

WATER 130: WATERWORKS MATHEMATICS



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Water 040

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Licensing

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Preface

There are a number of ways to solve waterworks mathematics problems. Many water operators look for short cuts in numbers like 448.8, 0.646, and 1440. However, understanding the process you take to get the answer is the key to “knowing” what you are doing versus “memorizing” what you are doing. There are certainly several useful numbers you can put to memory to make solving many of these problems easier, but knowing why you are using a specific “conversion factor” (number) is truly the key to your comprehension. This text is designed to provide you with basic knowledge and background of elementary mathematical problems and an understanding of typical entry-level and intermediate mathematical problems in the waterworks field.

Many of you will be preparing for a state-certified exam. This class will help you in your preparation for beginning distribution and treatment exams. However, this is not a “review” course for these exams. This text is designed to help you understand how to solve water-related mathematics problems. However, in preparation for a state or any exam, there are a number of things you should know.

Test-taking Tips

- Use a non-programmable calculator. The state exams do not allow programmable calculators and you should get used to one calculator.
- Have several sharpened pencils
- Take your time and verify your answers. This is especially helpful with mathematics questions.
- Eliminate as many answers as possible in multiple-choice problems. Statistically your chances of getting the answer correct become better.
- Do not over-prepare the morning before the state exam. If you don’t know the material the day of the exam, you probably won’t know it by the time the exam starts.
- Get a good night’s sleep the night before an exam
- Get to the exam site early. It is better to be early than late and risk the chance of being locked out of the exam.

Acronyms and Units of Measure

Acronyms	
feet	ft
inches	in
yard	yd
mile	mi
square feet	sq.ft or ft ²
square inches	sq.in or in ²
acre	ac
acre-feet	af
gallons	gal
cubic feet	cf or ft
liters	L
milliliters	mL
million gallons	MG
pounds	lbs
million gallons per day	MGD
cubic feet per second	cfs
gallons per minute	gpm

Linear	
1 foot	12 inches
1 yard	3 feet
1 mile	5,280 feet

Area	
1 square foot (sq.ft or ft ²)	144 square inches (sq.in or in ²)
1 acre (ac)	43,560 ft ²

Volume	
1 cubic foot (cf or ft ³)	7.48 gallon (gal)
1 cubic yard (yd ³)	27 cubic feet (cf)
1 gallon	3.785 liters (L)
1 liter (L)	1,000 milliliters (mL)
1 acre-foot (af)	325,829 gallons

1 million-gallon (MG)	1,000,000 gallons
-----------------------	-------------------

Weight	
1 cf of water	62.4 pounds (lbs)
1 gallon of water	8.34 pounds
1 ton	2,000 pounds

Short Cuts (NOT ADVISED)	
1 MGD	1.547 cfs
1 cfs	0.646 MGD
1 cfs	646,272 gpd
1 MGD	694.44 gpm
1 cfs	448.8 gpm
1 day	1,440 minutes

And a whole bunch more!

CHAPTER OVERVIEW

1: Mathematical Review- Fractions

1.1: Understanding Fractions

1.2: Reducing Fractions

1.3: Why Fractions

1.4: Multiplying Fractions

1.5: Dividing Fractions

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1.1: Understanding Fractions

Fractions are portions of whole numbers consisting of a numerator (or the top number of the fraction) and the denominator (or the bottom number of the fraction.) They are numbers that represent parts of a whole.

$$\frac{\text{Numerator}}{\text{Denominator}}$$
 Figure 1.1.1:
Fraction

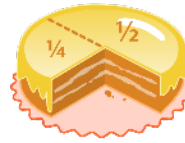


Figure 1.1.2: [Cake Fractions](#) by Acdx is in the public domain

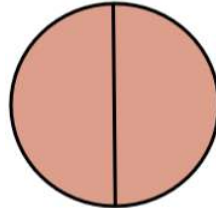


Figure 1.1.3: Circle with Proportions by [COC OER](#) is licensed under [CC BY 4.0](#)

Fractions are broken down into three classifications:

- Proper - $\frac{3}{4}$ - Where the numerator is smaller than the denominator
- Improper - $\frac{5}{2}$ - Where the numerator is larger than the denominator
- Mixed - $1\frac{6}{7}$ - Where a whole number precedes the fraction

Exercise 1.1

Identify the following as a proper fraction, improper fraction, or mixed number. Identify the correct word.

1.	$\frac{1}{2}$	Proper	Improper	Mixed
2.	$\frac{10}{12}$	Proper	Improper	Mixed
3.	$10\frac{1}{2}$	Proper	Improper	Mixed
4.	$\frac{11}{3}$	Proper	Improper	Mixed
5.	$\frac{101}{13}$	Proper	Improper	Mixed
6.	$130\frac{10}{13}$	Proper	Improper	Mixed
7.	$\frac{1,000}{1,111}$	Proper	Improper	Mixed
8.	$\frac{12}{7}$	Proper	Improper	Mixed
9.	$\frac{1}{7}$	Proper	Improper	Mixed
10.	$13\frac{1}{7}$	Proper	Improper	Mixed

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1.2: Reducing Fractions

Fractions can be reduced (expressed) in their lowest terms. This simply means that the fractions can no longer be divided by any other number.

In proper fractions, if the numerator and denominator can be divided by the same number, the fraction can be reduced.

Example: $\frac{2}{4} = \frac{1}{2}$

In the example above, this is accomplished by dividing the numerator and denominator by the number 2. Two fourths and one half represent the same number. They are just expressed differently. One half is a reduced form of two fourths.

Example: $\frac{2}{4} \div \frac{2}{2} = \frac{1}{2}$

At times a fraction can be divided multiple times in order to reduce it.

Example: $\frac{8}{12} \div \frac{2}{2} = \frac{4}{6} \div \frac{2}{2} = \frac{2}{3}$

This can also be performed in one step as follows. Both solutions provide the same answer.

Example: $\frac{8}{12} \div \frac{4}{4} = \frac{2}{3}$

In reducing improper fractions the denominator is divided into the numerator to create a mixed number. The remainder is written as a fraction.

Example:

$$\frac{8}{3} \rightarrow 3 \overline{) \frac{8}{3}} = 2 \frac{2}{3}$$

$$\begin{array}{r} 2 \\ 3 \overline{) 8} \\ \underline{-6} \\ 2 \end{array}$$

Remember: The resulting mixed number may also need to be reduced further.

Example:

$$\frac{18}{4} \rightarrow 4 \overline{) \frac{18}{4}} = 4 \frac{2}{4} = 4 \frac{2}{4} \div \frac{2}{2} = 4 \frac{1}{2}$$

$$\begin{array}{r} 4 \\ 4 \overline{) 18} \\ \underline{-16} \\ 2 \end{array}$$

Exercise 1.2

Reduce the following fractions to their lowest terms.

1. $\frac{7}{10}$
2. $\frac{4}{18}$
3. $\frac{4}{20}$
4. $\frac{6}{5}$
5. $\frac{5}{100}$
6. $\frac{39}{6}$
7. $1 \frac{8}{12}$
8. $2 \frac{9}{4}$
9. $\frac{4}{3}$
10. $\frac{4}{3}$

11. $\frac{14}{3}$
12. $\frac{140}{200}$
13. $\frac{10}{20}$
14. $7\frac{30}{40}$

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1.3: Why Fractions

Fractions are very common in waterworks mathematics. You may not see them in their “typical” form, for example:

$$\frac{3}{4} \quad \frac{2}{3} \quad \frac{1}{5}$$

You may see them as percentages:

$$75\% \quad 66\% \quad 20\%$$

Or you may see them as words:

Three quarters two thirds one fifth

However, these examples can also be expressed as fractions. We will discuss these later in the text. By understanding fractions, you can also understand how units are used to express things in terms of fractions. For example, if you drive a car at a velocity of 55 miles per hour, this is a form of a fraction.

$$\frac{55 \text{ miles}}{\text{hour}}$$

Fifty-five miles per hour is in fact a fraction. It is just expressed in a “per unit” example. It can be read as 55 miles per one unit of hour. What if you had an example of 110 miles per 2 hours? This could be written as:

$$\frac{110 \text{ miles}}{2 \text{ hours}}$$

Similar to reducing fractions such as:

$$\frac{2}{4} = \frac{1}{2}$$

The previous example of “55 miles per 2 hours” can be reduced as below:

$$\frac{110 \text{ miles}}{2 \text{ hours}} = \frac{55 \text{ miles}}{1 \text{ hour}} \text{ or } \frac{55 \text{ miles}}{hr}$$

The concept of “units” will be discussed in more detail later in this text, but understanding the concept is important to learn the process of solving waterworks mathematics problems. Since “adding” and “subtracting” fractions is not a common process in water-related math problems we will skip directly to multiplication and division of fractions.

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1.4: Multiplying Fractions

Multiplying and dividing fractions is a common practice when solving water related math problems. However, the process may not appear to be the multiplication and division of fractions and is commonly referred to as “unit conversion” or unit dimensional analysis. The example below demonstrates this process and will be discussed in more detail later in this text.

$$\frac{2\text{sqft}}{1} \times \frac{3\text{ft}}{1\text{sec}} = \frac{6\text{cf}}{\text{sec}}$$

For now, ignore the “units” and focus on solving the math. “Unit Dimensional Analysis” is a section we will spend a significant amount of time covering. Just look at the above problem as a fraction multiplication problem. Yes, both 2 over 1 and 3 over 1 are simply 2 and 3, but it helps to illustrate the process by looking at them as fractions.

$$\frac{2}{1} \times \frac{3}{1} = \frac{6}{1}$$

When multiplying fractions the numerators are multiplied by each other and the denominators are multiplied by each other. In other words, the numbers are multiplied straight across. So, in the example above, $2 \times 3 = 6$ and $1 \times 1 = 1$. The resulting answer is 6 over 1 or more simply put 6. However, when “units” are introduced, you can’t just say the answer is “6”. Always remember to reduce as necessary. Look at a couple other examples below:

Example 1.4.1

$$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

Example 1.4.2

$$\frac{2}{3} \times \frac{4}{6} = \frac{8}{18} \div \frac{2}{2} = \frac{4}{9}$$

In the first Example 1.4.1, if you multiply the numbers across as before, you would multiply 1 times 1 and then 2×2 . The resulting answer would be 1 over 4 or one fourth. In the next Example 1.4.2 you can do the same thing. Multiply the 2 and 4 to get 8 and then multiply the 3 and 6 to get 18. The resulting answer is 8 over 18 or eight eighteenths. However, remember to always reduce if necessary. In order to reduce you need to find a number, which will go into both 8 and 18. Since 2 will go into both of these numbers, you can reduce the answer to 4 over 9 or four ninths.

Cross canceling is also something you can do. Cross canceling is nothing more than reducing before you multiply. Look for any number that goes into both a numerator and a denominator. In the example below, 2 goes into both the 2 in the first fraction and the 6 in the second fraction.

Example 1.4.3

$$\frac{2}{3} \times \frac{4}{6} = \frac{\cancel{2}}{3} \times \frac{4}{\cancel{6}} = \frac{1}{3} \times \frac{4}{3} = \frac{4}{9}$$

In the Example 1.4.3, when you cross cancel, you reduce the two-thirds times four sixths to one third times four thirds. Then you multiply the 1 and 4 (numerators) and the 3 times 3 (denominators) to get an answer of four ninths.

When multiplying whole numbers and fractions you must first convert the whole number into an improper fraction and then, multiply. Be sure to cross cancel if possible and reduce if necessary. Placing a whole number over a 1 is an important step not only in solving these types of fraction problems, but will also be a helpful tool later in this text.

Example 1.4.4

$$5 \times \frac{3}{5} = \frac{5}{1} \times \frac{3}{\cancel{5}} \rightarrow \frac{\cancel{5}}{1} \times \frac{3}{\cancel{5}} = \frac{3}{1} = 3$$

The same rules apply when multiplying mixed numbers. Convert to improper fractions and multiply. In order to convert mixed numbers into improper fractions you must multiply the denominator by the whole number. Then add the numerator to the product

and put that number over the denominator. Be sure to cross cancel if possible and reduce if necessary. **Note: Never leave an answer as an improper fraction.**

Example 1.4.5

$$1\frac{1}{2} \times 2\frac{3}{4}$$

$$1\frac{1}{2} \rightarrow (2 \times 1) + 1 \rightarrow \frac{3}{2}$$

$$2\frac{3}{4} \rightarrow (4 \times 2) + 3 \rightarrow \frac{11}{4}$$

$$\frac{3}{2} \times \frac{11}{4} = \frac{33}{8} \rightarrow 8 \overline{)33} = 4\frac{1}{8}$$

Exercise 1.4

Multiply the following and reduce if necessary. Remember to cross cancel if possible. If you are multiplying a whole number by a fraction, place the whole number over 1.

1. $\frac{1}{2} \times \frac{2}{4}$
2. $8 \times 3\frac{2}{5}$
3. $\frac{18}{4} \times \frac{12}{9}$
4. $1\frac{10}{9} \times 4\frac{4}{7}$
5. $5\frac{3}{9} \times 7\frac{3}{5}$
6. $\frac{21}{24} \times \frac{4}{7} \times \frac{6}{3}$
7. $\frac{100}{13} \times \frac{10}{20}$
8. $\frac{13}{33} \times \frac{13}{33}$
9. $10\frac{12}{15} \times 10\frac{12}{15}$
10. $8\frac{1}{3} \times 5\frac{3}{5}$
11. $\frac{3}{4} \times \frac{6}{9} \times \frac{10}{12} \times \frac{12}{20}$
12. $\frac{100}{200} \times \frac{10}{20}$
13. $\frac{4}{5} \times \frac{5}{4}$
14. $15 \times 7\frac{1}{5}$

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1.5: Dividing Fractions

When dividing fractions you invert (flip upside down) the fraction on the right side of the equation (the dividend). Then it becomes a multiplication problem. Invert and multiply!

Example 1.5.1

$$\frac{2}{5} \div \frac{1}{2} \rightarrow \frac{2}{5} \times \frac{2}{1} = \frac{4}{5}$$

Example 1.5.2

$$\frac{\frac{4}{9}}{\frac{8}{9}}$$

This example reads $\frac{4}{9}$ divided by $\frac{8}{9}$.

However, after you “invert and multiply,” it becomes:

$$\frac{4}{9} \times \frac{9}{8} \rightarrow \frac{1}{1} \times \frac{1}{2} = \frac{1}{2}$$

After inverting the fraction, the same rules apply as previously mentioned when multiplying fractions. You need to change mixed numbers into improper fractions; you can cross cancel, and always remember to reduce if necessary.

Example 1.5.3

$$\frac{3}{8} \div \frac{12}{6} \rightarrow \frac{3}{8} \times \frac{6}{12} \rightarrow \frac{\cancel{3}}{\cancel{8}} \times \frac{\cancel{6}}{\cancel{12}} = \frac{1}{4} \times \frac{3}{4} = \frac{3}{16}$$

In the Example 1.5.3 above the 3 divided into itself once and into the 12 four times. Similarly, 2 divided into 6, three times and into 8, four times. Can you see a different way to cross cancel?

If the dividend is a whole number write it as a fraction before inverting. Always remember to cross cancel and reduce if necessary.

Example 1.5.4

$$\frac{5}{8} \div 10 \rightarrow \frac{5}{8} \div \frac{10}{1} \rightarrow \frac{5}{8} \times \frac{1}{10} \rightarrow \frac{\cancel{5}}{8} \times \frac{1}{\cancel{10}} \rightarrow \frac{1}{8} \times \frac{1}{2} = \frac{1}{16}$$

Exercise 1.5

Divide the following and reduce if necessary.

1. $\frac{1}{2} \div \frac{2}{4}$
2. $\frac{2}{22} \div 7\frac{2}{4}$
3. $\frac{8}{6} \div \frac{9}{12}$
4. $3\frac{1}{3} \div 10$
5. $5\frac{1}{4} \div 8\frac{1}{2}$
6. $\frac{8}{16} \div \frac{16}{8}$
7. $4 \div 3\frac{2}{3}$
8. $\frac{2}{5} \div 5\frac{6}{9}$
9. $\frac{13}{11} \div 9$
10. $\frac{11}{22} \div \frac{1}{2}$

11. $2\frac{9}{20} \div 5\frac{2}{5}$

12. $3\frac{1}{2} \div 9\frac{1}{2}$

13. $5 \div 25$

14. $\frac{10}{3} \div \frac{1}{6}$

15. $\frac{13}{33} \div \frac{6}{3}$

16. $100\frac{1}{2} \div 10\frac{5}{6}$

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CHAPTER OVERVIEW

2: Decimals

[2.1: Understanding Decimals](#)

[2.2: Multiplying and Dividing Decimals](#)

[2.3: Rounding](#)

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2.1: Understanding Decimals

Numbers written with decimals is another way of expressing fractions. However, decimals have a distinct differentiation with fractions in that decimals are based on 10. In that, one decimal place to the right of the whole number indicates *tenths*, two decimal places to the right of the whole number indicates *hundredths*, three decimal places to the right of the whole number indicates *thousandths*, etc.

Example 2.1.1

0.1 = tenths place

1.01 = hundredths place

0.001 = thousandths place

1.01 = ten thousandths place

1.

Decimals can easily be written as fractions by using the number to the right of the decimal point as the numerator and then using a 10, 100, 1,000, 10,000, etc. as the denominator. Determining which “base-ten” number to use as the denominator is determined by the number of digits there are to the right of the decimal point.

Example 2.1.2

0.1 $\rightarrow \frac{1}{10}$ 1 tenth

0.01 $\rightarrow \frac{1}{100}$ 1 hundredth

0.001 $\rightarrow \frac{1}{1,000}$ 1 thousandth

0.0001 $\rightarrow \frac{1}{10,000}$ 1 ten-thousandth

Exercise 2.1

Write the following decimals as fractions and reduce if necessary.

1. 0.2 =

2. 0.103 =

3. 0.13 =

4. 0.02 =

5. 0.1234 =

6. 0.0023 =

7. 0.0101 =

8. 0.1010 =

9. 0.020 =

10. 0.0202 =

11. 0.1000 =

12. 0.4500 =

Exercise 2.1.1

Write the following expressions as decimals and fractions.

		Decimal	Fraction
1.	7 tenths		
2.	1,000 ten-thousandths		
3.	475 thousandths		
4.	32 hundredths		
5.	12 thousandths		
6.	2,345 ten-thousandths		
7.	3 hundredths		
8.	10 thousandths		
9.	132 ten-thousandths		
10.	4,002 ten-thousandths		

Digits to the left of the decimal indicate a whole number. Whenever there is a whole number with a decimal fraction the expression is pronounced using “and.”

Example:

$$12.3 = \text{Twelve and three tenths} = 12\frac{3}{10}$$

$$100.07 = \text{One hundred and seven hundredths} = 100\frac{7}{100}$$

$$3,005.023 = \text{Three thousand five and twenty-three thousandths} = 3,005\frac{23}{1,000}$$

Exercise 2.1.2

Write the following expressions as a decimal and a fraction. Remember to reduce if necessary.

		Decimal	Fraction
1.	Two and five hundredths		
2.	Thirteen and two hundred thousandths		
3.	One thousand three and two ten-thousandths		
4.	Fifty-five and fifty hundredths		
5.	One and fourteen hundredth		
6.	Eleven thousand four and twelve thousandths		
7.	Ten and two tenths		
8.	Four hundred one and four ten-thousandths		
9.	Five thousand two hundred eight and one thousand ten-thousandths		

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2.2: Multiplying and Dividing Decimals

Multiplying and dividing decimals is simple enough if you use a calculator. When multiplying decimals, there is no certain order you need to type the numbers in your calculator.

Example 2.2.1

$$0.255 \times 0.23 = 0.05865$$

$$25 \times 35 = 875$$

$$100.5 \times 12.75 = 1,281.375$$

Exercise 2.2

Multiply the following problems

$$\begin{array}{r} 1. \quad \begin{array}{r} 5 \\ \times 0.35 \\ \hline \end{array} \end{array}$$

$$\begin{array}{r} 2. \quad \begin{array}{r} 65 \\ \times 0.2 \\ \hline \end{array} \end{array}$$

$$\begin{array}{r} 3. \quad \begin{array}{r} 0.515 \\ \times 0.15 \\ \hline \end{array} \end{array}$$

$$\begin{array}{r} 4. \quad \begin{array}{r} 20.54 \\ \times 5.01 \\ \hline \end{array} \end{array}$$

$$\begin{array}{r} 5. \quad \begin{array}{r} 0.002 \\ \times 1.07 \\ \hline \end{array} \end{array}$$

$$\begin{array}{r} 6. \quad \begin{array}{r} 0.9 \\ \times 0.8 \\ \hline \end{array} \end{array}$$

$$\begin{array}{r} 7. \quad \begin{array}{r} 8.5 \\ \times 0.2 \\ \hline \end{array} \end{array}$$

$$\begin{array}{r} 8. \quad \begin{array}{r} 52 \\ \times 0.11 \\ \hline \end{array} \end{array}$$

$$\begin{array}{r} 9. \quad \begin{array}{r} 0.4 \\ \times 0.04 \\ \hline \end{array} \end{array}$$

$$\begin{array}{r} 10. \quad \begin{array}{r} 4.23 \\ \times 2 \\ \hline \end{array} \end{array}$$

$$\begin{array}{r} 11. \quad \begin{array}{r} 0.2 \\ \times 0.45 \\ \hline \end{array} \end{array}$$

$$\begin{array}{r} 12. \quad \begin{array}{r} 2.68 \\ \times 0.298 \\ \hline \end{array} \end{array}$$

When dividing decimals, the denominator (or the divisor) is divided into the numerator (or the dividend). The resultant answer is termed the quotient. In the example below, 25 is divided into 125. On your calculator, you would type in the 125 first and then the 25. It is read as 125 divided by 25.

Example 2.2.2

$$\frac{125}{25} = 5$$

$$\frac{1.25}{25} = 0.05$$

$$\frac{1.25}{0.25} = 5$$

Exercise 2.2.1

Divide the following problems.

$$1. \quad 0.6 \div 5 =$$

$$2. \quad 28 \div 7 =$$

3. $14 \div 20 =$

4. $0.54 \div 12 =$

5. $75 \div 40 =$

6. $1.44 \div 12 =$

7. $0.48 \div 2.4 =$

8. $156 \div 0.78 =$

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2.3: Rounding

Rounding is another important process to understand and properly use mathematics. As we discussed in Section 2.1, decimal places can be carried out to the ten-thousandths place and further if needed. However, there is a practical rule to follow and in waterworks mathematics we seldom carry decimal places much further than the hundredths place, unless we are working in the area of water quality. The rule to follow is to “round” the decimal to the furthest decimal place in the question. Look at the examples below.

Example 2.3.1

$$2 \times 2 = 4$$

Since both numbers you are multiplying are whole numbers, then you would leave the answer as a whole number.

$$2.0 \times 2.0 = 4.0$$

Now, upon first glance, the answers may look like they are the same. After all, doesn't 4 and 4.0 equal the same number? The short answer is yes. However, 4.0 is actually more accurate than 4. Why? Because 4.0 is rounded to the tenths place and is saying the value is no more than 4 and 0 tenths. When we “round” the first answer “4” can be 4.1, 4.2, 4.3, or 4.4. We don't know, since the whole numbers are expressed as whole numbers and not round to the nearest tenth. Since both numbers being multiplied are rounded to the nearest tenth, then we round the answer to the nearest tenth.

$$2.0 \times 2 = 4.0$$

This answer is also rounded to the nearest tenth since one of the numbers being multiplied is rounded to the nearest tenth. However, the second example is still the most accurate.

Why?

Now let's look at how we round. The rule is simple. If the preceding number you are rounding to is ≤ 4 (0, 1, 2, 3, or 4) you round down, which is to say you round to the preceding number. If the number is ≥ 5 (5, 6, 7, 8, or 9), then you round up, which is to say the preceding number goes up by one. See the examples below.

Example 2.3.2

Round to the nearest whole number

$$1.2 = 1$$

$$1.24 = 1$$

$$1.25 = 1$$

Since we are rounding to the whole number, we look at the tenths place or the number to the right of the place we are rounding to. In these examples the number is 2, which is ≤ 4 .

Round to the nearest tenths place

$$1.2 = 1.2$$

$$1.24 = 1.2$$

$$1.27 = 1.3$$

We now need to look at the hundredths place or the number to the right of the tenths place. Since there is no hundredths place in the first example, the number stays at 1.2. In the second example you would round down since the preceding number is ≤ 4 and in the third example, you would round up since the preceding number is ≥ 5 .

Exercise 2.3

Round the following numbers

Round to the nearest whole number.

1. 29.05
2. 135.9
3. 0.4

Round to the nearest tenth place.

4. 20.045
5. 0.98
6. 200.03

Round to the nearest hundredth place.

7. 1.234
8. 0.976
9. 345.095

Round to the nearest thousandth place.

10. 3
11. 1,367.0982
12. 0.9855

Did any of the questions above give you difficulty? Let's look at number 5. The question said to round to the nearest tenth place. Therefore, we need to look at the preceding number or the hundredths place. The number was 0.98, so we need to look at the 8. Since 8 is ≥ 5 we must round the number in the tenths place up. However, in this case the number to be rounded up is a 9. Look at the example below:

0.98 the 9 becomes 10, but since it is a 0.9, it becomes 1.0

What about number 10? In this question, you need to round a whole number (3) to the thousandth place. Therefore, you need to add zeros until you get to the thousandths place. See below:

$3 = 3.000$

In this text we will typically round to the nearest whole number, tenths, or hundredths places.

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CHAPTER OVERVIEW

3: Percentages

[3.1: Expressing Numbers as Percentages](#)

[3.2: Word Problems](#)

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3.1: Expressing Numbers as Percentages

Percentages and decimals are commonly used in waterworks mathematics. Whether you are working with financial budgets, chemical percent concentrations, or water quality results, decimals and percentages are used often. Therefore, knowing how to convert to percentages from decimals is important and vice versa.

When expressing numbers as a percent they need to be whole numbers or decimals. Therefore, fractions must be converted first. Percent (%) simply means per hundred. Understanding that percent means per hundred indicates that 2 decimal places are involved.

When a number needs to be converted to a percent you multiply the number by 100 and put a percent sign (%) at the end.

Example 3.1.1

The number 1 written as a percent is

$$1 \times 100 = 100\%$$

The number 5 written as a percent is

$$5 \times 100 = 500\%$$

When a decimal is written as a percent do the same thing.

$$1.4 \times 100 = 140\%$$

Note that the decimal moves two places to the right.

When a percent is written as a decimal, you simply divide the number by 100. Dividing by 100 moves the decimal two places to the left.

Example 3.1.2

If 100% is to be written as a number, divide by 100.

$$100\% \div 100 = 1$$

$$8.25\% \div 100 = 0.0825$$

$$2,500\% \div 100 = 25$$

Exercise 3.1

Convert the following numbers to percentages and percentages to numbers (round all numbers to the nearest hundredth place).

1. 1 =
2. 30 =
3. 0.5 =
4. 0.75 =
5. 1.02 =
6. 35.5 =
7. 0.004 =
8. 5.005 =
9. 102% =
10. 2.3% =
11. 0.45% =
12. 1,570% =
13. 8% =
14. 0.9% =
15. 65% =
16. 12.5% =

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3.2: Word Problems

Word problems tend to give people some difficulty. Especially in problems where there is a lot of information that is not needed to solve the actual problem. However, most of the problems we deal with involve words.

How much money did I pay in taxes last year?

How many pounds of chemical do I need to add to this water supply?

How many gallons of water were sold last month?

What is the flow rate of water through that pipeline?

What is the area of the filter bed?

Yes, the questions posed above do not have any information to be able to solve for the answer, but these are some very common questions water operators are asked to solve. In word problems, there is always an underlying question that must be answered. Narrowing down the problem to the question you are trying to solve is an important step. Another important step is being able to pull out the information (numbers) in the question to help you solve for the answer.

In word problems with percentages, there are a couple of things you should take note of. The word “is” should be treated as an equal (=) sign and the word “of” as a multiplication ($\times$) sign. You must also remember to convert the percent to a decimal prior to solving.

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CHAPTER OVERVIEW

4: Equations and Word Problems

[4.1: Solving Equations](#)

[4.2: Ratios and Proportions](#)

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4.1: Solving Equations

Equations are a vital component to solve many mathematical questions. In fact most of all water related mathematical questions would require the use of one if not several equations. An equation is a mathematical statement that both sides of an “equal sign” are in fact equal.

Example 4.1.1

$$3 + 1 = 4 \text{ or } 5 - 3 = 4 - 2$$

Mathematical equations involve solving for an unknown or a variable. A variable is typically represented with a letter. That “letter” is what you are trying to solve.

Example 4.1.2

$$3 + X = 4$$

What number must X be in order to make this equation correct?

Obviously, the answer is 1.

Now, this is a very simple example, but it will allow you to begin the process for solving more complex equations.

How did you solve the example above? Did you simply look at the equation and intuitively know that the answer was 1? Or did you use some mathematical process to solve for the variable? Let’s break it down.

Steps to solving equations;

1. Get the unknown or unknowns on one side of the equation.
2. Get the numbers on the other side of the equation.
3. Try and follow these helpful tips.
 - a. If the problem is an addition problem, you will need to subtract
 - b. If the problem is a subtraction problem, you will need to add
 - c. If the problem is a multiplication problem, you will need to divide
 - d. If the problem is a division problem, you will need to multiply

Depending on the type of problem, this will involve adding, subtracting, multiplying, or dividing. Perhaps several steps will need to be done to solve for the variable.

Since we will not be adding or subtracting in this course, we will focus on multiplication and division problems.

If the variable is next to a fraction or directly next to a number, solving for the variable will require either multiplying or dividing.

These next two examples are using multiplication and division to get the variable by itself. In order to prevent confusion, the variable of choice will be something other than an “X.”

Example 4.1.3

$$2N = 10$$

What multiplied by 2 equals 10? In order to solve for “N” you will need to divide both sides of the equation by 2.

$$\frac{2N}{2} = 10$$

By dividing the left side of the equation by 2, you isolate the variable. However, since you divided one side of the equation by a number you must do the same to the other side of the equation.

$$N = \frac{10}{2}$$

$$N = 5$$

In this next example, a fraction of a variable will equal a number.

Example 4.1.4

$$\frac{2}{3}N = 14$$

In order to isolate the variable in this type of problem, you will need to multiply and divided. First, divide both sides of the equation by 2 and then multiply both sides of the equation by 3.

$$\frac{2}{(2)3}N = \frac{14}{2}$$

The two cancels out on the left side of the equation leaving N over 3 and 14 divided by 2 becomes 7.

$$\frac{N}{3} = 7$$

Now, multiply both sides of the equation by 3.

$$\frac{(3)N}{3} = 7 \times 3$$

Here, the 3 cancels out on the left and the right side of the equation becomes 21, which is the answer.

$$N = 21$$

How can you prove (or show) that 21 is the correct answer in the above example.

Exercise 4.1

1. $2X = 10$
2. $3N = 15$
3. $\frac{3}{4}G = 9$
4. $4H + 2 = 10$
5. $\frac{1}{5}J + 4 = 5$
6. $13 = \frac{3}{6}K - 1$
7. $3B - 5 = 2B + 8$
8. $10C - 7 = 3C + 14$
9. $\frac{4}{3}S - 3 = 5$
10. $14 = 2F + 2$
11. $7X + 2 = 9X - 10$
12. $15 = 5 + \frac{2}{5}P$

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4.2: Ratios and Proportions

Solving ratios and proportions is similar to the previous two exercises. It is simply just looking at the question a little differently. Instead of looking at it as numbers we will assign UNITS (or items) to the numbers, for example, 3 valves to 6 valves or 3 hours to 5 hours. However, the real comparisons of interest will be discussed in the next section when we compare different UNITS to each other, for example, 40 hours to 1 week, or 12 inches to 1 foot.

Example 4.2.1

$$\frac{2}{3} = \frac{F}{9}$$

You can read this as, 2 is to 3 as F is to 9.

In order to solve the above ratio or proportion is by cross multiplying.

$$9 \times 2 = 3 \times F$$

This would equate to

$$18 = 3F$$

Then using the method as previously used in the Equation Section, you would divide both sides of the equation by 3. Three would then cancel on the right side of the equation isolating the variable and 18 divided by 3 would give you 6. Therefore, F equals 6.

$$\frac{18}{3} = \frac{3F}{3} \rightarrow 6 = F$$

Exercise 4.2

1. $\frac{D}{7} = \frac{27}{9}$
2. $\frac{28}{L} = \frac{32}{8}$
3. $\frac{4}{H} = \frac{64}{28}$
4. $\frac{5}{K} = \frac{70}{1}$
5. $\frac{100}{L} = \frac{12}{3}$
6. $\frac{12}{9} = \frac{K^3}{12}$
7. $\frac{4}{7} = \frac{12}{5}$
8. $\frac{F}{H} = \frac{15}{20}$
9. $\frac{3}{2} = \frac{6}{Q}$
10. $\frac{5}{13} = \frac{35}{32}$
11. $\frac{F}{1} = \frac{64}{11}$
12. $\frac{7}{7} = \frac{J}{J}$

Not all proportional problems are exactly as they seem. The previous problems were directly proportional and can be solved with relative ease. However, sometimes you will encounter indirectly proportional or more properly termed “inversely” proportional.

Example 4.2.2

It takes 3 employees to flush 8 hydrants in 6 hours. How long would it take 5 employees to do the same job?

Solution

If you attempt to solve this problem as if it were directly proportional it would look like.

$$\frac{3}{6} = \frac{5}{W} \rightarrow W = \frac{30}{3} \rightarrow W = 10$$

By this result it would take 5 employees 4 hours longer to do the same job.

Inversely proportional problems need to be solved as follows. It is the product of the values not the ratio that you need to equate.

3 employees $\times$ 6 hours = 5 employees $\times$ W hours

$$\begin{aligned} 18 &= 5W \\ W &= \frac{18}{5} \\ W &= 3.6 \text{ hours} \end{aligned}$$

Exercise 4.2.1

1. A safety catalog sells dust masks. They are \$4.50 per dozen. How much would 4 dust masks cost?
2. An operator conducted a laboratory experiment by adding 1.5 pounds of chlorine to 5 gallons of water to get a certain chlorine dosage. If the operator wanted to disinfect 1,200 gallons of water to the same dosage, how many pounds of chlorine would she need?
3. Six water utility operators were able to exercise 75 valves in one work week. If 9 operators were assigned to do the same task, how long would it take them? (Assume 34 hours equates to a work week)

In the previous problem, you ended up with a fraction (expressed as a decimal) of an hour. What would be a better way to express this answer?

1. A water utility needs to install 2,375 feet of 16" diameter pipe. The pipe costs \$25.80 per foot. How much will all the pipe cost?
2. In the problem above, the pipe is manufactured in 20 foot sections. How many sections would need to be purchased?
3. A water storage tank needs to be recoated. A contractor gave an estimate that it would take 5 of his employees a total of 39 hours to complete the job. How sooner can the job be completed if 8 employees were to do the work?

In word problems with percentages, the first thing is to convert the percent to a decimal. Then, view the word "of" as a multiplication sign and the word "is" as an equals sign. Then, solve the problem

Example 4.2.3

10% of 100 is

$10\% \times 100 =$

$0.10 \times 100 = 10$

Exercise 4.2.2

Solve the following percent problems.

1. 30 is 20% of what number?
2. 10 is 45% of what number?
3. 12% of is 84.
4. What percent of 75 is 225?
5. 56% of is 182.
6. 35 is what percent of 500? _____
7. 100% of 2,000 is _____
8. What percent of 40 is 10? _____

Word problems give people fits! However, most of the problems that present themselves in practical situations are in fact word problems, we just don't always think of them that way. For example, if you are buying something from the store and you want to figure out how much the tax will be on a certain item, you probably just multiply the cost of the item by the sales tax. You can though look at this problem as a word problem.

Exercise 4.2.3

Solve the following word problems.

1. A water utility executive earned \$85,000 last year and received a 22% bonus. How much was her bonus?
2. A worker can paint a fire hydrant in $\frac{1}{2}$ hour. How many hydrants can she paint in 4 hours?
3. A 5 gallon jug of bottled water is labeled 60% spring water. How many gallons in the jug is spring water?
4. On a state certification treatment exam you must score at least 70% to pass. If there are 65 questions on the test how many must you get correct to pass?

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CHAPTER OVERVIEW

5: Unit Dimensional Analysis

5.1: Units

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5.1: Units

“Units” are the single most important component of many mathematical problems especially in the waterworks industry. If you are reporting a flow rate of 1,000, what does this mean? 1,000 gallons per minute? 1,000 cubic feet per second? Or, 1,000 acre feet per year? It is strongly recommended that you get in the habit of writing down the units for all the problems you are solving. Most of the problem solving in waterworks mathematics requires the conversion of units.

Cfs gpm MGD AFY

Therefore, Unit Dimensional Analysis (UDA) is the key to solving a majority of water related mathematical problems. UDA is the process of converting units of one type (e.g. gallons) to another similar type (e.g. cubic feet). Setting up your UDA problem is the most important step conversion problems. By “stacking” your units you create a visual representation of the problem where units can be canceled. This cancellation of units is very similar to cross canceling or reducing of fractions.

Example 5.1.1

Convert seconds to days using UDA

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

Solution

If we break the problem up into segments 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 step you can see that canceling seconds will yield minutes as the result. By continuing the same process you can end up with the unit the question is asking.

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

The reason seconds is set up over a “1” is because it is the units you are wanting to convert from and remember anything over 1 is that value.

Multiple units can be converted in a single problem too. However, convert one unit at a time. A common waterworks mathematics problem is the conversion from cfs to gpm. Cubic feet needs to be converted to gallons and seconds needs to be converted to minutes.

Example 5.1.2

Convert cfs to gpm.

$$\frac{\text{cf}}{\text{sec}} \rightarrow \frac{\text{gal}}{\text{min}}$$

Solution

An important thing to note is that you will be converting “like” units. This means that you will be converting **cubic feet** to **gallons** which are both a measurement of volume and converting **seconds** to **minutes** which are both a measurement of time.

There are two conversion factors that need to be used to perform this conversion. You need to ask yourself...How many seconds are in a minute? How many gallons are in a cubic foot?

There are 60 seconds in every minute.

There are 7.48 gallons in every cubic foot.

$$\frac{\text{lcf}}{\text{sec}} \times \frac{60\text{sec}}{\text{min}}$$

The expression 60 sec per minute is a conversion factor that is an equality. The conversion factor is deliberately written with the 60 sec on top of the equality because it needs to cancel the unit sec from the 1 cfs.

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

Since the sec cancel we end up with cubic feet per minute (cfm).

Now let's look at converting cubic feet to gallons. Remember that there are 7.48 gallons in every cubic foot.

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

If you combine both of the examples above you can see how cfs is converted to gpm.

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

Exercise 5.1

Solve the following problems using UDA

1. Convert 5 cfs to gpm.
2. Convert 1,500 gpm to cfs.
3. Convert 4 MGD to gpm.
4. Convert 2.5 cfs to MGD.
5. Convert 7 fps to mph.
6. A hose is flowing at a rate of 1.5 cfs. How many gallons will flow through it in one minute?
7. A well pumps 2,000 gallons per minute. How many million gallons of water will it pump in one day?
8. A water utility sold 10 million gallons of water. They need to report this in one hundred cubic feet (CCF or HCF). How many HCF is this?
9. A water utility operator is filling up a storage tank at a rate of 1,000 gallons per minute. How long will it take until the tank has 1.5 MG of water?
10. Water is moving through a pipe at a velocity if 5.75 feet per second. Express the velocity in miles per hour.
11. Last year a water utility delivered 2.35 million gallons per day. How many acre feet did they deliver in one year?
12. A water tank was being drained at a rate of 750 gallons per minute. If the tank holds 5 MG of water, how long will it take for the tank until the tank is empty? (Express your answer as Days, Hours, Minutes – ex 2 days, 3 hours, and 10 minutes)

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CHAPTER OVERVIEW

6: Geometric Shapes

In the waterworks industry geometric shapes are prevalent. For example, a pipe is a cylinder with the opening of a circle, a sedimentation basin can be a rectangle, and an aqueduct might be a trapezoid. These are a few of the shapes that we will cover in this text. It is important to understand how to work with these shapes to be able to calculate areas, volumes, perimeters, and circumferences.

We will first look at geometric shapes and how to calculate the corresponding area of these shapes. The answer when determining the area of a geometric shape should always be given in square feet (sqft or ft²). Other units can be used such as, square meters or square inches, but these are not typically used in the waterworks industry. Remember though that the units you are given in a question (or in “real life” for that matter, may not be the units you need to calculate square feet. Therefore, you should always convert the “given units” to feet before calculating the area. The first shape we will look at is the CIRCLE. Pipes are the backbone to water distribution systems and can also be found in treatment plants. Pipe lines carry raw water to the treatment plant, transmission lines can carry water from treatment plants to storage tanks, and distribution pipe lines delivery water to customers.

[6.1: Areas](#)

[6.2: Volumes](#)

[6.3: Circumference](#)

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6.1: Areas

Circle

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

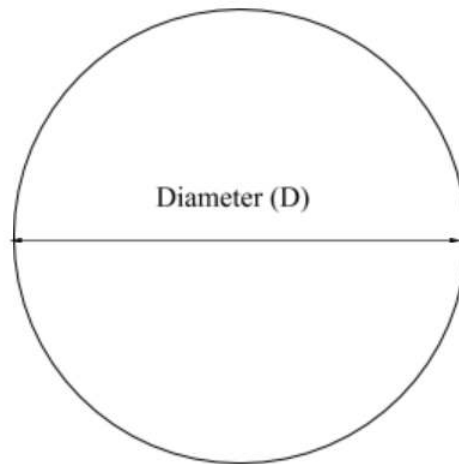


Figure 6.1.1: Area of a circle = $0.785 \times D^2$

Typically, you will know the diameter of a circle, for example the diameter of a pipe or a storage tank. You may have learned the following formula ($\pi \times r^2$) for calculating the area of a circle. However, in this text we will only use the previous formula. Both formulas work, but in the water industry diameters are most commonly used.

Much of the time you will be asked to calculate the area of the opening of a pipe. However, the unit given to you will typically be given in inches. There are two ways to go about solving this type of problem.

Example 6.1.1

What is the area of a 12" diameter pipe?

Solution

If you were to plug 12" into the formula ($0.785 \times D^2$) you would end up with square inches and then you would most likely need to then convert to square feet.

So, the easiest way to solve all area problems where "feet" are not given is to convert to feet first and then plug the numbers into the formula.

A 12" diameter pipe equals a 1 foot diameter pipe.

$$\frac{12 \text{ /inches}}{1} \times \frac{1 \text{ foot}}{12 \text{ /inches}} = 1 \text{ foot}$$

By converting to feet before starting the problem you will avoid getting into units you are not familiar with.

Rectangles

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

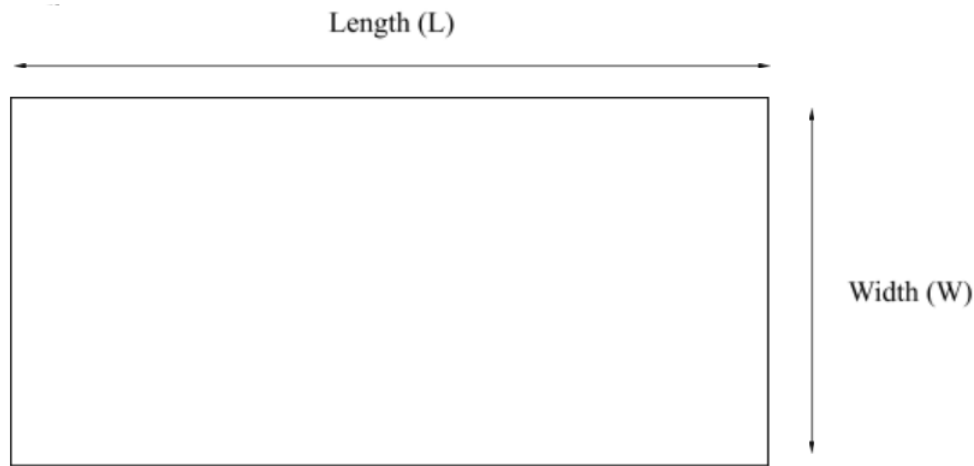


Figure 6.1.2: Area of a rectangle = $L \times W$

Rectangles are common shapes of storage reservoirs, sedimentation basins, and even room in an office. Calculating the area for these types of structures is simple if you know how the length and width of the structure. Remember, the area of a square is calculated the same way. These types of dimensions are typically given in feet.

Trapezoid

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

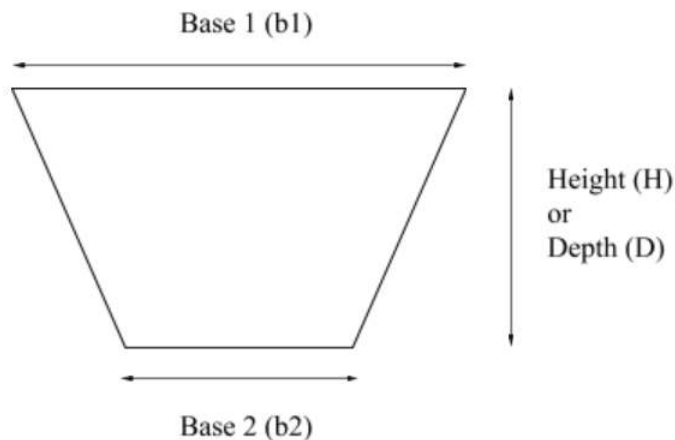


Figure 6.1.3: Area of a trapezoid = $\frac{b_1 + b_2}{2} \times H$

Trapezoids are not as common as circles, rectangles, and squares, but they are still found in the waterworks industry. Typically open channels and aqueducts are shaped like a trapezoid. In calculating the area of a trapezoid, you need to know the width across the aqueduct and the height of the water level. Now the width changes from the bottom of the trapezoid to the top. For example, the distance across the bottom of the trapezoid is a shorter distance then it is at the top of the trapezoid. The other point that needs to be addressed is the distance across the top of the trapezoid that is needed is the distance across the top of the water level. See the diagram below for an example of the base 1.

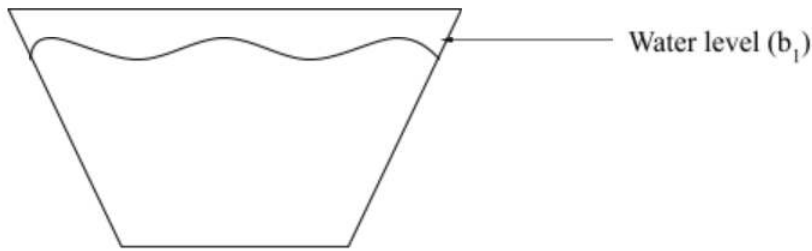


Figure 6.1.3: Example of the base 1

Once you know the distance across the trapezoid at the water level, then add it to the distance across the bottom of the trapezoid and divide that number by 2. Doing this finds the average distance across the trapezoid. Multiply this number by the height of the water level and you know have the area of the trapezoid.

Exercise 6.1

Calculate the following areas.

1. What is the area of a circle with a 2 foot diameter?
2. What is the area of a 36" diameter pipe?
3. What is the area of a sedimentation basin that is 30 feet wide and 10 feet deep?
4. What is the area of an aqueduct that is 5 feet across the bottom, 10 feet across the top and 7 feet deep?
5. The roof on an above ground storage tank has a 130 foot diameter. What is the area?
6. A filter is 25 feet long and 20 feet wide. What is the area?
7. A water aqueduct is 10 feet wide at the bottom and 20 feet wide at the top. If it is 20 feet deep what is the area?

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6.2: Volumes

Cylinder

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

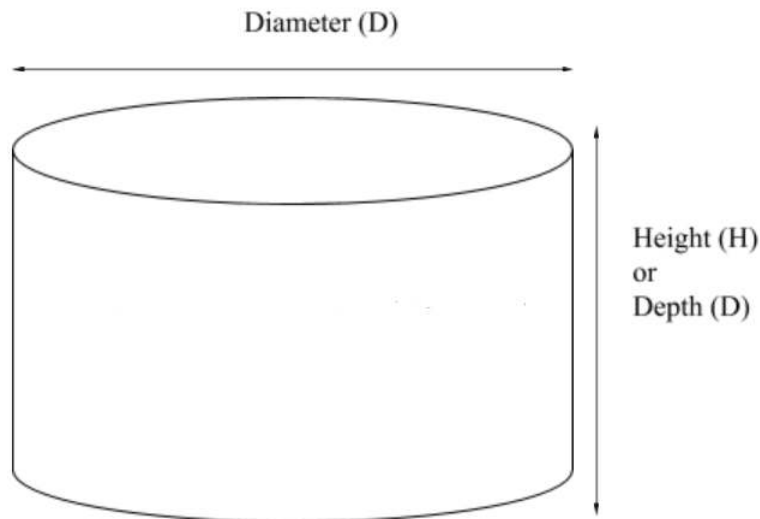


Figure 6.2.1: Volume of a cylinder = $0.785 \times D^2 \times H$

The volume of a cylinder uses the area formula of a circle with the addition of a third dimension. Notice that a cylinder can have either a depth or a height. They are one and the same. It all depends on your perspective. In fact all 3 dimensional structures can have a depth or a height.

Rectangle

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

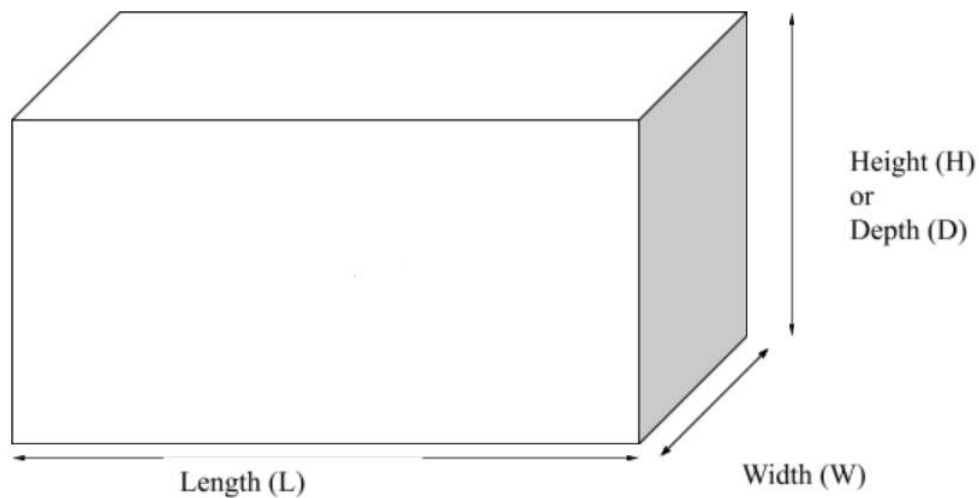


Figure 6.2.2: Volume of a rectangle = $L \times W \times H$

Trapezoid

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

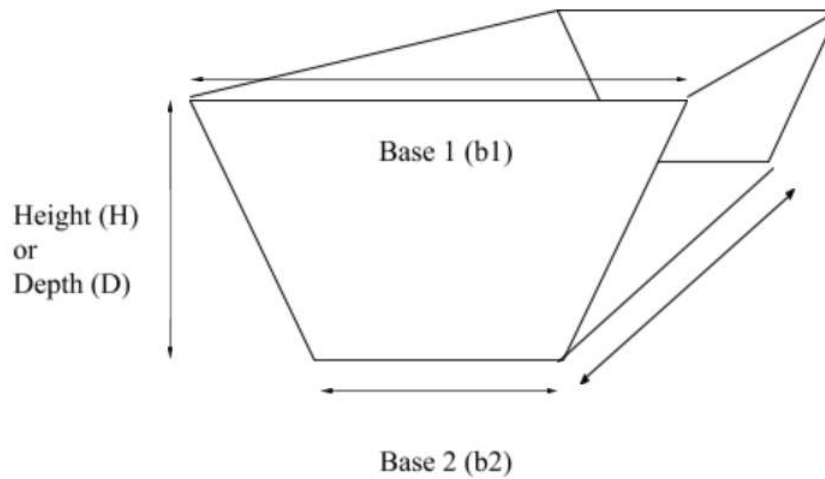


Figure 6.2.3: Volume of a trapezoid = $\frac{b_1 + b_2}{2} \times H \times L$

There is something to keep in mind when calculating volumes. Most units in waterworks are given in “feet.” The length of pipe, the height of water tanks, the depths of aqueducts are all typically measured in feet. Therefore, calculating the volume for these geometric shapes result in cubic feet as the unit of measure. However, sometimes measurements are given in “inches” and will need to be converted to feet before solving a problem.

Exercise 6.2

Solve the following

1. What is the area of a circle with a 10 foot diameter?
2. What is the area of a circle with a 10 inch diameter?
3. What is the area of a rectangle with a depth of 10 feet and a width of 20 feet?
4. What is the area of a trapezoid that has a distance across the base of 5 feet and a distance across the top of the water level of 7 feet. The water depth is 4 feet.
5. Calculate the volume of a pipe that has a 12” diameter and is 10 feet long.
6. How many gallons of water can fit in a storage tank that is 40 feet tall and has a 90 foot diameter? (Remember one cubic foot equals 7.48 gallons)
7. A rectangular basin is 100 feet long, 40 feet wide and has a depth of 25 feet. If the water level is 3 feet from the top, how much water is in the basin?
8. A one mile long water aqueduct is 10 feet deep and is half full. The width across the water level is 7 feet and the width at the base is 5 feet. How much water is in the aqueduct? (Remember that one mile equals 5,280 feet)
9. A 75 foot tall water tank is $\frac{3}{4}$ full and has a 30 foot diameter. How many gallons of water are in it?
10. What is the capacity of a water basin that is 200 feet long, 40 feet wide, and 30 feet deep?
11. A water tank is being emptied at a rate of 1 foot per hour. If the tank has a diameter of 100 feet, how many gallons will be emptied in 4 hours?
12. A reservoir with the following dimensions (75 feet long, 20 feet wide, 10 feet deep) is 35% empty. How many gallons of water are in the reservoir?

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6.3: Circumference

The last geometric shape formula we will look at is the circumference of a cylinder. The circumference is the distance around a closed curve. It is the distance around the length around a circle. The importance of this formula in waterworks mathematics displays itself in questions regarding the painting or coating of a cylinder. The picture below illustrates the circumference.

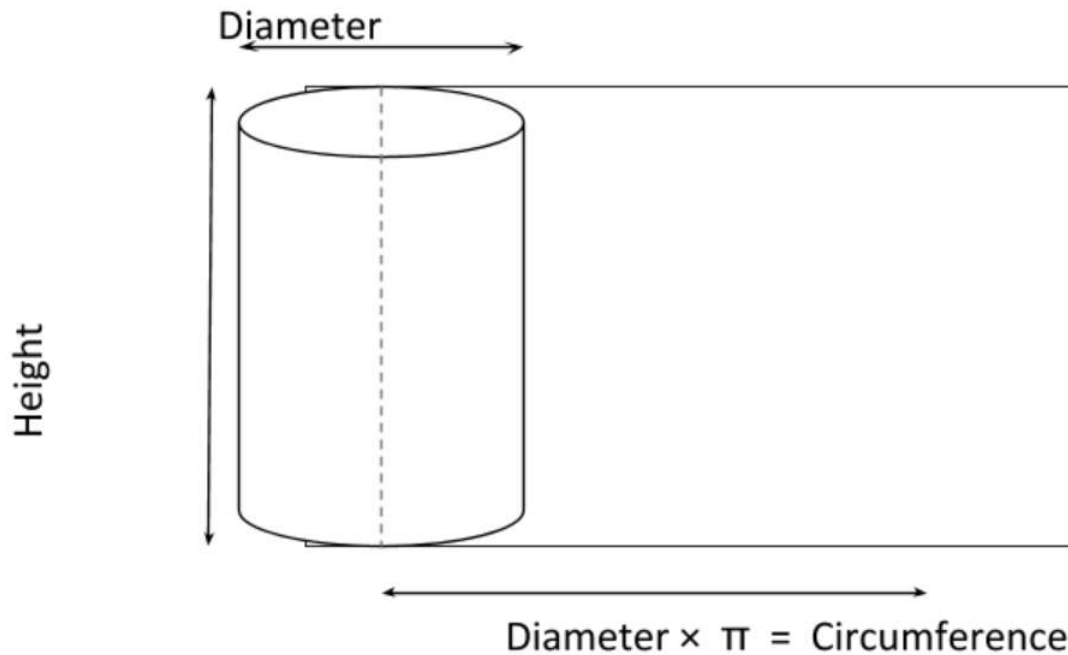


Figure 6.3.1: Circumference of a cylinder

If you “slice” open a cylinder and unravel it, it becomes a rectangle. The length of this rectangle is the circumference of the cylinder. In order to calculate the surface area of a cylinder, use the following formula.

$$\text{Area of a cylinder} = H \times (\text{Diameter} \times \pi)$$

Where $(\text{Diameter} \times \pi)$ is the length around the cylinder.

Exercises 6.3

Solve the following

1. What is the area of the wall of a 20 ft tall tank with a 30 ft diameter?
2. What is the area of the walls of a 1,000 ft section of 24” diameter pipe?
3. You have been asked to calculate how many gallons of paint would be needed to paint a 30 ft tall tank with a 100 ft diameter. You need to paint the inside roof, floor, and walls. One gallon of paint covers approximately 200 ft². How many gallons of paint are needed?

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CHAPTER OVERVIEW

7: Water Hydraulics

Hydraulics is a fundamental theory in waterworks mathematics. Hydraulics involves the mechanical properties of liquids. In this text we look at two different hydraulic principles, pressure and flow.

[7.1: Pressure](#)

[7.2: Force](#)

[7.3: Flow Rate](#)

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7.1: Pressure

Pressure is related to the vertical distance from the surface of water to a reference point somewhere below the water surface typically expressed in feet. For example, a water storage tank has a certain water level inside of it. The reference point below could be a water faucet a certain distance in feet below the water level. This distance in feet is the head pressure (in feet). The other common unit for pressure is POUNDS PER SQUARE INCH, (psi). You can convert back and forth between feet and pounds per square inch using one of the following conversion factors.

$$1 \text{ foot} = 0.433 \text{ psi} \quad \text{or} \quad 1 \text{ psi} = 2.31 \text{ feet}$$

To stay consistent with UDA, view the following conversion factors as

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

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

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

Example 7.1.1

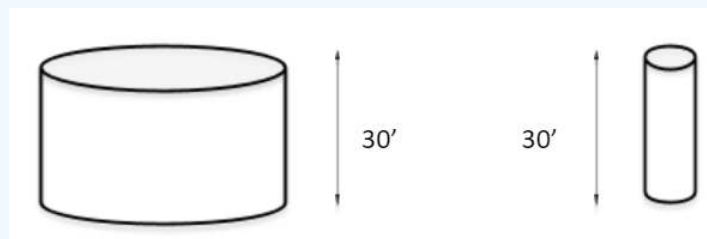


Figure 7.1.1

- Assume both cylinders above are filled with water, which one has a greater pressure at the base of it?
- What is the pressure at the base of each cylinder?

Solution

- The answer is neither! The pressure at the base of each cylinder is the same because the height of the water is the same.
- $\frac{30 \text{ feet}}{1} \times \frac{1 \text{ psi}}{2.31 \text{ feet}} = 12.98 \text{ psi}$ or (if you round) **13 psi**

Exercise 7.1

Calculate the following pressure problems

- What is the pressure in psi at the bottom of a 30 foot tall tank if it is full?
- What is the pressure in feet if the psi is 130?
- A storage tank is 45 feet tall and half full. What is the pressure in psi?
- A water tank sits on a 50 foot hill and is 25 feet tall. Assuming the tank is full, what is the pressure in psi at the bottom of the hill?
- A fire hydrant was hit and water is spraying up approximately 75 feet. What is the approximate pressure in psi?

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7.2: Force

Pressure is the force applied over a specific area. It is the weight of water expressed as pounds divided by the area expressed as inches squared (in²). Therefore, the resulting unit is pounds per square inch (psi). However, in the previous section we looked at pressure based on the height or elevation of a column of water and compared it against a conversion factor.

Recall the following conversion factors:

$$0.433 \text{ psi} = 1 \text{ foot and } 1 \text{ psi} = 2.31 \text{ feet}$$

Let's take a look at what 1 psi is actually saying. One (1) pound of force per square inch of surface area. Therefore, if you have one (1) pound of water and place it on one (1) square inch of area, the resulting pressure would be 1 psi.

The definition of force can be explained as the push or pull which an object can change the velocity of the object on which it is applied. If the pressure is known and the area of which the pressure is being applied, the force can be calculated. See the example below:

A pressure of 100 psi exerts how much force against an area of 1 in²?

In this example, there is

$$\frac{100\text{lbs}}{\text{in}^2} \times \text{in}^2$$

This would equate to 100 lbs of force because the in² would cancel.

This says that 100 pounds of force is being exerted. Another example of calculating the force in pounds would be by calculating the entire volume of water and then converting to the weight of the volume of water. Look at the example below.

If a tank with a 100 ft diameter and is 20 ft tall, what is the force at the bottom? In this example, the dimensions of the tank can be used to calculate the volume of water.

$$V = 0.785 \times (100\text{ft})^2 \times 20\text{ft} \times 7.48 = 1,174,360\text{gal}$$

This volume can now be converted to pounds.

$$1,174,360 \text{ gal} \times 8.34 \text{ lbs/gal} = 9,794,162 \text{ lbs}$$

This is the force exerted.

Exercise 7.2

1. Calculate the force exerted on a 6" diameter valve with a pressure of 90 psi.
2. What is the force at the base of a 100 ft tall tower filled with water and a diameter of 10 ft?
3. A water tank is 50 feet tall and half full. If the diameter is 75 feet, what is the force exerted at the bottom?
4. A fire hydrant with a 2 ½" opening has a pressure of 130 psi. What is the corresponding force?

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7.3: Flow Rate

Flow is the path that a certain liquid (water) takes for a specific time. It is commonly referred to as Flow Rate. A garden hose, a water main, an aqueduct, a gutter, have flow rates. You must know the area of the vessel or container that is flowing the liquid and you must also know the velocity that the liquid is moving. Flow Rate is simply expressed as volume over time.

$$\frac{\text{Volume}}{\text{Time}}$$

The volume can be gallons, million gallons, cubic feet or any other volume unit. The time can be any time such as, seconds, minutes, hours, etc. However, when solving Flow Rate ALWAYS use the UNITS – CUBIC FEET PER SECOND, where Q represents Flow Rate.

Expressed as

$$Q = \frac{\text{Volume}}{\text{Time}} = \frac{\text{cubic feet}}{\text{second}}$$

In order to calculate a Flow Rate, you need to know the Area of the vessel that the liquid is traveling through and the Velocity in which the liquid is traveling. The formula for Flow Rate is

$$Q = A \times V$$

Where the Area is expressed as – $0.785 \times D^2$ (for circles) - $L \times H$ (for rectangles) and $\frac{b1 + b2}{2} \times H$ (for trapezoids)

And

Where Velocity is expressed as – $\frac{\text{Distance}}{\text{Time}}$

The UNITS for AREA should always be in SQUARE FEET and the UNITS for VELOCITY should always be in FEET PER SECOND.

Therefore, the equation should look like this

$$\frac{\text{cubic}}{\text{feet}} = \frac{\text{ft}^2}{1} \times \frac{\text{ft}}{\text{second}} \rightarrow \frac{\text{ft} \times \text{ft} \times \text{ft}}{\text{second}} = \frac{\text{ft} \times \text{ft}}{1} \times \frac{\text{ft}}{\text{second}}$$

If you like using the “Pie Wheel” the following can be applied for Flow Rate.

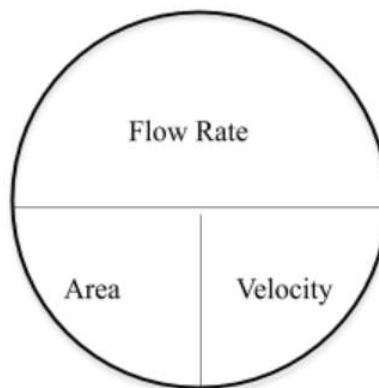


Figure 7.3.1: Pie Wheel

Exercise 7.3

1. What is the pressure in pounds per square inch at the bottom of a 45 foot tall water storage tank?
2. An 80 foot tall standpipe is $\frac{3}{4}$ full. What is the pressure in psi at the bottom?
3. A 30 foot water tank has a pressure gauge installed 2 feet from the bottom of the tank. If the pressure gauge reads 11 psi, what is the level in the tank?
4. A 12” pipeline is flowing water at a velocity of 3.5 fps. What is the corresponding flow rate?

5. A 36" diameter pipe is flowing water at a velocity of 5 fps. How many gallons of water will flow through it in 2 hours?
6. An 18" pipe is flowing 1,500 gpm. What is the velocity?
7. What is the area of a box culvert that is flowing 4.5 MGD at a velocity of 2.45 fps?
8. An 8" diameter pipe is flowing water at a velocity of 7.65 fps. What is the flow rate in gallons per minute?
9. A 28 foot tall water tank is sitting on a 75 foot tall hill. What is the pressure in a home at the bottom of the hill? (Assume the pressure gauge is 3 feet from the bottom of the home and the tank is full)
10. What is the velocity through a 20" diameter pipe that flows 2.5 MGD?
11. A home that is receiving water from a water tank that is on top of a 115 foot hill has a pressure of 57 psi. What is the water level in the tank?
12. What is the area of a pipe that flows 2,550 gpm at a velocity of 5 fps?

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CHAPTER OVERVIEW

8: Chemical Dosage Analysis and Waste Water Treatment

One of the most common and useful formulas in waterworks mathematics is one in which you use to calculate the amount of chemical needed to add to water. It is commonly known as the Pound Formula. 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.

Wastewater has several treatment processes to help breakdown the sewage as it moves through a wastewater treatment plant. In addition to adding chemicals, bacteria and microorganisms are used to establish adequate balances during the treatment process to remove organic material and reduce ammonia.

[8.1: The “Pound Formula”](#)

[8.2: Food to Microorganism Ratio](#)

[8.3: Mean Cell Residence Time \(MCRT\)](#)

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8.1: The “Pound Formula”

When solving the “Pound” formula the following two formulas are used.

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

$$\frac{\text{MG}}{1} \times \frac{8.34\text{lbs}}{\text{gal}} \times \frac{\text{parts}}{\text{millionparts}} = \frac{\text{lbs}}{1}$$

The second formula 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.

$$\frac{\text{MG}}{\text{D}} \times \frac{8.34\text{lbs}}{\text{gal}} \times \frac{\text{parts}}{\text{millionparts}} = \frac{\text{lbs}}{\text{day}}$$

Note that the only difference between the two formulas is the unit for time. It is also important to note that the formula uses specific units for volume and flow...MILLION GALLONS and MILLION GALLONS PER DAY.

Therefore if you are given a volume in cubic feet, gallons, acre-feet or some other unit, you must convert to million gallons.

The same holds true for flow rates. If you are given a flow rate in cubic feet per second, gallons per minute, acre-feet per year or some other unit, you must convert to million gallons per day.

The following charts are helpful in illustrating how to use the pound formula. Look at the horizontal line as a division sign. Anything above the line is divided by anything below the line. Everything below the line (that are next to each other) would be multiplied together.

Here is an example.

Example 8.1.1

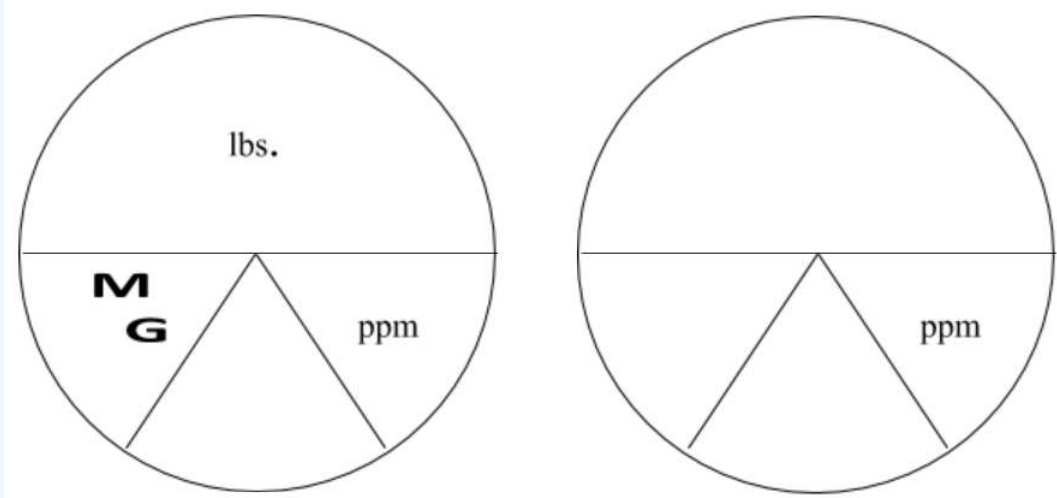


Figure 8.1.1

MG(D) and ppm are the two variables below the line. Therefore, they would be multiplied by each other and multiplied by 8.34 lbs./gallon. Since lbs or lbs/day are above the line then you would divide the product of the values below the line.

In this class we will assume that any chemical we are using is in its pure form. In other words there is no adjustment for a lesser concentration form of a chemical. When chlorine is used, it is 100% chlorine.

In addition to drinking water treatment, wastewater treatment uses this same formula to calculate the chemical dosage needed to add certain chemicals to wastewater. Also, this formula is used to determine the amount of “waste” present in wastewater. A common way to measure the amount of organic waste is by the Biochemical Oxygen Demand (BOD) test. Wastewater has a large amount of organic material that would put a certain demand on an aquatic system by depleting the available oxygen. The results of

the test are typically expressed as mg/L or ppm and can be used in the “pound formula.” The following questions cover both drinking water and wastewater treatment processes.

Exercises 8.1

1. How many pounds of chlorine are needed to dose 1 MG of water to 2 ppm?
2. How many pounds of chlorine are needed to dose 2,200,000 gallons of water to a concentration of 3.5 mg/L?
3. Dry Alum is added at a rate of 150 lb/day in a treatment plant operating at a rate of 16 MGD. What is the dosage in milligrams per liter?
4. How many gallons of water can be treated to a dosage of 10 ppm with 150 pounds of chlorine?
5. A wastewater treatment plant has a primary tank that can hold 2.5 MG. If the BOD test results are 450 mg/L, how many pounds of BOD are in the tank?
6. An operator added 75 pounds of chlorine to a water storage tank that has a 100 foot diameter and is 30 feet tall. The tank was only half full. What was the dosage?
7. A wastewater treatment plant treats 37,500 lbs of BOD per day. If the average daily flow is 8 MGD, what is the BOD concentration?
8. A well is flowing at a rate of 1,600 gpm and requires a dosage of 0.5 mg/L. How pounds of chlorine are needed per day?
9. An aeration tank receives a flow rate of 4,500 gpm. If the BOD concentration is 210mg/L, how many pounds of BOD are loading the aeration tank?
10. A treatment plant operates at a rated capacity of 15 MGD and maintains a constant 1.25 mg/L chlorine dosage. How many pounds of chlorine are needed per year?
11. In question 10, what is the annual budget for chlorine if the cost is \$1.65 per pound?
12. A wastewater treatment plant receives an average daily flow of 9.5 MGD. If the BOD test results are 320 mg/L, how many pounds of BOD does the treatment plant receive in a single day?
13. A water tank has a 150 foot diameter and is 35 feet tall. If 200 pounds of chlorine were added to it, what is the dosage?
14. How pounds of ferric chloride are needed to treat a basin that is 120 feet long, 30 feet wide, and 15 feet deep to a dosage of 3.25 mg/L?

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8.2: Food to Microorganism Ratio

Wastewater treatment relies on a biological process to treat the large amounts of organic material found in sewage. Bacteria consume the organic material (measured as BOD) and thus removes it from the wastewater. BOD can be thought of as food available to the bacteria.

The amount of bacteria in the system can also be measured by a test called the Mixed Liquor Suspended Solids (MLSS). The ratio of how much food (BOD) in pounds is available to the population of microorganisms (MLSS) in pounds, is critical to the proper operation of a conventional wastewater treatment plant. This ratio is a baseline to determine how much food a single pound of organisms will eat every day.

In aerobic wastewater treatment, operators supply bacteria with air in aeration tanks, so they can breathe. Typically, there is food available in the incoming wastewater for the bacteria. Under these conditions the microorganisms thrive and actually grow their population. If operators did not periodically “waste” the excess microorganisms from the system the MLSS would become too high and alter the F/M ratio.

To calculate the Food to Microorganism ratio (F/M) we need to determine the amount of BOD in pounds, being sent to through the treatment system as well as the amount of available MLSS in pounds, in the system. The equation for F/M is:

$$F/M = \text{Pounds of BOD per day} / \text{Pounds of MLSS in tanks}$$

Typical Food to Microorganism ratios are between 0.2 and 0.5. A low F/M ratio means there are many microorganisms and a limited food supply. Conversely, a high F/M ratio means there is much more food available compared to microorganisms. Therefore, a very high or low ratio would result in a dispersed floc that will not settle well in the secondary clarifier.

Exercise 8.2

1. A wastewater treatment plant receives an average flow of 5 MGD and the influent BOD is 260 mg/L. If the MLSS test shows there are 1,800 mg/L in the aeration tank that has a volume of 1.5 MG, what is the F/M ratio?
2. The primary effluent flow of wastewater treatment plant is 3.8 MGD and has a BOD concentration of 295 mg/L. The aeration tank is 150 feet long, 10 feet wide, and 8 feet deep. What is the F/M ratio if the MLSS is found to 2,600 mg/L?
3. What is the F/M of a wastewater treatment facility with the following process control data?

Influent Q = 4.8 MGD

Influent BOD = 425 mg/L

Primary Effluent BOD = 272 mg/L

MLSS = 2,100 mg/L

Aeration Volume = 2,890,000 gallons

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8.3: Mean Cell Residence Time (MCRT)

As we just learned with the F/M ratio, bacteria and microorganisms are essential to a properly functioning wastewater treatment plant. Another operational control parameter is the mean cell residence time (MCRT). This estimates how long a single bacteria or microorganism stays in the treatment process. The treatment process takes a certain amount of time to effectively remove the organic material and reduce the high amounts of ammonia. If the MCRT is too low then treatment will be insufficient. If the MCRT is too high then there is excess MLSS in the system which adds to the cost of operation.

The equation to find out the MCRT is based on how much MLSS is in the system and how much MLSS is leaving the system through wasting. There are other equations and terms very similar to MCRT such as the Solids Retention Time (SRT). Some textbooks include the pounds of solids available in the secondary clarifiers as well as the final effluent suspended solids that are leaving the system.

For this introductory class we will use the following equation:

$$\text{MCRT} = \text{Lbs under aeration} / \text{Lbs per day wasted}$$

The pounds under aeration is exactly the same as in determining the “M” in the F/M ratio. To determine the pounds wasted we need to know the flow rate of the waste activated sludge (WAS) and the concentration. Most treatment plants waste from the return activated sludge (RAS). The RAS is the microorganisms that have been settled out in a secondary clarifier. Therefore, the concentration of RAS is typically higher than MLSS.

The MCRT will depend on the type of wastewater treatment system. Extended air plants will generally have MCRTs greater than 30 days. Conventional activated sludge plants generally have MCRTs between 5 to 10 days. Biological nutrient removal plants typically operate with a MCRT between 12 and 20 days, and high rate oxygen plants between 1 and 3 days. However, it is important to note that there are plenty of case studies showing plants operating outside these ranges while still achieving optimal treatment. Each plant is different and will develop their own optimal operating range.

Exercise 8.3

1. A wastewater treatment plant has a total of 35,000 lbs of MLSS and has 2,900 lbs/day leaving the system. What is the MCRT in days?
2. What is the MCRT of a wastewater treatment facility with the following parameters?

Influent flow = 10.5 MGD

Primary Effluent BOD = 285 mg/L

Aeration Volume = 5 MG

MLSS = 2,280 mg/L

WAS Q = 115 gpm

WAS Conc. = 8,110 mg/L

3. An aeration tank has a volume of 375,000 gallons. The MLSS test results show there is 2,860 mg/L in the aeration tank. If a total of 2,100 lbs/day are wasted from the system, what is the MCRT of the facility?

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CHAPTER OVERVIEW

9: Water Treatment Mathematics

[9.1: Detention Time](#)

[9.2: Weir Overflow Rate](#)

[9.3: Filtration Rate](#)

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9.1: Detention Time

Detention Time is the amount of time it takes for a molecule of water to travel a certain distance. In a sedimentation basin it is the time it takes for a particle to travel across the basin. Water treatment operators calculate detention times for settling basins, flocculation basins, or rapid mixing chambers. The term “Contact Time” can also be applied using this formula. Contact Time is not to be confused with CT (Concentration Time). Contact Time is best described as the time a certain chemical is in contact with water. For instance, if you add chlorine to a water supply you can ask yourself “how long is it in contact with the water before a customer drinks the water?” For reference, Detention Times are commonly expressed in hours. However, as you will see when solving for Detention Time the resulting answer will not be in hours and will have to be converted.

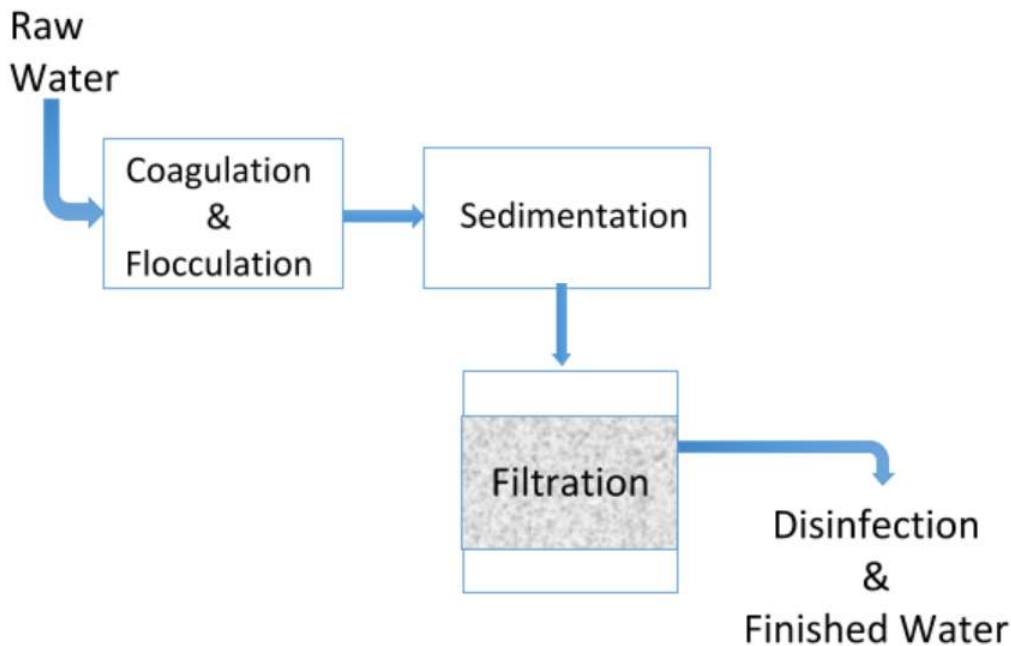


Figure 9.1.1: Treatment Process Example

The following formula is used for calculating detention times.

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

The “Pie Wheel” for Detention Time looks like this.

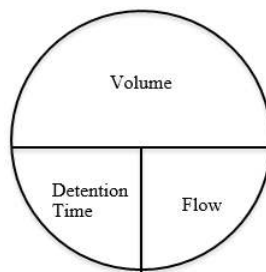


Figure 9.1.2: Pie Wheel

“Units” are extremely important with this formula. There are three variables in this formula; Detention Time, Flow, and Volume. Here are some examples for each.

Detention Time – seconds, minutes, hours, days

Flow – cubic feet per second, gallons per minute, million gallons per day

Volume – cubic feet, gallons, million gallons

Take note at the above examples. 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.

When solving for Detention Time, the units for Volume and Flow must match. Solving for Detention Time is not the only variable to solve for with this formula. If Detention Time and Volume are given then you will be solving for Flow. Similarly, if Detention Time and Flow are given then you will be solving for Volume. In all of these examples, the units must be similar in order to cancel out and yield your answer.

Using the “unit” examples above, list all possible matches of units in order to cancel and yield an answer.

Volume	Flow	Detention Time

Remember, using the above examples will not provide any answer in HOURS. Always remember to convert your answer to the units specified in the question.

Exercise 9.1

1. What is the detention time in minutes of a 400,000 gallon sedimentation basin with an average flow rate of 5,000 gpm? An 80 foot tall standpipe is $\frac{3}{4}$ full. What is the pressure in psi at the bottom?
2. What is the detention time in hours through a 100,000 gallon reservoir with a flow rate of 750 gpm? A 12” pipeline is flowing water at a velocity of 3.5 fps. What is the corresponding flow rate?
3. It has been determined that a basin has a detention time of 2 hours and 10 minutes. If the flow through the basin is 2.67 cfs, what is the volume of the basin in gallons? An 18” pipe is flowing 1,500 gpm. What is the velocity?
4. What is the flow rate (in gpm) through a 40 foot wide, 10 foot deep, 50 foot long basin if the detention time is 1 hour and 55 minutes? ng 4.5 MGD at a velocity of 2.45 fps?
5. A 25 foot tall reservoir with a 120 foot diameter has a detention time of 3 hours and 22 minutes. What is the daily flow (in MGD) through the reservoir? A 28 foot tall water tank is sitting on a 75 foot tall hill. What is the pressure in a home at the bottom of the hill? (Assume the pressure gauge is 3 feet from the bottom of the home and the tank is full)
6. A 75 foot long, 30 foot wide, and 20 foot deep basin has a flow of 2.25 MGD. What is the detention time? (Express as hours, minutes, seconds – ex. 5 hours, 3 minutes, and 2 seconds) A home that is receiving water from a water tank that is on top of a 115 foot hill has a pressure of 57 psi. What is the water level in the tank?
7. A series of tracer studies determined that the detention time through a 2,350,000 gallon basin is 2 hours and 12 minutes. What is the daily flow (in MGD)?
8. If a flow of 4.45 cfs is moving through 2 miles of 36” diameter pipe, what is the detention time?
9. A treatment plant has a daily flow of 30 MG. There are two 200,000 gallon sedimentation basins. What is the detention time through the plant.
10. What is the volume of a reservoir that has a detention time of 29 minutes and a flow of 5.4 cfs?

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9.2: Weir Overflow Rate

Another calculation is one that measures the flow of water over a structure called a “weir.” A weir is an obstruction used to raise the level of flow and evenly disperse it. It allows the measurement of flow to be easily calculated. In a treatment plant process weirs are commonly used to “skim off” the flow of water from the sedimentation process before the water travels to the filters. Weir overflow rates are typically expressed as gallons per minute per foot of weir. They can also be expressed as million gallons per day per foot of weir.

The important thing with this formula is that you determine the actual length of the weir and express it using the flow rate specified in the problem.

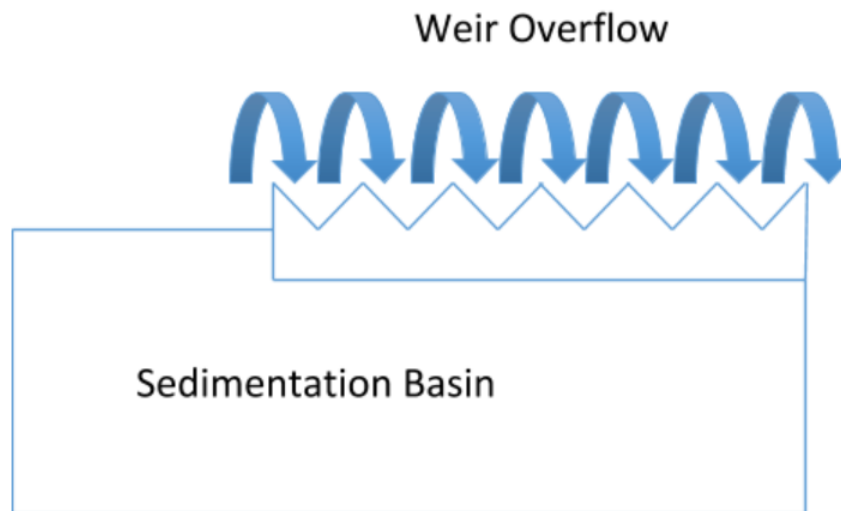


Figure 9.2.1: Overflow

This formula is used:

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

Exercise 9.2

1. What is the weir overflow rate of a 100 foot long weir with a flow of 3,450 gpm?
2. A weir over flow rate is 28 gpm/ft with a flow rate of 2,300 gpm. What is the length of the weir?
3. A 75 ft weir has a daily flow 1.25 MG. What is the weir overflow rate?
4. A circular weir with a diameter of 85 feet has a weir overflow rate of 17.5 gpm/ft. What is the flow rate in MGD? (Note: you will need the formula for circumference in this problem)
5. A 8.5 MGD treatment plant has a calculated weir overflow rate of 32 gpm/ft. How long is the weir?

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9.3: Filtration Rate

Filtration is the last stage in the treatment process for removing particles from the water. The filtration media can vary from sand to gravel to anthracite coal to garnet or a variety of materials layered to trap the remaining suspended solids in the water. Filtration rate is the measure of how much water passes through a certain sized filter over a specific time. Typically filtration rates are expressed in gallons per minute per square foot of filter area (gpm/ft²). It is the flow of water through the surface area of a filter.

In the picture below a filter is 5 ft by 5 ft and divided into 1 ft by 1 ft sections. This is done to demonstrate how filtration rates are expressed (in 1 ft² sections).

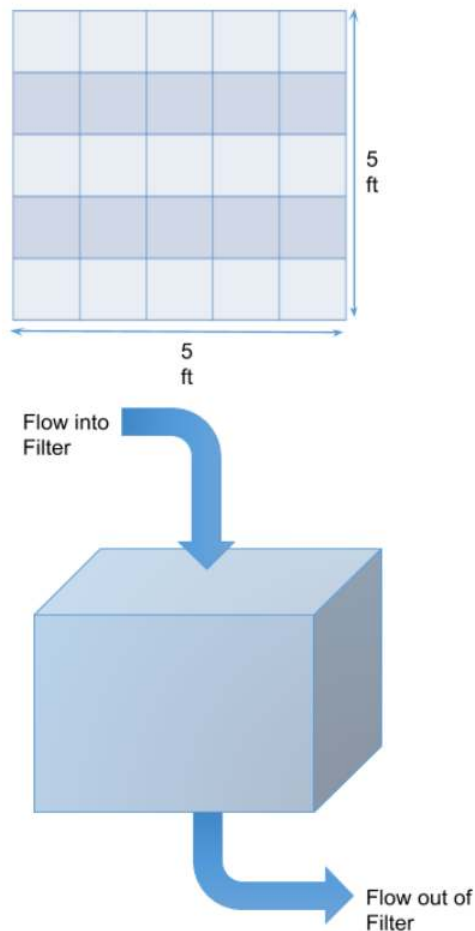


Figure 9.3.1: Demonstration of how filtration rates are expressed

As flow enters a filter it travels down through the media and then out to either a finished water clear well for distribution or perhaps disinfected prior to delivery.

This is the formula used for Filtration Rates:

$$FR = \frac{\text{Flow}}{\text{SurfaceArea}}$$

Since Filtration Rates are expressed as gpm/ft² then it only makes sense to convert the flow rate to gpm prior to dividing by the filter surface area. However, in this equation it is not necessary to do so prior to dividing.

The "Pie-Wheel" for Filtration Rates looks like this:

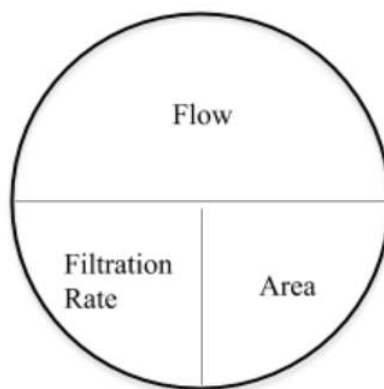


Figure 9.3.2: Pie wheel for Filtration Rates

Remember that the units for the flow and area will determine the unit for filtration rate.

Example 9.3.1

A water treatment plant with a 100 ft² filter has a flow of 1,650 gpm. What is the filtration rate expressed in gpm/ft².

Solution

$$\frac{1,650\text{gpm}}{100\text{ft}^2} = 16.5\text{gpm/ft}^2$$

This is a straight forward example with the units given in the same units requested to be expressed in the answer. Let's try another.

Example 9.3.2

A water treatment plant has an average daily flow of 10.5 MGD. The filter at the end of the treatment process is 22 ft by 15 ft. What is the filtration rate expressed as gpm/ft²?

Solution

In this question you need to calculate the area of the filter and determine if you want to convert the daily flow to gpm before or after you divide it by the area. Both ways of solving are explained below.

$$\frac{10.5\text{MGD}}{22\text{ft} \times 15\text{ft}} = \frac{10.5\text{MGD}}{330\text{ft}^2} = 0.032\text{MGD/ft}^2$$

Note that the units are million gallons per day per square feet and need to be converted to gpm/ft².

$$\frac{0.032\text{MG}}{\text{Day}} = \frac{32,000\text{gal}}{\text{Day}} \times \frac{1\text{ day}}{24\text{ hours}} \times \frac{1\text{ hour}}{60\text{min}} = 22.2\text{gpm/ft}^2$$

Another way to solve this is to convert the flow to gpm before you divide it by the area.

$$\frac{10,500,000\text{ gal}}{\text{day}} \times \frac{1\text{ day}}{24\text{ hours}} \times \frac{1\text{ hour}}{60\text{ min}} = \frac{7,291.7\text{ gallons}}{\text{minute}}$$

Then plug this into the filtration rate formula.

$$\frac{7,292\text{ gal}}{22\text{ft} \times 15\text{ft}} = \frac{7,291\text{gal}}{330\text{ft}^2} = 22.1\text{gpm/ft}^2$$

Take note that the answers are slightly different (0.1 off.) This is only due to rounding. If both solutions for this problem are rounded to the same number of digits you would get the exact same answer.

Exercise 9.3

(Express all filtration rates as gpm/ft²)

1. A water treatment plant has a typical flow through a 175 ft² filter of 755 gpm. What is the filtration rate?

2. A circular filter with a diameter of 74 feet receives a flow of 2,200 gpm. What is the filtration rate?
3. A three-hour test revealed that 75,000 gallons passed through a filter with dimensions of 10 ft by 20 ft. Find the filtration rate.
4. A water treatment plant has a total of 4 filters. The plant is designed to treat a daily flow of 7.25 million gallons. The target filtration rate is 2.25 gpm/ft^2 . Assuming that all 4 filters are identical in size, what is the area of each filter?
5. What is the rated capacity in MGD of a rapid sand filter that is 25 ft long and 16 feet wide when operated at a filtration rate of 1.75 gpm/ft^2 ?
6. It was determined that the optimum filtration rate of a filter with the dimensions of 12 ft wide and 18 feet long is 2.45 gpm/ft^2 . What is the maximum flow rate in cfs?
7. A water treatment plant treated 70 million gallons through 3 identical filters in one week. If the average filtration rate was 3.15 gpm/ft^2 , what is the area of each filter?

Periodically, filters will need to be cleaned. Cleaning is done through a routine process called backwash. As filters remove particles, the efficiency decreases and the flow rates slow. At predetermined intervals, treatment operators will backwash the filters. Backwashing is nothing more than reversing the flows. However, backwashing rates are typically 10 or more times greater than filtration rates.

8. After 6 hours in operation a 20ft by 30 ft filter required backwashing. Assuming a flow rate of 10,000 gpm, what was the backwash rate?
9. A 15 ft by 17 ft filter was backwashed at a rate of 22.5 gpm/ft^2 for 20 minutes. How many gallons were used for the backwashing process?
10. It was determined that a filter with a surface area of 725 ft^2 needs to be backwashed for 12 minutes using 94,500 gallons. What would the corresponding backwash rate be in gpm/ft^2 ?

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CHAPTER OVERVIEW

10: Engineering and Construction

There are a number of different treatment and distribution water utility careers ranging from laborer to skilled technicians. Each has a very important function in making sure the water system is properly maintained and operates efficiently. Something that is often overlooked in many operator certification courses is a discussion on how a system is planned, designed, constructed, and repaired. While this section of the text will focus on several key aspects of introductory concepts of engineering and construction waterworks mathematics, the following paragraphs will highlight a general overview of the planning, design, construction, and repair processes.

10.1: Planning

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10.1: Planning

Planning is important in many aspects of one's life. From planning out your day to planning out a career path, planning is an important step before tackling many different projects. Just as there are various simplicities and complexities to planning in your personal life, the same can be said in the business world. An example of this is building a water treatment plant. This is one of the more complex examples requiring many different phases of planning. A simpler project, which still requires planning, is the construction of a pipeline installation. Let's take a closer look at several planning steps to a small pipeline installation project.

Pipeline Installation Project Planning

Budget

Any project requires a budget process. There are many different expenses for water utility jobs such as labor, equipment, material, traffic control, disposal, and a variety of other types of costs. Before proceeding with any project, a budget needs to be prepared and staff needs to determine if there is enough money for the project.

Environmental

Any time a construction project is planned there are various environmental review procedures that must be followed. Will there be any environmental impacts such as air, water, noise, or biological species. Some projects are considered small enough to be exempt, while other larger projects may require extensive environmental impact reports.

Timing

When will the project be started and completed? Are there enough staff resources available? Water utility operators are very busy and each project needs to have a project timeline identifying the required resources and expected start and end dates to avoid conflicts.

Design

In order to properly construct a project there needs to be a minimum amount of engineering work. Some projects, such as water system repairs can require little to no engineering work. While other projects might require extensive engineering design and oversight. Most pipeline construction projects require at least some type of engineering work.

The above examples are by no means an exhausted list. However, it does give a good example of the complexities of water utility construction projects.

Stationing

Stationing is a process to measure distances on construction plans. A "station" is the horizontal measurement distance along a surveyed centerline of a project. Station numbers typically increase from the beginning of a project to the end point of a project. They usually reference points from south to north or from west to east. Station intervals are expressed in 100-foot sections. A half station is 50 feet and is expressed as +50.

In order to understand sectioning, take a look at a few examples below:

Example 10.1.1

If a station begins at "0" it is expressed as 0+00. One hundred feet from this station would be expressed as 1+00.

One foot sections increase as 0+01. Therefore, after ten feet, it would look like this 0+10.

The difference between station 101+00 and 100+00 is 100 feet.

If the beginning of a set of construction water plans start at station 100+00 and a valve is located at station 100+99 means the valve is located 99 feet from the start of the plans.

The following is an example of someone calculating the distance between two fire hydrants on a set of construction water plans.

Example 10.1.2

Fire hydrant A is located at station 530+50

Fire hydrant B is located at station 527+00

What is the distance between fire hydrant A and B?

Solution

$$53,050 - 52,700 = 350 \text{ feet}$$

As previously stated, stations typically reference points from south to north and from west to east. However, streets sometimes curve and change directions. An “above” segment on a road simply means a direction toward a higher station. A segment below or behind means a direction toward a lower station number.

Exercise 10.1

1. A set of construction water plans shows stationing to mark locations. The start of the plans has a station number of 01+50. The first fire hydrant on the plans is located at station 01+25. How many feet is the fire hydrant located from the start of the plans?
2. A water utility requires fire hydrants to be located 350 feet apart in residential areas. If a street is 1,500 feet long, begins at station 101+55 and the first fire hydrant is located at the start, how many fire hydrants will be installed?
3. A water valve is located at station 345+03 and another at 350+08. What is the distance between the two valves?
4. A domestic water service is located at station 102+45. Two more services need to be installed, one 75 below and one 75 above this station. What is the station of these two new services?
5. A water utility operator is looking at a set of water plans with the following information.
Fire hydrant located at 534+00
Valve located at 534+45
Water service located at 532+99
What is the total distance between these items?
6. An engineer is designing a water system for a cul-de-sac with 10 homes (5 on each side). The street begins at station 105+30. Each service must be one hundred feet apart and there must be a fire hydrant 25 feet past the second house on either side of the street. Answer the following two questions.
 - a. What is the station for the last house on one side of the street?
 - b. What is the station of the fire hydrant?
7. On a street 1,250 feet long, a fire hydrant is located at the end of the street at station 12+95. Three services are located at 10+33, 09+04, and 08+94, and a valve located 7 feet from the start of the street. What is the starting station number?
8. In the question above, what is the distance from the start point to each service?

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CHAPTER OVERVIEW

11: Using What You Learned and Preparing for Certification Exams

This text provides a basic look in to water related math problems. Various concepts are introduced and several formulas to apply to those concepts are presented. However, sometimes there are water related math questions, which are basic in nature, but are not part of the framework of the core concepts in this text. This section will attempt to introduce some of those questions and delve into simple math problems presented in questions you may not have seen before.

[11.1: Examples](#)

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11.1: Examples

Let's start with a simple question:

Example 11.1.1

The diameter of a circle is?

- a. One-half the radius
- b. Twice the radius
- c. Twice the circumference
- d. One-half the circumference
- e. Both b and d

Solution

Upon first examination, the answer appears to be rather obvious. It is “b”, twice the radius. However, whenever a multiple choice question uses an answer such as “e”, both a and b, you need to take a deeper look. In order to rule out answers, you need to have a good understanding of the question.

1. One-half the radius – this one should be fairly easy to rule out since you know that twice the radius is the answer.
2. Twice the radius – the correct answer
3. Twice the circumference
4. One-half the circumference

Both of these answers require you to know the formula for circumference to make an educated guess as to whether or not either of these are correct.

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

Knowing this equation allows you to easily rule out both of these possible answers.

This was a fairly easy example. Now let's take a look at something a little more deceiving and requires additional work to solve.

Example 11.1.2

One acre-foot of water contains?

- a. 43,560 cubic feet
- b. 325,829 gallons
- c. 1,233,263 liters
- d. Only a and b
- e. All of the above

Solution

Upon first glance, most of you might say “b” is the correct answer. You would be correct, because one acre-foot does contain 325,829 gallons. However, there is a better answer.

If your next instinct tells you “d” is correct, then you would also be right. Remember, one acre of land is equal to 43,560 square feet. If you fill this land one foot deep, then it becomes 43,560 cubic feet. Therefore, both “a” and “b” are correct answers.

However, 1,233,263 liters is a large number and it might actually be equivalent to one acre-foot. Here is where you need to know how many liters are in a gallon.

1 gallon = 3.785 liters

Therefore, $325,829 \text{ gal} \times 3.785 \text{ L} = 1,233,262.7 \text{ L}$

So, the best answer is “e” all of the above.

Meter reading is a common task for both water distribution and treatment operators. Mechanical equipment such as, meters, pumps and motors require maintenance and have a certain operating life. In addition, knowing how much water a utility pumps and sells is critical to a utilities revenue stream. There are flow meters and hour meters at various facilities in a water system. Understanding some of the terminology is critical to understanding how to solve some very basic math problems.

Example 11.1.3

A water treatment operator had a start read of a certain pump on January 1 and an end read on January 31. If the start read was 1,200,425 gallons and the end read was 6,342,076 gallons how much water flowed through this pump?

- a. 5,142 gallons
- b. 51,416 gallons
- c. 5,141,651 gallons
- d. None of the above

Solution

This is a relatively simple subtraction problem but you need to know what “start” and “end” reads are. Flow meters can be read daily, weekly, monthly, etc. A “start” read is nothing more than the beginning read of a certain period. In this example a monthly read. The “end” is then the last read of a certain period. So in this example, letter “c” is the correct answer, 5,141,651 gallons flowed through this pump in the month of January. Do you notice anything else interesting with this question? All the answers have similar numbers, just an order of magnitude different. The certification exams often do this to try and confuse test takers. Sometimes people get confused and might see a comma as a decimal and will select the incorrect answer.

These are only a few examples of some very basic problems and some test taking tips when you finally begin taking operator certification exams. Below are a series of questions to further illustrate the subtle differences in ways of asking questions.

Exercise 11.1

1. How many gallons of water are in 2 acre-feet?
 - a. 43,560
 - b. 87,120
 - c. 325,829
 - d. 651,658
 - e. Both b and d
2. A customer used 25 CCF in February and the ending read was 8052 CCF. If the ending reading in March was 8080 CCF, how many CCF did they use in March?
 - a. 25 CCF
 - b. 28 CCF
 - c. Not enough information to solve
 - d. None of the above
3. A pressure gauge reads 100 psi. This is equivalent to
 - a. 43.3 feet
 - b. 110 psig
 - c. 2.31 feet
 - d. 231 feet
 - e. 231 psig
4. The volume of cylinder is calculated by multiplying its height by
 - a. 3.14
 - b. 3.14 x the radius

- c. 0.785
 - d. 0.785 x the diameter
 - e. 0.785 x the diameter squared
5. At the beginning of the day, a totalizer on a pump station effluent meter reads 2,813,572 gallons. The next morning, the totalizer reads 4,612,931 gallons. The average daily flow during this 24-hour period was approximately
- a. 0.18 MGD
 - b. 1.8 MGD
 - c. 18 MGD
 - d. 180 MGD
 - e. 1,800 MGD
6. The past three year-end hour meter readings for a booster pump are 1152.1, 4433.3, and 7542.4. What is the greatest number of hours that the pump operated in a single year in this period?
- a. 7542.4 hours
 - b. 6390.3 hours
 - c. 3281.2 hours
 - d. 3109.1 hours
7. A meter indicates 20 hundred-cubic feet (ccf) of water was delivered during a billing period. This is approximately
- a. 1,000 gallons
 - b. 1,500 gallons
 - c. 10,000 gallons
 - d. 15,000 gallons
 - e. None of the above
8. You are to excavate a pipe trench that is 300-feet in length, 6-feet deep, and 3-feet wide, and export all of the soil removed. Your dump truck holds 10 yards. How many trips will your truck need to make to complete the job?
- a. 5
 - b. 10
 - c. 15
 - d. 20
 - e. 25
9. A flow meter indicates a flow rate of 1,500 gallons per minute. How much water per day will flow through the meter in 110 hours?
- a. 132,353 cf
 - b. 1,323,529 cf
 - c. 990,000 gal
 - d. 9,900,000 gal
 - e. Both b and d

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