\text{MG} \times \text{8.34 lbs/gal}}$

SEDIMENTATION

Surface Loading Rate, (GPD/ sq. ft.) $= \dfrac{\text{(Total Flow, GPD)}}{\text{(Surface Area, sq.ft.)}}$

Detention Time $= \dfrac{\text{Volume}}{\text{flow}}$

Detention Time hours =
$\dfrac{\text{volume (cu ft)} \times \text{7.48 gal/cu ft} \times \text{24 hr/day}}{\text{Gal/day}}$

Flow Rate $= \dfrac{\text{Volume}}{\text{Time}}$

Weir Overflow Rate, GPD/L.F. $= \dfrac{\text{(Flow, GPD)}}{\text{(Weir length, ft.)}}$

State Water Resources Control Board

Operator Certification Examination—Equivalents and Formulas Sheet (Revised Dec 2015)

Equivalents

1 yd^3 = 27 ft^3	1 ft (water) = 0.43 psi
1 acre = 43,560 ft^2	1 psi = 2.31 ft (water)
1 ft^3 = 7.48 gal	1 yr = 365 d
1 gal (water) = 8.34 lb	1 d = 24 hr
1 L (water) = 1 kg	1 hr = 60 min
1 g = 1,000 mg	1 d = 1,440 min
1 kg = 1,000 g	1 hp = 550 ft·lb/s
1 L = 1,000 cm^3	1 hp = 0.746 kW
1 m^3 = 1,000 L	1 hp = 33,000 ft·lb/min
1 ml = 1 cm^3	1 hp = 3960 gpm·ft
1 ton = 2,000 lb	1 Mgal/d = 694 gal/min
1 mg/L = 1 ppm (water)	1 Mgal/d = 1.547 ft^3/s
1% (conc) = 10,000 mg/L	1 Mgal/d = 3.069 acre·ft/d

Units of Measure

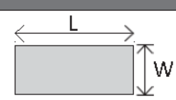
yd = yard	hr = hour
ft = foot	min = minute
gal = gallon	hp = horsepower
lb = pound	Mgal/d = MGD
L = liter	gal/min = gpm
g = gram	
kg = kilogram	
mg = milligram	
ml = milliliter	
psi = lb/in^2	
yr = year	
d = day	

Abbreviations [typical units]

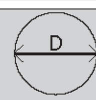
A = area [ft^2]
C = conc = concentration [mg/L]
Cl_{demand} = chlorine demand [mg/L]
Cl_{dosage} = chlorine dosage [mg/L]
$Cl_{residual}$ = chlorine residual [mg/L]
Q = flow rate [Mgal/d or MGD]
V = volume [gal]
v = velocity [ft/d]
VS_{in} = influent volatile solids
VS_{out} = effluent volatile solids

Perimeter (P)/Circumference (C)

Rectangle: P [ft] = 2L [ft] + 2W [ft]
where L = length and W = width



Circle: C [ft] = π × D [ft]
where π = constant = 3.1415; and D = diameter

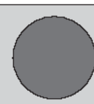


Area (A)

Rectangle: A [ft^2] = L [ft] × W [ft]
where L = Length and W = Width

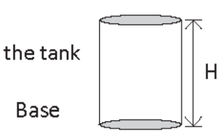
Circle: where π = constant = 3.1415; D = diameter

$$A\left[ft^2\right] = \frac{1}{4} \times \pi \times D^2 \left[ft^2\right]$$

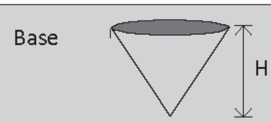


Volume (V)

Regular Prism: V [ft^3] = A $_{base}$ [ft^2] × H [ft]
where A_{base} is the area of the base; and H is the height or depth of the tank



Cone: $V\left[ft^3\right] = \frac{1}{3} A_{base}\left[ft^2\right] \times H\left[ft\right]$



Detention Time or Hydraulic Retention Time (HRT)

$HRT\left[hr\right] = \frac{V}{Q}$ If Q is in $\left[\frac{gal}{d}\right]$ and V is in [ft^3], then detention time is

$$HRT = \frac{V\left[ft^3\right] \times \frac{7.48\,gal}{ft^3}}{Q\left[\frac{gal}{d}\right] \times \frac{d}{24\,hr}} = \frac{V\left[ft^3\right] \times \frac{7.48\,gal}{ft^3} \times \frac{24\,hr}{d}}{Q\left[\frac{gal}{d}\right]}$$

Acronyms [typical units]

AST = activated sludge tank
BOD = biochemical oxygen demand [mg/L]
DO = dissolved oxygen [mg/L]
DLR = digester loading rate
ET = evapotranspiration
F/M = food to microorganism ratio
HLR = hydraulic loading rate
hp = horsepower
HRT = hydraulic residence time or detention time [d]
kW = kilowatt
MCRT = mean cell residence time [d]
Mgal = million gallons
MLSS = mixed liquor suspended solids [mg/L]
MLVSS = mixed liquor volatile suspended solids [mg/L]
OLR = organic loading rate
RAS = return activated sludge
RBC = rotating biological contactor
RP = removal percentage
SS = suspended solids [mg/L]
TDH = $H_{dynamic}$ = total dynamic head [ft]
TF = trickling filter
VS = volatile solids
WAS = waste activated sludge
WOR = weir overflow rate
SLR = solids loading rate [lb/d]

Flow and Velocity

$$Q\left[\frac{ft^3}{d}\right] = v\left[\frac{ft}{d}\right] \times A\left[ft^2\right]$$

Removal Percentage (RP)

$$RP = \left(\frac{In - Out}{In}\right) \times 100$$

where In = influent concentration, Out = effluent concentration

State Water Resources Control Board

Operator Certification Examination—Equivalents and Formulas Sheet **(Revised Dec 2015)**

Hydraulic Loading Rate (HLR): typical units [gal/(d·ft²)]

$HLR = \frac{Q}{A}$, If Q $\left[\frac{gal}{d}\right]$ and A $\left[ft^2\right]$, then

$$HLR\left[\frac{gal}{ft^2 \cdot d}\right] = \frac{Q\left[\frac{gal}{d}\right]}{A\left[ft^2\right]}$$

or

$$HLR\left[\frac{ft}{d}\right] = \frac{Q\left[\frac{gal}{d}\right] \times \frac{ft^3}{7.48\,gal}}{A\left[ft^2\right]}$$

Note: If consistent units are used for flow rate and area, then the HLR is in units of length over time (ft/d).

Weir Overflow Rate (WOR): typical units [gal/(d·ft)]

Weir overflow rate is the flow rate per unit length of weir.

$$WOR\left[\frac{gal}{d \cdot ft}\right] = \frac{Q\left[\frac{gal}{d}\right]}{L\left[ft\right]}$$

where L = length of weir

Loading Rate: typical units [lb/d]

BOD or SS loading rate [lb/d] =

$$8.34\left[\frac{lb \cdot L}{Mgal \cdot mg}\right] \times Q\left[\frac{Mgal}{d}\right] \times C\left[\frac{mg}{L}\right]$$

Hydraulic Loading Rate (HLR): typical units [gal/d/ft²]

$$HLR\left[\frac{gal}{d \cdot ft^2}\right] = \frac{Q\left[\frac{gal}{d}\right]}{A\left[ft^2\right]}$$

Solids Loading Rate (SLR): typical units [lb/d/ft²]

$$SLR\left[\frac{lb}{d \cdot ft^2}\right] = \frac{Solids\ applied\left[\frac{lb}{d}\right]}{A\left[ft^2\right]}$$

Food to Microorganism Ratio (F/M): typical units $\left[\frac{\text{lb BOD}}{\text{lb VSS·d}}\right]$

$$F/M\left[\frac{lb}{lb \cdot d}\right] = \frac{BOD\ applied\left[\frac{lb}{d}\right]}{MLVSS\left[lb\right]}$$

Return Activated Sludge (RAS) Flow Rate ($Q_{RAS\text{-}SS}$): typical units [Mgal/d or MGD]

$$Q_{RAS\text{-}SS}\left[\frac{Mgal\ or\ MGD}{d}\right] = \frac{Q\left[\frac{Mgal}{d}\right] \times MLSS_{tank}\left[\frac{mg}{L}\right] - Q_{WAS}\left[\frac{Mgal}{d}\right] \times SS_{RAS}\left[\frac{mg}{L}\right]}{SS_{RAS}\left[\frac{mg}{L}\right] - MLSS_{tank}\left[\frac{mg}{L}\right]}$$

Note: $SS_{RAS} = SS_{WAS}$

Mean Cell Residence Time (MCRT): typical units [d]

$$MCRT\left[d\right] = \frac{MLSS_{tank}\left[lb\right] + MLSS_{clarifier}\left[lb\right]}{SS_{effluent}\left[\frac{lb}{d}\right] + SS_{WAS}\left[\frac{lb}{d}\right]}$$

Waste Sludge Rate (SS_{WAS}): typical units [lb/d]

$$SS_{WAS}\left[\frac{lb}{d}\right] = \frac{MLSS_{tank}\left[lb\right] + MLSS_{clarifier}\left[lb\right]}{MCRT\left[d\right]} - SS_{effluent}\left[\frac{lb}{d}\right]$$

Sludge Volume Index (SVI): typical units [mL/g]

$$SVI\left[\frac{mL}{g}\right]=\frac{\text{Sludge Volume}\left[\frac{mL}{L}\right]\times 1{,}000\left[\frac{mg}{g}\right]}{MLSS\left[\frac{mg}{L}\right]}$$

The organic loading rate is the mass (lb) of organic (BOD) per unit area per day.
OR, it can be the mass (lb) of organic (BOD) per unit volume per day.

Organic loading rate = $OLR_{Area} = \frac{Q \times BOD}{A}$

where Q = flow rate, BOD = concentration of BOD, and
A = surface area of the treatment system (for example, RBC or ponds)

Organic loading rate = $OLR_{Volume} = \frac{Q \times BOD}{V}$

where Q = flow rate, BOD = concentration of BOD, and
V = volume of treatment system (typically applies to trickling filters)

For Rotating Biological Contactor (RBC)

The organic loading rate is expressed per 1,000 ft^2 of area.

$$OLR_{RBC} = \frac{Q \times BOD}{A}$$

$$OLR_{RBC}\left[\frac{lbBOD}{1000\,ft^2\cdot d}\right]=\frac{Q\left[\frac{Mgal}{d}\right]\times BOD\left[\frac{mg}{L}\right]\times 8.34\left[\frac{L\cdot lb}{Mgal\cdot mg}\right]}{A\left[ft^2\right]\times\frac{1}{1,000\,ft^2}}$$

For Trickling Filters (TF)

The organic loading rate is expressed per 1,000 ft^3 volume of the filter:

$$OLR_{Volume}\left[\frac{lbBOD}{1000\,ft^3\cdot d}\right]=\frac{Q\left[\frac{Mgal}{d}\right]\times BOD\left[\frac{mg}{L}\right]\times 8.34\left[\frac{L\cdot lb}{Mgal\cdot mg}\right]}{V\left[ft^3\right]\times\frac{1}{1,000\,ft^3}}$$

For Ponds

The organic loading rate is expressed per unit area in acres:

$$OLR_{Area}\left[\frac{lbBOD}{Area\cdot d}\right]=\frac{Q\left[\frac{Mgal}{d}\right]\times BOD\left[\frac{mg}{L}\right]\times 8.34\left[\frac{L\cdot lb}{Mgal\cdot mg}\right]}{A\left[acre\right]}$$

State Water Resources Control Board

Operator Certification Examination—Equivalents and Formulas Sheet **(Revised Dec 2015)**

Pump Efficiency (E_{pump}): typical units [%]

$$E_{pump}[\%] = \frac{HP_{water}}{HP_{brake}} \times 100$$

Brake Power (P_{Brake}): typical units [hp]

$$\boldsymbol{P_{Brake} = P_{motor} \times E_{motor}}$$

where P_{brake} = brake power, P_{motor} = motor power, and E_{motor} = motor efficiency

If the water power is given in kW, the brake power can be expressed in horsepower using the following equation:

$$P_{Brake\,HP}[hp] = P_{motor}[kW] \times \frac{[hp]}{0.746[kW]} \times E_{motor}$$

Water Power (P_{water})

$P_{water} = Q \times H_{dynamic}$; where P_{water} = water power, Q = flow rate, and $H_{dynamic}$ = total dynamic head

If horsepower is desired as a unit for water power, with gal/min (gpm) for flow rate and feet for total dynamic head, then

$$P_{water\,HP}[hp] = Q\left[\frac{gal}{\min}\right] \times H_{dynamic}[ft] \times \left[\frac{ft^3}{7.48gal}\right] \times \left[62.4\frac{lb}{ft^3}\right] \times \frac{HP}{33,000\left[\frac{lb \cdot ft}{\min}\right]}$$

$$P_{water\,HP}[hp] = Q\left[\frac{gal}{\min}\right] \times H_{dynamic}[ft] \times \frac{1}{3,960}\left[\frac{HP}{gal/\min \cdot ft}\right]$$

Percent Volatile Solids Reduction ($\%VS_{reduction}$): typical units [%]

$$\%VS_{reduction}[\%] = \frac{VS_{in} - VS_{out}}{VS_{in} - (VS_{in} \times VS_{out})} \times 100$$

Chlorine Demand (Cl_{demand}): typical units [mg/L]

$$Cl_{demand}\left[\frac{mg}{L}\right] = Cl_{dosage}\left[\frac{mg}{L}\right] - Cl_{residual}\left[\frac{mg}{L}\right]$$

BOD Test – Estimation of BOD Value

$$BOD\left[\frac{mg}{L}\right] = \frac{DO_{initial}\left[\frac{mg}{L}\right] - DO_{final}\left[\frac{mg}{L}\right]}{\frac{V_{sample}[mL]}{V_{bottle}[mL]}}$$

Pond Hydraulic Loading Rate (HLR_{pond}): typical units [in/d]

$$HLR_{pond}\left[\frac{in}{d}\right] = \frac{d_{pond}[in]}{HRT_{pond}[d]}$$

Pond Hydraulic Balance

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$$Q_{in}\left[\frac{in}{d}\right] - Q_{out}\left[\frac{in}{d}\right] = Q_{pond}\left[\frac{in}{d}\right] + Q_{rain}\left[\frac{in}{d}\right] - Q_{ET}\left[\frac{in}{d}\right]$$